Australian Government
National Health and Medical Research Council
Natural Resource Management Ministerial Council

National Water Quality Management Strategy

AUSTRALIAN DRINKING WATER GUIDELINES 6

2004

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Chapter 1 Introduction

Safe drinking water is essential to sustain life. Therefore, every effort needs to be taken to ensure that drinking water suppliers provide consumers with water that is safe to use.

The *Australian Drinking Water Guidelines* (the ADWG) are intended to provide a framework for good management of drinking water supplies that, if implemented, will assure safety at point of use. The ADWG have been developed after consideration of the best available scientific evidence. They are designed to provide an authoritative reference on what defines safe, good quality water, how it can be achieved and how it can be assured. They are concerned both with safety from a health point of view and with aesthetic quality.

The ADWG are not mandatory standards, however, they provide a basis for determining the quality of water to be supplied to consumers in all parts of Australia. These determinations need to consider the diverse array of regional or local factors, and take into account economic, political and cultural issues, including customer expectations and willingness and ability to pay.

The ADWG are intended for use by the Australian community and all agencies with responsibilities associated with the supply of drinking water, including catchment and water resource managers, drinking water suppliers, water regulators and health authorities.

1.1 Guiding principles

The ADWG contain a great deal of information about management of drinking water systems, monitoring and the vast array of contaminants that may be present in drinking water. An ever-increasing knowledge base means that the document has continued to grow both in detail and complexity. Although the increased information needs to be included, a danger is that the fundamental principles vital to ensuring safe drinking water quality become obscured in the detail. These fundamental principles, described below, should always be remembered.

The greatest risks to consumers of drinking water are pathogenic microorganisms. Protection of water sources and treatment are of paramount importance and must never be compromised.

Waterborne pathogens can cause outbreaks of illness affecting a high proportion of the community and in extreme cases causing death. How much treatment is needed will depend on the level of protection of water supplies. Completely protected groundwater may not require treatment, but all other supplies will require continuous disinfection. If water supplies are not completely protected from human and livestock waste, filtration is likely to be required.

Disinfection is the single process that has had the greatest impact on drinking water safety. There is clear evidence that the common adoption of chlorination of drinking water supplies in the 20th century was responsible for a substantial decrease in infectious diseases. Disinfection will kill all bacterial pathogens and greatly reduce numbers of viral and most protozoan pathogens. Combined with protection of water sources from human and livestock waste, disinfection can ensure safe drinking water. In the absence of complete protection of source water, filtration is likely to be required to improve the removal of viruses and protozoa.

All waterborne disease outbreaks are avoidable. Pathogens can only cause disease and death in humans if water source protection, pathogen removal by disinfection or filtration, or integrity of distribution systems fail.

Chemical byproducts of disinfection have been suggested as potential health risks. However, the possibility of such health risks remains highly uncertain in comparison to the well-established risks from inadequate disinfection and contamination of water supplies with pathogens. Therefore, although concentrations of byproducts should be kept as low as possible, efforts to achieve this should never jeopardise effective disinfection.

The drinking water system must have, and continuously maintain, robust multiple barriers appropriate to the level of potential contamination facing the raw water supply.

The multiple barrier approach is universally recognised as the foundation for ensuring safe drinking water. No single barrier is effective against all conceivable sources of contamination, is effective 100 per cent of the time or constantly functions at maximum efficiency. Robust barriers are those that can handle a relatively wide range of challenges with close to maximum performance and without suffering major failure.

Although it is important to maintain effective operation of all barriers, the advantage of multiple barriers is that short-term reductions in performance of one barrier may be compensated for by performance of other barriers. Prevention of contamination provides greater surety than removal of contaminants by treatment, so the most effective barrier is protection of source waters to the maximum degree practical. Knowing how many barriers are required to address the level of potential contamination in individual systems is important. This requires a thorough understanding of the nature of the challenges and the vulnerabilities of the barriers in place. In terms of reliability, there is no substitute for understanding a water supply system from catchment to consumer, how it works and its vulnerabilities to failure.

Finally, a robust system must include mechanisms or failsafes to accommodate inevitable human errors without allowing major failures to occur.

Any sudden or extreme change in water quality, flow or environmental conditions (e.g. extreme rainfall or flooding) should arouse suspicion that drinking water might become contaminated.

Disease outbreaks from drinking water are almost invariably linked to changes in measurable water quality parameters or to the failure of treatment processes to cope with extreme weather events such as high rainfall and flooding. Water treatment processes generally function best under steady state conditions, and performance can seriously deteriorate when there are major fluctuations in quality or flow. It is vitally important that water quality after treatment should remain as constant as possible, no matter how much the quality of the source water varies. Operators and managers need to be aware of normal operating requirements, the measurement criteria that define normal operation and the enormous risks that can be associated with operating outside normal limits.

System operators must be able to respond quickly and effectively to adverse monitoring signals.

Sudden changes in water quality or flow are likely to be a sign of imminent problems; such variations should always trigger appropriate responses. Wherever possible, key processes should be monitored continuously. Operators and managers must have the knowledge and appropriate responsibility to implement the necessary responses, which could range from modifying treatment processes to, in extreme cases, advising health regulators to consider issuing public advice such as 'boil water' notices or shutting down water supplies.

Previous water quality failures or 'close calls' should be studied so that operators are aware of the relationship between operational indicators and subsequent water quality failures. Even seemingly small faults should be addressed because these can accumulate and lead to a serious incident. Many waterborne disease outbreaks are caused by a combination of faults.

System operators must maintain a personal sense of responsibility and dedication to providing consumers with safe water, and should never ignore a consumer complaint about water quality.

Consumers are the ultimate assessors of water quality. Consumers may not be able to detect trace concentrations of individual contaminants, but their ability to recognise change should not be discounted. In some cases, consumer complaints may provide valuable information on potential problems not detected by testing water quality or monitoring treatment processes. Water quality testing has limitations and there are many possibilities for contamination of water in reticulation systems after treatment. All consumer complaints should be investigated to ensure that otherwise undetected problems that might compromise drinking water safety have not occurred. Meeting reasonable consumer expectations and maintaining confidence in the water supply is vitally important.

Ensuring drinking water safety and quality requires the application of a considered risk management approach.

The process of keeping drinking water safe is one of risk management. This requires steering a sensible course between the extremes of failing to act when action is required and taking action when none is necessary. Lack of action can seriously compromise public health, whereas excessive caution can have significant social and economic consequences. Corrective action or system upgrades should be undertaken in a considered, measured and consultative manner. Failure to act when required (e.g. failing to shut down a system when disinfection is not working effectively) may lead to an outbreak of waterborne disease. Acting when not required (e.g. issuing a 'boil water' notice when that is not necessary) is usually less severe in the short term, but repeated occurrences waste resources and are likely to cause complacency in the long term, leading to failure to respond when it is truly necessary. Similarly, failing to install a treatment process when required could lead to waterborne disease; however, installing treatment processes that are not required could have a high financial cost and divert funds needed elsewhere.

Risk management is about taking a carefully considered course of action. As the obligation is to ensure safe water and protect public health, the balancing process must be tipped in favour of taking a precautionary approach.

1.2 About the ADWG

1.2.1 SCOPE OF THE ADWG

Drinking water is defined as water intended primarily for human consumption, either directly, as supplied from the tap, or indirectly, in beverages, ice or foods prepared with water. Drinking water is also used for other domestic purposes such as bathing and showering.

With the exception of bottled or packaged water, the ADWG apply to any water intended for drinking irrespective of the source (municipal supplies, rainwater tanks, bores etc) or where it is consumed (the home, restaurants, camping areas, shops etc). Bottled water and packaged water are subject to the Food Standards Code (ANZFA 2001). The ADWG do not address water used for specialised purposes such as renal dialysis and some industrial purposes where water of a higher quality than that specified in the Guidelines may be required.

1.2.2 PURPOSE OF THE ADWG

The ADWG provide the authoritative Australian reference for use within Australia's administrative and legislative framework to ensure the accountability of drinking water suppliers (as managers) and of state/territory health authorities (as auditors of the safety of water supplies). The ADWG are not, however, mandatory legally enforceable standards.

With appropriate consultation with the community, the ADWG may be used directly as agreed levels of service or they may form the basis for developing local levels of service. In the case of health-related water quality characteristics there is less latitude for variation because the safety of drinking water is paramount. However, with regard to aesthetic characteristics, what is acceptable or unacceptable depends on public expectations and can therefore be determined by water authorities in consultation with consumers, taking into account the costs and benefits of further treatment of the water. The ADWG provide a starting point for that process. The ADWG may also be used by a standards body for defining quality processes suitable for third party accreditation of a quality management system.

1.2.3 STRUCTURE OF THE ADWG

The remainder of this document is divided into five parts.

Part I deals with the management of drinking water quality.

- Chapter 2 summarises a preventive strategy for the management of drinking water quality. It outlines a Framework for developing the approach; explains the need for water suppliers to work in partnership with other agencies in implementing the Framework; describes the purpose, structure, benefits and application of the Framework; and illustrates how the Framework is related to other management approaches such as Hazard Analysis and Critical Control Point (HACCP) and ISO 9001.
- Chapter 3 details the 12 elements of the Framework.
- Chapter 4 considers how the Framework can be applied to small water supplies.

Part II considers the characteristics of water.

- Chapters 5–7 present overviews of the microbial, physical and chemical, and radiological characteristics, respectively, that determine water quality.
- Chapter 8 provides information on chemicals commonly used in treatment of drinking water and how they affect water quality.

Part III considers the monitoring of drinking water quality.

- Chapter 9 provides an overview of characteristics to monitor and considers factors such as the location and frequency of sampling.
- Chapter 10 details monitoring procedures for specific characteristics – microbial, physical, chemical and radiological – and for small water supplies.

Part IV presents information sheets for disinfection of drinking water, sampling and statistics.

Part V presents fact sheets on a wide range of individual water quality characteristics, arranged by category and alphabetically within each category. Each fact sheet contains, where appropriate, the guideline values (aesthetic or health-related, or both) and their derivation, a general description of the characteristic, typical values in Australian drinking water, methods for removing the characteristic from drinking water, measurement techniques and health considerations.

An appendix gives additional guidance on certain elements of the Framework for Management of Drinking Water Quality. The appendix is located at the end of the ADWG, together with a glossary.

1.3 Water quality characteristics

1.3.1 INTRODUCTION

The ADWG are concerned with the safety and aesthetic quality of drinking water for consumers. Drinking water does not need to be absolutely pure to be safe. Because water is such a good solvent, pure water containing nothing else is almost impossible to attain. What is required is that drinking water should be safe to drink for people in most stages of normal life, including children over six months of age and the very old. It should contain no harmful concentrations of chemicals or pathogenic microorganisms, and ideally it should be aesthetically pleasing in regard to appearance, taste and odour.

The Guidelines are derived so as to take account of the needs of an individual through a normal lifetime, including changes in sensitivity that may occur between life stages. Those at greatest risk of waterborne disease are infants and young children, people who are debilitated or living under insanitary conditions and the elderly. Sensitive sub-populations, (including the severely immuno-compromised), should seek further medical advice.

A wide range of measurable characteristics, compounds or constituents can be found in water and may affect its quality. They fall into several categories:

- physical
- microbial
- chemical, including
  - inorganic chemicals
  - organic compounds
  - pesticides
- radiological.

Appearance, taste and odour are useful indicators of quality because they are generally the characteristics by which the public judges water quality. However, water that is turbid or coloured, or has an objectionable taste or odour, may not be unsafe to drink. Conversely, the absence of any unpleasant qualities does not guarantee that water is safe.

The safety of water in public health terms is determined by its microbial, physical, chemical and radiological quality; of these, microbial quality is usually the most important.

1.3.2 GUIDELINE VALUES

The ADWG include two different types of guideline value:

- A **health-related guideline value**, which is the concentration or measure of a water quality characteristic that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption.
- An **aesthetic guideline value**, which is the concentration or measure of a water quality characteristic that is associated with acceptability of water to the consumer, e.g. appearance, taste and odour.

The guideline values should be used in two separate but complementary ways: as action levels for the short-term verification of drinking water quality and as a means to assess performance over the longer term (e.g. over a 12-month period). Using a guideline value for short-term verification entails assessing whether individual results conform to the requirements of good quality water. If a value is exceeded, some form of immediate corrective action will generally be initiated. For example, if a guideline value for a health-related characteristic is exceeded, the response should be to take immediate action to reduce the risk to consumers, and, if necessary, to advise the health authority and consumers of the problem and the action taken. If the characteristic affects only aesthetic quality, the action may be to advise the community of deterioration in water quality.

When guideline values are used in assessing overall performance (e.g. as presented in an annual report) the aim is to assess whether management strategies are effective. The assessment is used to identify emerging problems and to determine priorities for improvement. Resulting actions will generally be applied in the longer term.

The guideline values relate to the quality of water at the point of use (e.g. kitchen or bathroom tap). They apply to reticulated water at the consumer's tap, rainwater for drinking, and source water if it is to be used without prior treatment. This does not, however, imply that the drinking water supplier is responsible for water quality problems caused by plumbing or other factors within a consumer's property. However, although it is not possible to control consumers' actions, suppliers should consider how drinking water quality may be affected in private plumbing systems and provide appropriate information to consumers.

The drinking water supplier should ensure that the quality of water in the reticulation mains meets the guideline values or agreed levels of service. The drinking water supplier would normally monitor quality in a service pipeline directly off a water main selected to represent the quality of water in the system. This is not usually within a private consumer's property. However, it may sometimes be necessary to check at the consumer's tap, either to confirm that chosen distribution sampling points are representative for microbial monitoring, to investigate specific problems such as leaching of metals into water, or as a consumer service.

The guideline values define water that, based on current knowledge, is safe to drink over a lifetime; that is, it constitutes no significant risk to health. For most of the water quality characteristics discussed, there is a grey area between what is clearly safe and what is clearly unsafe. Often the latter has not been reliably demonstrated and the guideline values always err on the side of safety. Therefore, for most characteristics, occasional excursions beyond the guideline value are not necessarily an immediate threat to health. The amount by which and the duration for which any health-related guideline value can be exceeded without raising concerns for public health depends on the particular circumstances. Exceeding a guideline value should be a signal to investigate the cause and, if appropriate, to take remedial action. If the characteristic is health related, the relevant health authority should be consulted.

Nevertheless, the ADWG provide the minimum requirements for drinking water of good quality, both aesthetically and from a public health viewpoint. Water suppliers should adopt a preventive risk management approach, as stipulated in the ADWG, to maintain the supply of water at the highest practicable quality. The guideline values should never be seen as a licence to degrade the quality of a drinking water supply to that level.

1.4 Community consultation

The ADWG are intended to provide consumers with safe and aesthetically pleasing water and ultimately it is consumers who will be the final judges of water quality. It is vitally important that consumers are viewed as active partners in making decisions about drinking water quality and the levels of service to be adopted. Community expectations and willingness to pay must be considered. It is the responsibility of drinking water suppliers to keep the community fully informed about water quality, existing problems and needs for improvement.

Consumers also need to be informed about their responsibilities in relation to domestic plumbing and of any possible issues associated with the interaction of mains water with this plumbing.

1.5 Development of the Guidelines

National guidance for drinking water were first published by the National Health and Medical Research Council (NHMRC) in 1972 as *Desirable Standards for Public Water Supplies in Australian Capital Cities* adopting the Biennial Conference of Engineers *Criteria and Objectives for Water Quality for Capital Cities* (1969). The NHMRC standards were updated in 1975 as *Recommended Quality Criteria for Drinking Water* and in 1977 as *Desirable Quality for Drinking Water*. In 1980, *Desirable Quality for Drinking Water* was revised and jointly published with the Australian Water Resources Council (AWRC). This was considered a significant advance in water quality management because, for the first time, water supply and health authorities in Australia combined to produce a single guideline document. The 1980 guidelines were based on published criteria and standards recommended by overseas and international agencies, in particular the 1971 *International Standards for Drinking Water* of the World Health Organization (WHO).

Following a review of the 1980 Guidelines, and taking into consideration the 1984 WHO *Guidelines for Drinking-Water Quality,* the NHMRC and the AWRC published the *Guidelines for Drinking Water Quality in Australia* in 1987.

In 1996, the NHMRC and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ, formerly AWRC) published the ADWG. The Guidelines were based on working papers and assessments prepared by the WHO expert panels, and reflected recent improvements in understanding problems of water quality. Referenced material included scientific papers, Guidelines published by overseas agencies, issues papers prepared by Australian water authorities and assessments made by the NHMRC. Only key references were cited, particularly those that were used as a basis for determining guideline values.

The guideline values in the 1996 ADWG were based primarily on the latest WHO recommendations, and any departures from these were detailed in the text. It should be noted, however, that the WHO *Guidelines for Drinking Water Quality* seek to define drinking water which, as well as being safe, is aesthetically ***acceptable***, whereas the emphasis in the Australian Guidelines is on producing drinking water that is safe and of ***good*** aesthetic quality.

During the development of the ADWG, it became evident that undertaking a major review of the ADWG in the future would be time consuming and resource intensive. To improve development and ensure that the Guidelines continued to represent the latest scientific evidence, the NHMRC and ARMCANZ agreed to initiate a 'rolling revision' process for the ADWG. Through this process, the Guidelines would remain under constant revision, with specific issues identified for review as required.

In 1998, NHMRC and ARMCANZ established a joint committee, the Drinking Water Review Coordinating Group, to oversee and manage the review process. In 2001–2002, ARMCANZ and the Australia and New Zealand Environment Conservation Council were replaced with the Natural Resource Management Ministerial Council (NRMMC) and the Environment Protection and Heritage Council. The ADWG continue to be developed under the auspices of the NHMRC and NRMMC.

The current revised ADWG supersede the 1996 Guidelines. Specialist panels prepared the Framework outlined in Chapters 2 and 3 and the sections on microorganisms, physical quality, inorganic chemicals, organic chemicals, radiological quality and pesticides. The specialist panels and the joint committee included representatives from the NHMRC, water authorities, private industry, universities, departments of health, departments of water resources and others.

There are two main differences between the current ADWG and those of 1996: the section on radiological contaminants has been rewritten, and the Guidelines now include the Framework for Management of Drinking Water Quality. In addition, fact sheets on a number of contaminants have been revised.

The ADWG are part of the National Water Quality Management Strategy. The strategy aims to 'achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development'. It provides information and tools to help communities manage their water resources to meet current and future needs.

A regulatory impact statement (RIS) including a cost-benefit evaluation of regulatory alternatives, was not undertaken as part of this review. The Productivity Commission's Office of Regulation Review has previously determined that the NHMRC is not required to undertake an RIS as the Guidelines do not have a regulatory status. Implementation of the Guidelines by the States and Territories is at the discretion of the State and Territory Health Department, usually in consultation with water suppliers and should include an appropriate economic analysis prior to implementation.

1.5.1 ACKNOWLEDGMENTS

The NHMRC and NRMMC expresses gratitude to the Cooperative Research Centre for Water Quality and Treatment for its continued support in the development of the ADWG, and in particular the Framework for Management of Drinking Water Quality. NHMRC and NRMMC are grateful to the following people for the excellent work they do on its behalf. The work is usually performed on an honorary basis and in addition to their usual work commitments, and has been crucial in the continued development of the ADWG:

NHMRC Drinking Water Review Coordinating Group

Prof Don Bursill (Chair)	Cooperative Research Centre for Water Quality and Treatment
Dr David Cunliffe	Department of Human Services, South Australia
Peter Scott	Melbourne Water
Dr Anne Neller	University of the Sunshine Coast
Alec Percival	Consumers' Health Forum
Dr John Langford	Water Services Association of Australia
Brian McRae	Australian Water Association
Phil Callan (Technical Secretary)	National Health and Medical Research Council

Drinking Water Quality Management Working Party

Dr David Cunliffe (Chair)	Department of Human Services, South Australia
Dr Martha Sinclair	Monash University
Samantha Rizak	Monash University
Roslyn Vulcano	Department of Infrastructure, Planning and Environment, NT
Dr John Howard	South Australian Water Corporation
Prof Steve Hrudey	University of Alberta, Canada

Drinking Water Treatment Chemicals Working Party

Prof Michael Moore (Chair)	National Research Centre for Environmental Toxicology
Dr Peter Di Marco	Health Department of Western Australia
Mary Drikas	South Australian Water Corporation
Dr Jim Fitzgerald	Department of Human Services, South Australia
Dr Peter Mosse	Gippsland Water
Colin Nicholson	Sydney Water Corporation

Microbial Working Party

Mike Burch (Chair)	South Australian Water Corporation
Dr David Cunliffe	Department of Human Services, South Australia
Glen Shaw	National Research Centre for Environmental Toxicology
Dr Brenton Nicholson	South Australian Water Corporation
Dr Ian Falconer	Australian National University

Pesticides Working Party

Dr Les Davies (Chair)	Therapeutic Goods Administration
Dr Jim Fitzgerald	Department of Human Services, South Australia
Dr Brenton Nicholson	South Australian Water Corporation

Protozoa Working Party

Dr David Cunliffe (Chair)	Department of Human Services, South Australia
Assoc Prof Christopher Fairley	Monash University
Prof Nick Ashbolt	University of New South Wales
Peter Scott	Melbourne Water
Dr Dennis Steffensen	South Australian Water Corporation

Radiological Working Party

Dr Malcolm Cooper (Chair)	Australian Radiation Protection and Nuclear Safety Agency
Philip Crouch	Department of Human Services, South Australia
Richard Walker	Water Corporation Western Australia

Priority Setting Group (28 January 1998)

Dr Charles Guest	National Centre for Epidemiology and Population Health
Barry Sanders	Agriculture and Resource Management Council of Australia and New Zealand
Prof Don Bursill	Cooperative Research Centre for Water Quality and Treatment
Annette Coburn	Australian Consumers Association
Christine Cowie	New South Wales Health
David Lambert	National Water Quality Management Strategy Secretariat
Dr John Langford	Water Services Association of Australia
Dr Peter Liehne	Commonwealth Department of Health and Family Services
Dr Udomsri Low	National Health and Medical Research Council
Sharon Tuffin	National Health and Medical Research Council

Others involved in the development of the *Australian Drinking Water Guidelines* include:

Dr Jenny Stauber	Commonwealth Scientific and Industrial Research Organisation
Sam Mangas	Department of Human Services, South Australia
Barry Sanders	Water Corporation, Western Australia
Chris Davis	Australian Water Association
Dr Melita Stevens	Melbourne Water

1.5.2 PUBLIC CONSULTATION ON THE AUSTRALIAN DRINKING WATER GUIDELINES

Consultation on the guidelines has included calls for submissions from stakeholders on issues to be addressed through the rolling review process (first stage consultation) and call for submission on the draft guidelines as they have been developed. The call for submissions were publicised in the *Commonwealth Notices Gazette, The Weekend Australian,* and invitations forwarded to known interested parties through the enHealth Council, the Australian Water Association, Water Services Association of Australia.

All submissions received during the consultation were taken into consideration in finalising these Guidelines. Comments were considered by the relevant working party and the NHMRC/NRMMC Drinking Water Review Coordinating Group. Submissions were received from the following individuals/ organisations

First Stage consultation (February 1999)

Dr John Langford, Bob Dorrat	Water Services Association of Australia
Alan Shea	Hobart Water
New South Wales Cabinet Office	
David Cox	Water Services Association of Australia
Barry Sanders	WA Water Corporation
Bill Stanford	Citiwater, Townsville
Peter Scott	Melbourne Water
Dr Annette Davison	AWT, Sydney
Dr Daniel Deere	South East Water
David Murdoch	Halpern Click Maunsell
Cynthia Joll	Curtin University
Paul Grover	ProMinent Fluid Control

Public consultation – 28 July to 27 August 1999 (Cryptosporidium and Giardia)

Dr Robert Thurman	Ballarat Victoria
Jean Williams	Nambour, New South Wales
Tony Garner	Ultraviolet Technology of Australia, South Australia
Scott Webber	Queensland Health
Dr Martha Sinclair	Monash University
Geoff Davis	Department of Health and Aged Care
Bob Gray	Brisbane Water
Dr Melita Stevens	Melbourne Water
Prof Paul Greenfield	University of Queensland
Pierre Mazounie	Australian Water Services
Harold Wright	Trojan Technologies, Ontario, Canada
Jennie Ludlow	Environment Australia
Paul Prendergast	Ministry of Health, New Zealand
Dr Andrew Langely	Department of Human Services, South Australia
Greg Dorricott	Queensland Health
Martyn Kirk	Department of Human Services, Victoria
Anthony MacCormick	USF Filtration

Public consultation 13 September to 10 November 2000
(Arsenic, aluminium, coliforms, copper, Pseudomallei Burkholderia, taste and odour, Turbidity, Water Quality Management)

Philip Broad	Sydney Water
John Cugley	SA Water
Prof Michael Moore	National Research Centre for Environmental Toxicology
Dr Daniel Deere	South East Water
Anne Wooley	Department of Natural Resources, Queensland
Dr Brad Cassels	Territory Health Services, Northern Territory
David Sheehan	AWT Environment Laboratory, Queensland
Dr Peter Harty	Department of Human Services, Victoria
Alan Maus	WA Water Corporation
Paul Prendergast	Ministry of Health, New Zealand
Dr Sue Phillips	Department of Human Services, Victoria
Dr Jan Bowman	Department of Human Services, Victoria
B Dowling	Cold Coast Water
Emma Campbell	Environment Australia
Dr D Leece	NSW Government Radiation Advisory Council
GSR Walker	Freedom from Fluoridation Federation of Australia
Dr Jonathon Streeton	Consulting Respiratory Physician

Public consultation 9 May 2001 to 6 July 2001
(Framework for Management of Drinking Water Quality)

Peter McCleery	AQWEST Water
Sophie Dwyer	Queensland Health
Laurie Gleeson	Goulburn Valley Water
Richard Birrell	Sydney Water
Robert Butler	Australian Dental Association
David Roberts	Gippsland Water
Victor Fazakerley	Power and Water Authority (Northern Territory)
Richard Theobald	Health Department of Western Australia
Sylvertre Fink	Federation of Canadian Municipalities
Greg Ryan	South East Water Limited
Michael Leak	North East Region Water Authority
Chloe Munro	Natural Resources and Environment, Victoria
Adrian Langdon	Department of Land and Water Conservation, New South Wales
Sam Austin	Yarra Valley Water
Jeff Wright	Sydney Catchment Authority
Brian Labza	Melbourne, Victoria

Public consultation 29 September 2001 to 9 November 2001
(Review of Coliforms as Microbial Indicators of Drinking Water Quality)

Dr Paul Van Buynder	Department of Human Services, Victoria
Christine Cowie	NSW Health Department
Jim Martin	North East Water
Dr Martha Sinclair, Samantha Rizak	Monash University
Greg Ryan	South East Water Limited
David Heeps	City West Water
Mark Harvey	Victorian Water Industry Association Inc.
Jacqui Goonrey	ActewAGL
Les Mathiesons	East Gippsland Water
Dr Christ Saint, Phil Adcock	Australian Water Quality Centre
Keith Neaves	Lower Murray Water
Ian Tanner	Sydney Catchment Authority
Brian Bayley	Melbourne Water
Philip Berger	US Environmental Protection Agency
Harry Ferguson	Brisbane Water
Sam Austin	Yarra Valley Water
Alan Thornton	Hunter Water Corporation
Clare Bailey	Queensland Health
Darryl Day	Power and Water Authority (Northern Territory)
David Sheehan	AWT Environment Laboratory, Queensland

Public consultation 2 November 2002 – 24 January 2003
(Australian Drinking Water Guidelines, 2003, incorporating the Framework for Management of Drinking Water Quality)

Phillip Bingley	Derwent Valley Council, Tasmania
Jennifer Higgins	Gold Coast Water
Robert JF Butler	Australian Dental Association
Dennis Brockenshire	Barwon Water
Georges Rutta	City West Water
Laurie Gleeson	Goulburn Valley Water
Sam Austin	Yarra Valley Water
Richard Walker	WA Water Corporation
David Sheehan	Environlabs, Gippsland
Peter Mosse, Steven Healy	Gippsland Water
Dr John Harries	Australian Nuclear Science and Technology Organisation
Dr G Stewart	International Association of Hydrogeologists
Dr Jonathon Streeton	Consulting Respiratory Physician, Melbourne
David Smith	Gold Coast Water
Andrew Gibbes	Shoalhaven City Council
Ashley Fletcher	Tyco Water

Alison Smith	Aboriginal and Torres Strait Islander Commission
Adrian Ray	Australian Inland, Broken Hill
Dr Martha Sinclair, Samantha Rizak	Monash University
Mark Harvey	Victorian Water Industry Association, Inc
Dennis Cavagna	South East Water
Adrian Spall	Department of Sustainability and Environment, Victoria
Dr John Langford	Water Services Association of Australia
Mark Stone	Parks Victoria
Dr Paul Van Buynder	Department of Human Services, Victoria
Dr Paul Byleveld	NSW Health Department
Alan Humphries	Department of Infrastructure, Energy and Resources, Tasmania
Richard Birrell	Sydney Water
Colin Nicholson	Sydney Water
Charles Lewis	Environment Australia
Michael Leak	North East Region Water Authority
Anne Howe	SA Water
Peter Scott	Melbourne Water

1.5.3 WORKSHOP ON GUIDELINES FOR WATER QUALITY MANAGEMENT SYSTEMS

A workshop involving representatives from health, water, and resource management agencies and academia, was convened in 8 October 1999 to discuss preventive management of water quality and the development of the *Framework for Management of Drinking Water Quality*. Participants at the Workshop were:

Prof Don Bursill	Cooperative Research Centre for Water Quality and Treatment
Dr Richard Lugg	Health Department of Western Australia
Christine Cowie	New South Wales Health Department
Greg Dorricott	Queensland Health
Dr David Cunliffe	South Australian Department of Human Services
Martyn Kirk	Department of Human Services, Victoria
Mark Lobban	Department of Health and Human Services, Tasmania
Richard Walker	WA Water Corporation
Dr Daniel Deere	South East Water
Alan Dodds	Sydney Catchment Authority
Mark Pacsoe	Brisbane City Council
Paul Freeman	Sydney Water Corporation
Darryl Day	Power and Water Authority, Northern Territory
Howard Lacy	South Australia Water Corporation
Alan Shea	Hobart Water
Carl Magyar	ECOwise Environmental
Peter Scott	Melbourne Water
Dr Anne Neller	University of the Sunshine Coast
Dr John Langford	Water Services Association of Australia
Chris Davis	Australian Water Association

Ross Dalton	Agriculture, Fisheries and Forestry Australia
Steve Clark	Agriculture, Fisheries and Forestry Australia
Dr Roscoe Taylor	Queensland Health
Dr Steve Hrudey	University of Alberta, Canada
Dr Martha Sinclair	Monash University
Samantha Rizak	Monash University
Alec Percival	Consumer's Health Forum
Gary Mitchell	NSW Local Government Water Directorate
Phil Callan	National Health and Medical Research Council
Karina Desarmia	National Health and Medical Research Council

1.5.4 PILOT STUDIES ON THE FRAMEWORK FOR MANAGEMENT OF DRINKING WATER QUALITY

Prior to the finalisation of the *Framework for Management of Drinking Water Quality*, and subsequent inclusion into the ADWG, Sydney Water, Melbourne Water, NT Power and Water Authority and Western Australia Water Corporation agreed to participate in the desktop pilot study on the draft Framework. The pilot studies were conducted from January to March 2000. Participants in the pilot trials were:

Sydney, NSW

Dr Annette Davison	Australian Water Technologies
Greg Helm	Sydney Water Corporation
Steve Horton	Sydney Catchment Authority

Perth, WA

Peter Engler	WA Water Corporation
Ross Sheridan	WA Water and Rivers Commission
Richard Theobald	Health Department of WA

Katherine, NT

Victor Fazakerley	NT Power and Water
Roslyn Vulcano	NT Power and Water

Melbourne

Kevin Hellier	Melbourne Water
John Hearn	South East Water
Dr Peter Nadebaum	Egis Consulting
Peter Guttman	Department of Natural Resources, Victoria
Sue Phillips	Vic Department of Human Services

Prior to approval by the NHMRC, the ADWG was technically edited by Biotext Pty Ltd, and subjected to an independent review against the NHMRC key criteria for assessing Guidelines.

1.6 Future revisions of the ADWG

The ADWG will continue to be subject to regular review by the joint committee, with representatives from national health, water, environmental and community organisations, supported by specialist panels.

Submissions for updating the ADWG should be forwarded to:

Technical Secretary

NHMRC Drinking Water Review Coordinating Group (MDP 24)
National Health and Medical Research Council
GPO Box 9848
Canberra ACT 2601

Chapter 2 Framework for Management of Drinking Water Quality – Overview

Chapter 2 Framework for Management of Drinking Water Quality: overview

This chapter introduces the Framework for Management of Drinking Water Quality (the Framework) and describes its purpose, benefits and structure. It outlines how the Framework can be applied and explains the importance of various agencies working in partnership with drinking water suppliers to apply the Framework successfully.

2.1 A preventive strategy from catchment to consumer

The most effective means of assuring drinking water quality and the protection of public health is through adoption of a preventive management approach that encompasses all steps in water production from catchment to consumer.

In the Australian water industry, risk management and quality management are increasingly being used as a means of assuring drinking water quality by strengthening the focus on more preventive approaches. Some water authorities have implemented management systems based on ISO 9001 (Quality Management), ISO 14001 (Environmental Management), AS/NZS 4360 (Risk Management) or more recently the Hazard Analysis and Critical Control Point (HACCP) system that has been adopted internationally by the food industry.

These available frameworks provide generic requirements for organisations undertaking a diverse range of activities. As such, they are not intuitively translated to management of drinking water quality, and therefore result in a range of interpretations and various applications within the water industry. Furthermore, management of drinking water quality from catchment to consumer poses several challenges that are unique to the water industry and that may not be sufficiently addressed in these models.

The Framework was developed to guide the design of a structured and systematic approach for the management of drinking water quality from catchment to consumer, to assure its safety and reliability.

The Framework incorporates a preventive risk management approach; it includes elements of HACCP, ISO 9001 and AS/NZS 4360, but applies them in a drinking water supply context to support consistent and comprehensive implementation by suppliers.

The Framework addresses four general areas, which are described below and illustrated in Figure 2.1:

- **Commitment to drinking water quality management**. This involves developing a commitment to drinking water quality management within the organisation. Adoption of the philosophy of the Framework is not sufficient in itself to ensure its effectiveness and continual improvement. Successful implementation requires the active participation of senior executive and a supportive organisational philosophy.
- **System analysis and management**. This involves understanding the entire water supply system, the hazards and events that can compromise drinking water quality, and the preventive measures and operational control necessary for assuring safe and reliable drinking water.
- **Supporting requirements**. These requirements include basic elements of good practice such as employee training, community involvement, research and development, validation of process efficacy, and systems for documentation and reporting.
- **Review**. This includes evaluation and audit processes and their review by senior executive to ensure that management system is functioning satisfactorily. These components provide a basis for review and continual improvement.

2.2 Structure of the Framework

The Framework includes 12 elements considered good practice for system management of drinking water supplies, outlined in figure 2.1 and detailed in table 2.1.

Figure 2.1 *Framework for management of drinking water quality*

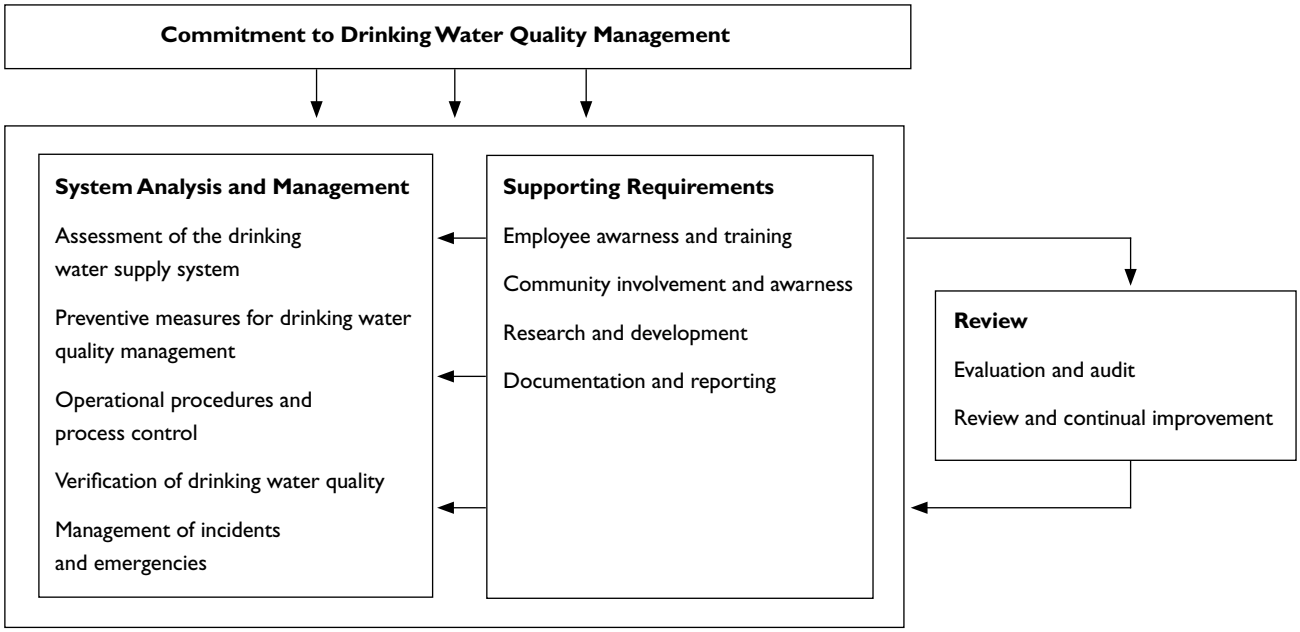

Table 2.1 *Framework for Management of Drinking Water Quality*

COMMITMENT TO DRINKING WATER QUALITY MANAGEMENT
Element 1 Commitment to drinking water quality management
Drinking water quality policy
Regulatory and formal requirements
Engaging stakeholders
SYSTEM ANALYSIS AND MANAGEMENT
Element 2 Assessment of the drinking water supply system
Water supply system analysis
Assessment of water quality data
Hazard identification and risk assessment
Element 3 Preventive measures for drinking water quality management
Preventive measures and multiple barriers
Critical control points
Element 4 Operational procedures and process control
Operational procedures
Operational monitoring
Corrective action
Equipment capability and maintenance
Materials and chemicals
Element 5 Verification of drinking water quality
Drinking water quality monitoring
Consumer satisfaction
Short-term evaluation of results
Corrective action
Element 6 Management of incidents and emergencies
Communication
Incident and emergency response protocols
SUPPORTING REQUIREMENTS
Element 7 Employee awareness and training
Employee awareness and involvement
Employee training
Element 8 Community involvement and awareness
Community consultation
Communication
Element 9 Research and development
Investigative studies and research monitoring
Validation of processes
Design of equipment
Element 10 Documentation and reporting
Management of documentation and records
Reporting
REVIEW
Element 11 Evaluation and audit
Long-term evaluation of results
Audit of drinking water quality management
Element 12 Review and continual improvement
Review by senior executive
Drinking water quality management improvement plan

Although listed as discrete components, the 12 elements are interrelated and each supports the effectiveness of the others. To assure a safe and reliable drinking water supply, these elements need to be addressed together because most water quality problems are attributable to a combination of factors.

The Framework outlines principles of management applicable to all water supply systems regardless of size and system complexity (i.e. both small and large supplies, ranging from those with minimal treatment to those with full treatment). To reflect the diversity of individual water supplies and the varying institutional arrangements (e.g. corporations, local authorities, wholesale, retail and contractors), the Framework is flexible. It provides generic guidance and the content should not be regarded as being prescriptive or exhaustive.

2.3 Benefits of the Framework

Management of drinking water quality through a comprehensive preventive strategy benefits the water industry by providing an overall framework that:

- promotes public health by assuring safer drinking water for consumers
- enables an in-depth systematic evaluation of water systems, the identification of hazards and the assessment of risks
- fosters a holistic approach to, and understanding of, management of drinking water quality
- emphasises prevention and places drinking water quality monitoring in an appropriate verification role
- introduces a common and standard approach throughout the industry, which establishes due diligence and credibility
- provides the opportunity for various agencies and stakeholders to identify their areas of responsibility and become involved, and offers the outcome of a cooperative and coordinated approach with improved understanding of the responsibilities of all parties
- provides a framework for communication with the public and with employees
- addresses the uncertainties in setting accurate guideline values when insufficient scientific data are available
- identifies future research needs for individual systems and throughout the water industry, and assists the development of improved risk assessment for specific hazards.

2.4 The need for multiagency involvement

Restructuring of the water industry in Australia over recent years has increasingly transferred catchment and water resource management to agencies other than drinking water suppliers. These agencies may include water resource departments, natural resource and environment departments, agriculture departments, local governments, planning authorities, catchment water management boards, and community-based interest groups and organisations.

In some cases, restructuring has extended to dividing the traditional functions associated with the supply of drinking water, so that separate agencies are responsible for bulk water supply, water treatment and water reticulation. In addition, regulation of drinking water quality can take various forms. Health departments generally take a leading role in regulation; however, in some areas, specific water regulators may be established.

The Framework is intended to apply from catchment to consumer; as such, it addresses the necessity of inter-agency involvement. Drinking water suppliers are responsible for the quality of drinking water delivered to consumers and accordingly must show leadership in application of the Framework; however, implementation will generally require coordination and consultation with other agencies.

The range of agencies involved in individual water supply systems will need to be determined. Relevant agencies need to be encouraged to recognise their roles and responsibilities within the Framework, and to support drinking water suppliers through partnership agreements. The breadth and depth of partnership arrangements between agencies and the mechanisms by which they operate will vary between different jurisdictions, depending on the division of responsibilities and legislative authorities. If possible, a state- or territory-wide commitment to drinking water quality management and a formal coordination of responsible agencies should be developed (see Box 2.1).

Even where commitments and partnership agreements with other agencies are difficult to establish, the Framework should still be implemented. Gradually, as partnerships with other agencies are established, the Framework can be further improved and a more integrated approach developed.

***Box 2.1** Application of the Framework in Western Australia*

In Western Australia, drinking water quality management is a shared responsibility between the Water and Rivers Commission (WRC) and the Water Corporation of Western Australia (WCWA). The WRC is responsible for administration of catchment and source protection legislation; the WCWA is the major licensed drinking water supplier responsible for the collection, treatment and distribution of drinking water to consumers. Other key agencies in the supply of drinking water are the regulators, including the health authority, which provides interpretation and guidance on potential health impacts of drinking water quality.

A variation to application of the Framework that is proposed by Western Australia is to apply the Framework at the state level using a whole-of-government approach, with each agency responsible for implementing the Framework within its areas of control and consulting with relevant partnership agencies. This approach requires a high level of commitment by all agencies, clear definition of accountabilities and responsibilities within the Framework, and increased communication and coordination of planning and management activities.

Under these circumstances, the WRC would be the lead agency to implement the catchment aspects of the Framework, with the WCWA a significant stakeholder. Downstream of the catchment, WCWA would be responsible for implementing the Framework in its areas of control. It is proposed that the Health Department, as the agency with responsibility for protecting public health, will have a key coordinating role in ensuring effective implementation and operation of the Framework.

2.5 Applying the framework

Although the guidelines are not intended to be applied as standards, it is recognised that some jurisdictions may choose to regulate the guidelines through legislation or operating licences. In determining how the guidelines are translated into standards, operators and regulators should consider costs and benefits of these actions as well as developing an appropriate implementation timetable. The timetable should allow for endorsement of tools and processes used by water suppliers, and the establishment of mechanisms to ensure continual improvement. Just as important is an early determination and agreement on how the Framework will be monitored, audited and reported against. These aspects need clarification to ensure effective, unambiguous implementation.

Application of the Framework will vary depending on the arrangements for water supply within each jurisdiction, eg in some states water supply is managed by the one agency, whereas in other states water supply is managed locally by numerous water suppliers. This is likely to affect the manner and degree to which the Framework is implemented. However, all water suppliers and relevant Government agencies should still be encouraged to use the Framework as a model for best practice.

How the Framework is applied will depend on the needs of the organisation, the separation of responsibilities and the institutional arrangements. Each organisation should develop an internal plan for implementing the Framework in a manner that suits its particular circumstances. The Framework can be applied as a stand-alone drinking water quality management system or can be integrated with an existing management system.

The time and resources required to develop a drinking water quality management system will depend on how many features of the Framework are already being practised and on how advanced existing

management systems are. Current management applied by most drinking water suppliers and associated agencies will already incorporate many of the elements specified in the Framework. However, existing practices may not be sufficiently comprehensive to fully address the range of drinking water quality issues that can arise, and may not be systematically structured or sufficiently visible to ensure that all employees know and understand the system. In many instances, all that may be needed is to review, document and formalise these practices and address any areas where improvements are required.

The first step in initiating a drinking water quality management system based on the Framework is to identify appropriate personnel with defined roles and responsibilities. Establishing a core group with the necessary skills will help to ensure consistency throughout the implementation. This group can be supplemented by other expertise as necessary when dealing with specific issues. One option is to establish a water quality committee or water quality department with responsibility for the implementation and ongoing management of the overall system.

Some elements of the Framework will require more effort than others, and improvements may need to be prioritised and implemented sequentially. Additional guidance on two elements of the Framework – *Assessment of the drinking water supply system* (element 2) and *Preventive measures for drinking water quality management* (element 3) – is provided in the Appendix *Additional guidance on elements 2 and 3 of the Framework for Management of Drinking Water Quality* (located at the end of the Guidelines). To assist with implementation of the Framework, users are encouraged to draw on the numerous sources providing detailed technical guidance (see Section A9 of the Appendix).

The most important step is getting started. Documenting current practice is often the most effective way to begin. However, in doing this it is important not to get involved in so much detail that making progress on implementing the Framework is inhibited. Documentation of the drinking water quality management system should make maximum use of existing documentation where that is adequate. A manual should be developed to provide an overview of the system and a summary of all relevant documentation.

Training personnel, including senior executives, in quality and risk management methods such as ISO 9001 and HACCP may assist in the development and implementation of a drinking water quality management system. Where necessary, help from outside experts should be sought to facilitate implementation of the Framework.

Effective management systems are not static and must be capable of accommodating change such as catchment developments, emerging issues, advances in technology or new institutional arrangements. Development should be an ongoing and iterative process whereby performance is continually evaluated and reviewed.

2.6 Correlations of the Framework with other systems

The Framework is not intended to duplicate or replace adequately working management systems; rather, it is intended to be compatible and complementary. The Framework includes principles of established systems such as HACCP, ISO 9001 and AS/NZS 4360, and is sufficiently flexible to allow implementation to be built on programs and systems already present in an organisation. However, the relationships between the Framework and these systems should be understood.

The HACCP system was developed for the food industry and has become an internationally recognised risk management system to prevent or reduce the health risks from hazards associated with food processing. It is designed primarily as a preventive system of control to assure product safety while reducing reliance on end-product testing.

The application of the HACCP system to drinking water supplies has received increasing recognition due to the many parallel issues in food and drinking water supply. The HACCP system comprises seven principles. These principles and the equivalent Framework elements are shown in Table 2.2.

The HACCP system offers a systematic approach to the identification of hazards and their prevention, with a particular focus on process control to ensure that preventive measures are operating effectively. HACCP was not designed to be a fully comprehensive management system but was intended to be added on to existing good management practices. Thus, its scope and application are limited in several important areas of the Framework such as commitment, stakeholder involvement, emergency response, employee training, community consultation and research and development. Furthermore, while HACCP is aligned quite readily to the treatment component of drinking water supply, its application may not transfer as easily to the important areas of catchment and distribution systems.

Table 2.2 *Correlations between HACCP and the Framework*

HACCP	Framework for Management of Drinking Water Quality
1. Hazard identification and preventive measures	Water supply system analysis, hazard identification and risk assessment (element 2)
	Preventive measures and multiple barriers (element 3)
2. Critical control points	Critical control points (element 3)
3. Critical limits	Operational monitoring (element 4)
4. Monitoring system for each critical control point	Operational monitoring (element 4)
5. Corrective actions	Corrective action (elements 4 and 5)
6. Verification / validation	Equipment capability and maintenance (element 4)
	Drinking water quality monitoring, consumer satisfaction (element 5)
	Validation of processes, design of equipment (element 9)
	Audit of drinking water quality management (element 11)
7. Documentation and record keeping	Management of documentation and records (element 10)

ISO 9001 provides a generic framework that specifies requirements for quality management systems to address customer satisfaction by assuring a consistent end product. The standard puts emphasis on continuous improvement; it adopts a process model approach that sets out the responsibilities, processes and resources needed to achieve specified objectives with respect to quality.

Table 2.3 lists the detailed ISO 9001 requirements and identifies links and correlations with the Framework. While the Framework and ISO 9001 are compatible, the structures of the two are somewhat different and correlations between them are not as close as those with HACCP. Table 2.3 shows correlations of general themes and areas.

Table 2.3 *Correlations between ISO 9001 and the Framework*

ISO 9001	Framework for Management of Drinking Water Quality
Quality management system	
General requirements	See Section 2.5 Applying the Framework
Documentation requirements	Management of documentation and records (element 10)
Management responsibility	
Management commitment	Drinking water quality policy, regulatory and formal requirements (element 1)
	Review by senior executive, drinking water quality management improvement plan (element 12)
Customer focus	Regulatory and formal requirements (element 1)
	Community consultation (element 8)
Quality policy	Drinking water quality policy (element 1)

Table 2.3 *Correlations between ISO 9001 and the Framework (continued)*

Planning	Regulatory and formal requirements (element 1)
	Operational monitoring (element 4)
	Drinking water quality monitoring (element 5)
Responsibility, authority and communication	See Section 2.5 Applying the Framework
Management review	Long-term evaluation of results, audit of drinking water quality management (element 11)
	Review by senior executive, drinking water quality management improvement plan (element 12)
ISO 9001	**Framework for Management of Drinking Water Quality**
Resource management	
Provision of resources	Drinking water quality management improvement plan (element 12)
Human resources	Employee awareness and involvement, employee training (element 7)
Infrastructure	Equipment capability and maintenance (element 4)
	Design of equipment (element 9)
Work environment	
Product realisation	
Planning of realisation processes	Preventive measures and multiple barriers, critical control points (element 3)
Customer-related processes	Community consultation, communication (element 8)
	Regulatory and formal requirements (element 1)
Design and development	Investigative studies and research monitoring, validation of processes, design of equipment (element 9)
Purchasing	Materials and chemicals (element 4)
Production and service provision	Operational procedures, operational monitoring, corrective action, equipment capability and maintenance (element 4)
	Validation of processes (element 9)
Control of measuring and monitoring devices	Equipment capability and maintenance (element 4)
Measurement, analysis and improvement	
General	
Monitoring and measurement	Operational monitoring (element 4)
	Drinking water quality monitoring, consumer satisfaction (element 5)
	Audit of drinking water quality management (element 11)
Control of nonconforming product	Corrective action (elements 4 and 5)
	Incident and emergency response protocols (element 6)
	Reporting (element 10)
Analysis of data	Operational monitoring (element 4)
	Short-term evaluation of results (element 5)
	Long-term evaluation of results (element 11)
Improvement	Review by senior executive, drinking water quality management improvement plan (element 12)

ISO 9001 includes several aspects of the Framework, but in a general sense, and it does not always provide a good fit to the specific requirements of drinking water quality management. The most important limitation of ISO 9001 is that it fails to address the preventive requirements of system analysis, hazard identification and control, and risk assessment, which are all critical for effective management of drinking water quality. There are other limitations in the areas of stakeholder involvement (for stakeholders other than consumers), research and development, management of large-scale emergencies, communication and reporting.

There is scope to implement the Framework within the structure of these established systems by expanding them to encompass all the necessary elements for drinking water quality management. For example, when integrated, HACCP and ISO 9001 can satisfy many of the key elements for drinking water quality management. However, if established management systems are applied to meet the requirements for management of drinking water quality as outlined in the Framework, then it should be ensured that all the necessary elements of drinking quality management are addressed.

Table 2.4 provides a general comparison indicating the applicability of established quality and risk management systems to the Framework.

Table 2.4 *Comparison of features from various management frameworks*

Framework for Management of Drinking Water Quality	HACCP	ISO 9001 (2000)	AS/NZS 4360 (1999)
Commitment to drinking water quality management			
Drinking water quality policy		+++	+++
Regulatory and formal requirements	+++	+++	
Engaging stakeholders			
Assessment of the drinking water supply system			
Water supply system analysis	+++		
Assessment of water quality data			
Hazard identification and risk assessment	+++		+++
Preventive measures for drinking water quality management			
Preventive measures and multiple barriers	+++	+	+++
Critical control points	+++		
Operational procedures and process control			
Operational procedures	+	+++	
Operational monitoring	+++	+++	
Corrective action	+++	+++	
Equipment capability and maintenance	+	+++	
Materials and chemicals	+	+++	
Verification of drinking water quality			
Drinking water quality monitoring	+++	+++	+++
Consumer satisfaction		+++	
Short-term evaluation of results		+++	+
Corrective action	+++	+++	
Management of incidents and emergencies			
Communication			
Incident and emergency response protocols			
Employee awareness and training			
Employee awareness and involvement		+++	
Employee training	+++	+++	
Community involvement and awareness			
Community consultation		+++	+++
Communication	+	+	+++

Table 2.4 *Comparison of features from various management frameworks (Continued)*

Framework for Management of Drinking Water Quality	HACCP	ISO 9001 (2000)	AS/NZS 4360 (1999)
Research and development			
Investigative studies and research monitoring			
Validation of processes	+++	+++	
Design of equipment		+++	
Documentation and reporting			
Management of documentation and records	+++	+++	+++
Reporting			+++
Evaluation and audit			
Long-term evaluation of results		+	
Audit of drinking water quality management	+++	+++	+++
Review and continual improvement			
Review by senior executive	+++	+++	+
Drinking water quality management improvement plan		+++	

Notes:
+++ Aspect explicitly stated
+ Aspect not explicitly stated but interpreted to include

Chapter 3 Framework for Management of Drinking Water Quality – the twelve elements

Chapter 3 Framework for Management of Drinking Water Quality: the twelve elements

This chapter details the 12 elements that make up the Framework for Management of Drinking Water Quality (the Framework). Each element includes an introduction and lists the components that make up the element. The components of each element are then described in further detail. A 'summary of actions' box heads each component and provides an overview of the steps involved in implementation.

Some elements of the Framework are more complex than others, and therefore require further explanation. The Appendix (located at the end of the Guidelines) provides additional information and guidance for two elements – *Assessment of the drinking water supply system* (element 2) and *Preventive measures for drinking water quality management* (element 3).

3.1 Commitment to drinking water quality management (element 1)

Components: Drinking water quality policy
Regulatory and formal requirements
Engaging stakeholders

Organisational support and long-term commitment by senior executive is the foundation to implementation of an effective system for drinking water quality management.

Successful implementation requires:

- an awareness and understanding of the importance of drinking water quality management and how decisions affect the protection of public health
- the development of an organisational philosophy that fosters commitment to continual improvement and cultivates employee responsibility and motivation
- the ongoing and active involvement of senior executive to maintain and reinforce the importance of drinking water quality management to all employees as well as those outside the organisation.

Senior executive should ensure that its actions and policies support the effective management of drinking water quality (e.g. appropriate staffing, training of employees, provision of adequate financial resources, active participation and reporting to the board or chief executive).

3.1.1 DRINKING WATER QUALITY POLICY

Summary of actions

- Formulate a drinking water quality policy, endorsed by senior executive, to be implemented throughout the organisation.
- Ensure that the policy is visible and is communicated, understood and implemented by employees.

Development of a drinking water quality policy is an important step in formalising the level of service to which the drinking water supplier is committed and in increasing focus on water quality management throughout the organisation. The policy provides the basis on which all subsequent actions can be judged. It should define the organisation's commitments and priorities relating to drinking water quality.

The drinking water quality policy should provide a basis from which more detailed policies and implementation strategies can be developed. As such, it should be clear and succinct, and should address broad issues and requirements of the organisation's commitment and approach to drinking water quality management. The policy may cover issues such as:

- commitment to drinking water quality management
- the level of service provided
- the involvement of employees
- compliance with relevant regulations and other requirements
- liaison and cooperation with relevant agencies including health departments and other regulators
- communication with employees and the public
- intention to adopt best practice management and multiple barriers
- continual improvement in the management of drinking water quality.

Box 3.1 provides an example of a generic drinking water quality policy.

In developing the drinking water quality policy, the opinions and requirements of employees, consumers and other stakeholders should be considered.

Management should ensure that the policy is highly visible, continually communicated, understood and implemented by all employees of the organisation. It is the responsibility of all employees to support this commitment.

***Box 3.1** Example of a drinking water quality policy*

The organisation is committed to managing its water supply effectively to provide a safe, high-quality drinking water that consistently meets the NHMRC/NRMMC *Australian Drinking Water Guidelines,* and consumer and other regulatory requirements. To achieve this, in partnerships with stakeholders and relevant agencies, the organisation will:

- manage water quality at all points along the delivery chain from source water to the consumer
- use a risk-based approach in which potential threats to water quality are identified and balanced
- integrate the needs and expectations of our consumers, stakeholders, regulators and employees into our planning
- establish regular monitoring of the quality of drinking water and effective reporting mechanisms to provide relevant and timely information, and promote confidence in the water supply and its management
- develop appropriate contingency planning and incident response capability
- participate in appropriate research and development activities to ensure continued understanding of drinking water quality issues and performance
- contribute to the debate on setting industry regulations and guidelines, and other standards relevant to public health and the water cycle
- continually improve our practices by assessing performance against corporate commitments and stakeholder expectations.

The organisation will implement and maintain a drinking water quality management system consistent with the *Australian Drinking Water Guidelines* to effectively manage the risks to drinking water quality.

All managers and employees involved in the supply of drinking water are responsible for understanding, implementing, maintaining and continuously improving the drinking water quality management system.

Dated Signed by Responsible Officer

3.1.2 REGULATORY AND FORMAL REQUIREMENTS

Summary of actions

- Identify and document all relevant regulatory and formal requirements.
- Ensure responsibilities are understood and communicated to employees.
- Review requirements periodically to reflect any changes.

Drinking water quality management may be subject to a range of regulatory and other formal requirements such as:

- Federal, state or territory legislation and regulation
- operating licences and agreements
- contracts and agreed levels of service
- memoranda of understanding
- industry standards and codes of practice.

All regulatory and formal requirements should be identified and documented. Individual drinking water suppliers need to understand their responsibilities in supplying water for their particular jurisdictions. Relevant information should be communicated to employees and a registry of relevant regulations and other requirements should be readily accessible for reference. This registry should be regularly reviewed and updated as necessary to reflect any changes.

3.1.3 ENGAGING STAKEHOLDERS

Summary of actions

- Identify all stakeholders who could affect, or be affected by, decisions or activities of the drinking water supplier.
- Develop appropriate mechanisms and documentation for stakeholder commitment and involvement.
- Regularly update the list of relevant agencies.

Several aspects of drinking water quality management require involvement with other agencies. For example, collaboration with the appropriate agency is necessary where catchments and source waters are beyond the drinking water supplier's jurisdiction. Similarly, consultation with relevant health and other regulatory authorities is necessary for establishing many elements of drinking water quality management, such as monitoring and reporting requirements, emergency response plans and communication strategies.

The range of agencies involved in individual water supply systems will vary depending on local organisational and institutional arrangements. Agencies may include:

- health and environment protection authorities
- catchment and water resource management agencies
- local government and planning authorities
- non-government organisations
- community-based groups
- industry associations.

An integrated management approach with collaboration from all relevant agencies is essential for effective drinking water quality management. All major stakeholders that could affect (e.g. regulators, catchment boards) or be affected by (e.g. consumers, industry, plumbers) decisions or activities of the drinking water supplier should be identified. The list of stakeholders should be regularly updated.

The various agencies involved should be encouraged to define their accountabilities and responsibilities to support the drinking water supplier, and where appropriate, to coordinate their planning and management activities. Appropriate mechanisms and documentation should be established for stakeholder commitment and involvement. This may include establishing working groups, committees or task forces, with appropriate representatives, and development of partnership agreements, including signed memoranda of understanding.

3.2 Assessment of the drinking water supply system (element 2)

Components: Water supply system analysis
Assessment of water quality data
Hazard identification and risk assessment

Assessment of the drinking water supply system is an essential prerequisite for subsequent steps in which effective strategies for prevention and control of hazards are planned and implemented. This includes understanding the characteristics of the drinking water system, what hazards may arise, how these hazards create risks, and the processes and practices that affect drinking water quality.

The drinking water supply system is defined as everything from the point of collection of water to the consumer and can include:

- catchments, including groundwater systems
- source waters
- storage reservoirs and intakes
- treatment systems
- service reservoirs and distribution systems
- consumers.

Water quality can be affected at each of these points and because they are all interrelated integrated management is essential. Generally, a drinking water supplier is only responsible for delivery of water to the consumer's meter. However, although it is not possible to control consumers' actions, suppliers should consider how drinking water quality may be affected in private plumbing systems and provide appropriate information to consumers.

Additional guidance on this element is provided in the Appendix.

3.2.1 WATER SUPPLY SYSTEM ANALYSIS

Summary of actions

- Assemble a team with appropriate knowledge and expertise.
- Construct a flow diagram of the water supply system from catchment to consumer.
- Assemble pertinent information and document key characteristics of the water supply system to be considered.
- Periodically review the water supply system analysis.

Effective system management needs, first and foremost, an understanding of the water supply system from catchment to consumer. Each element of the water supply system should be characterised with respect to drinking water quality and the factors that affect it. This characterisation promotes understanding of the water supply system, and assists with identification of hazards and assessment of risks to water quality.

A team with appropriate knowledge and expertise should be assembled to carry out the analysis. The team should include management and operations staff from the drinking water supplier as well as representatives from relevant agencies. In most cases, consultation with other agencies will be required for the analysis of catchments, which should include the potential impacts of land uses on water quality and stream and river flows. Health and other regulatory agencies should also be involved.

A generalised flow diagram should be constructed describing the water supply system from catchment to consumer. The diagram should:

- outline all steps and processes, whether or not they are under control of the drinking water supplier
- summarise the basic characteristics of each component
- make explicit any characteristics that are unique to the system
- be verified by field audits and checked by those with specific knowledge of the system.

The water supply system analysis should be reviewed periodically to incorporate any changes that occur, for example in land use, treatment processes or consumer distribution.

3.2.2 ASSESSMENT OF WATER QUALITY DATA

Summary of actions

- Assemble historical data from source waters, treatment plants and finished water supplied to consumers (over time and following specific events).
- List and examine exceedances.
- Assess data using tools such as control charts and trends analysis to identify trends and potential problems.

A review of historical water quality data can assist in understanding source water characteristics and system performance both over time and following specific events such as heavy rainfall. This can aid the identification of hazards and aspects of the drinking water system that require improvement.

Where available, water quality data should be assessed from monitoring of source waters, the operation of treatment processes and drinking water as supplied to consumers. Trends analysis and control charts can be valuable tools for recognising potential problems or hazards and the accumulation of any gradual changes or cumulative effects.

Further information is provided in Section 10.7 and Information Sheet 3.

3.2.3 HAZARD IDENTIFICATION AND RISK ASSESSMENT

Summary of actions

- Define the approach and methodology to be used for hazard identification and risk assessment.
- Identify and document hazards, sources and hazardous events for each component of the water supply system.
- Estimate the level of risk for each identified hazard or hazardous event.
- Evaluate the major sources of uncertainty associated with each hazard and hazardous event and consider actions to reduce uncertainty.
- Determine significant risks and document priorities for risk management.
- Periodically review and update the hazard identification and risk assessment to incorporate any changes.

Effective risk management requires identification of all potential hazards, their sources and hazardous events, and an assessment of the level of risk presented by each. A structured approach is important to ensure that significant issues are not overlooked and that areas of greatest risk are identified.

In this context:

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

The distinction between hazard and risk needs to be understood so that attention and resources can be directed to actions based primarily on the level of risk rather than just the existence of a hazard.

To give an example, the protozoan parasite *Cryptosporidium parvum* is a hazard; failure at a water treatment plant leading to *C. parvum* passing into the distribution system is a hazardous event; and the likelihood of the organism being present in source water and passing through the treatment plant in sufficient numbers to cause illness is a risk.

Realistic expectations for hazard identification and risk assessment are important. Rarely will enough knowledge be available to complete a detailed quantitative risk assessment. Hazard identification and risk assessment are predictive activities that will often include subjective judgments. They will inevitably contain uncertainty, and these inherent limitations must be recognised to maintain flexibility and ensure that effective responses are provided when events differ from predictions. A realistic perspective on the limitations of these predictions should be understood by staff and conveyed to the public.

A consistent methodology should be established for both hazard identification and risk assessment. The methodology needs to be transparent and fully understood by everyone involved in the process. Staff should be included and need to be aware of the outcomes of the risk assessment.

Hazard identification

A comprehensive list of potential hazardous agents in drinking water is provided in Part V. Hazardous agents include, microbial, chemical, physical and radiological agents. All potential hazards, sources and events that can lead to the presence of these hazards (what can happen and how) should be identified and documented for each component of the water supply system, regardless of whether or not the component is under the direct control of the drinking water supplier. This includes point sources of pollution (e.g. human and industrial waste discharge) as well as diffuse sources (e.g. those arising from agricultural and animal husbandry activities). Continuous, intermittent or seasonal pollution patterns should also be considered, as well as extreme and infrequent events such as droughts or floods.

The hazard identification and risk assessment should be reviewed and updated periodically because changing conditions may introduce important new hazards or modify risks associated with identified hazards.

Risk assessment

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

The level of risk for each hazard or hazardous event can be estimated by identifying the likelihood of occurrence (e.g. certain, possible, rare) and evaluating the severity of consequences if the hazard were to occur (e.g. insignificant, major, catastrophic). The aim should be to distinguish between very high and low risks.

An example of an approach to estimating the level of risk is provided in Tables 3.1-3.3. These tables have been adapted from AS/NZS 4360:1999 Risk Management, and can be modified to meet the needs of an organisation.

A likely outcome of risk assessment is the identification of specific areas where further information and research is required (see Box 3.7 in Section 3.9).

Risk prioritisation

Based on the assessment of risks, priorities for risk management and application of preventive measures can be established. Risk should be assessed at two levels:

- **maximum risk** in the absence of preventive measures
- **residual risk** after consideration of existing preventive measures.

Assessing maximum risk is useful for identifying high priority risks, determining where attention should be focused and preparing for emergencies. Residual risk provides an indication of the need for additional preventive measures.

Unforeseen and rare events

In well-managed systems problems should be rare, making them more challenging to anticipate and possibly to counter. This highlights the need to learn constructive lessons from the experiences of other Australian and international drinking water suppliers and water agencies. Many problems are triggered by short periods of sudden change, such as heavy rainfall or equipment failure. There are catalogues of waterborne disease outbreaks and the events that caused them. Some of these events should have been foreseeable while others have been attributable to more unusual or rare events. Maintaining awareness of such incidents can enable preventive measures to be implemented to safeguard against similar occurrences (see Box 3.3 in Section 3.4).

Table 3.1 *Qualitative measures of likelihood*

Level	Descriptor	Example description
A	Almost certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur or should occur at some time
D	Unlikely	Could occur at some time
E	Rare	May occur only in exceptional circumstances

Table 3.2 *Qualitative measures of consequence or impact*

Level	Descriptor	Example description
1	Insignificant	Insignificant impact, little disruption to normal operation, low increase in normal operation costs
2	Minor	Minor impact for small population, some manageable operation disruption, some increase in operating costs
3	Moderate	Minor impact for large population, significant modification to normal operation but manageable, operation costs increased, increased monitoring
4	Major	Major impact for small population, systems significantly compromised and abnormal operation if at all, high level of monitoring required
5	Catastrophic	Major impact for large population, complete failure of systems

Table 3.3 *Qualitative risk analysis matrix: level of risk*

Likelihood	Consequences				
	1 Insignificant	**2 Minor**	**3 Moderate**	**4 Major**	**5 Catastrophic**
A (almost certain)	Moderate	High	Very high	Very high	Very high
B (likely)	Moderate	High	High	Very high	Very high
C (possible)	Low	Moderate	High	Very high	Very high
D (unlikely)	Low	Low	Moderate	High	Very high
E (rare)	Low	Low	Moderate	High	High

Uncertainty

There will always be uncertainty associated with hazard identification and risk assessment. Uncertainty can be caused by a lack of knowledge or by variability in parameters. Whereas variability can only be better understood (e.g. by improved characterisation of a hazard), knowledge uncertainty can be reduced through better measurement and research. For example, uncertainty in our ability to identify the source, human infectivity or infectious dose of *Cryptosporidium* oocysts can be addressed through increased research.

Characterising the major sources and types of uncertainty can provide a better understanding of the limitations of the hazard identification and risk assessment and how these limitations can be reduced. Investigative studies and research monitoring can often be used to provide further information to input into the risk assessment process and reduce uncertainty (see Section 3.9).

3.3 Preventive measures for drinking water quality management (element 3)

Components: Preventive measures and multiple barriers
Critical control points

Prevention is an essential feature of effective drinking water quality management. Preventive measures are those actions, activities and processes used to prevent hazards from occurring or reduce them to acceptable levels.

Hazards may occur or be introduced throughout the water system and preventive measures should be comprehensive from catchment to consumer. Many preventive measures may control more than one hazard, while, as prescribed by the multiple barrier approach, some hazards may require more than one preventive measure for effective control. Preventive measures by their nature should be applied as close to the source as possible, with a focus on prevention in catchments rather than sole reliance on downstream control.

The identification and planning of preventive measures should always be based on system-specific hazard identification and risk assessment. The level of protection to control a hazard should be proportional to the associated risk. Assessment of preventive measures involves:

- identifying existing preventive measures from catchment to consumer for each significant hazard or hazardous event
- evaluating whether the preventive measures, when considered together, are effective in reducing risk
  to acceptable levels (i.e. residual risk – Section 3.2.3)
- if improvement is required, evaluating alternative and additional preventive measures that could be applied.

If additional measures are required, factors such as level of risk, benefits, effectiveness, cost, community expectations and willingness to pay should be considered. Preventive measures often require considerable expenditure, and decisions about water quality improvements cannot be taken in isolation from other aspects of water supply that compete for limited financial resources. Priorities will need to be established and many improvements may need to be phased in over time.

All preventive measures are important and should be given ongoing attention. However, some can significantly prevent or reduce hazards and are amenable to greater operational control than others. These measures could be considered as critical control points (see Section 3.3.2).

Additional guidance on this element is provided in the Appendix.

3.3.1 PREVENTIVE MEASURES AND MULTIPLE BARRIERS

Summary of actions

- Identify existing preventive measures from catchment to consumer for each significant hazard or hazardous event and estimate the residual risk.
- Evaluate alternative or additional preventive measures where improvement is required.
- Document the preventive measures and strategies into a plan addressing each significant risk.

Identification and implementation of preventive measures requires consideration of the important principle of the multiple barrier approach. The strength of this approach is that a failure of one barrier may be compensated by effective operation of the remaining barriers, minimising the likelihood of contaminants passing through the entire treatment system and being present in sufficient amounts to cause harm to consumers.

Traditional preventive measures are incorporated as or within a number of barriers, including:

- catchment management and source water protection
- detention in protected reservoirs or storages
- extraction management
- coagulation, flocculation, sedimentation and filtration
- disinfection
- protection and maintenance of the distribution system.

The types of barriers required and the range of preventive measures employed will be different for each water supply and will generally be influenced by characteristics of the source water and surrounding catchment (see Box 3.2). Selection of appropriate barriers and preventive measures will be informed by hazard identification and risk assessment.

***Box 3.2** Examples of multiple barriers*

Large parts of Melbourne are supplied with high-quality source water from a highly protected catchment. Melbourne Water focuses much of its attention and resources on maintaining prevention of contamination at the source. The series of barriers for the majority of the water supply system include:

- protected forested catchments for harvesting of water with no human or livestock access
- large catchment reservoirs with long detention times
- additional detention time in seasonal storage systems
- disinfection of water before it enters the distribution system
- closed distribution systems.

In contrast, Adelaide is supplied with surface water derived from multi-use catchments and the Murray River where there is limited control over activities with potential impacts on water quality. As a result, the barriers applied are heavily weighted towards water treatment and downstream control to remove turbidity and microorganisms. Barriers include the use of multiple storage reservoirs, coagulation, flocculation, sedimentation, filtration and disinfection with long contact times before supply.

Provision of residual disinfectant through large parts of the distribution system is also an important barrier for both systems.

Catchment management and source water protection

Catchment management and source water protection provide the first barrier for the protection of water quality. Where catchment management is beyond the jurisdiction of drinking water suppliers, the planning and implementation of preventive measures will require a coordinated approach with relevant agencies such as planning authorities, catchment boards, environmental and water resources regulators, road authorities and emergency services.

Effective catchment management and source water protection include the following elements:

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

Whether water is drawn from surface catchments or underground sources, it is important that the characteristics of the local catchment or aquifer are understood, and the scenarios that could lead to water pollution are identified and managed. The extent to which catchment pollution can be controlled is often limited in practical terms by competition for water and pressure for increased development in the catchment.

Effective catchment management has additional benefits. By decreasing contamination of source water, the amount of treatment and quantity of chemicals needed is reduced. This may lead to health benefits through reducing the production of treatment byproducts, and economic benefits through minimising operational costs.

In surface water catchments, preventive measures can include:

- selection of an appropriate source water (where alternatives exist)
- exclusion or limitations of uses (e.g. restrictions on human access and agriculture)
- protection of waterways (e.g. fencing out livestock, management of riparian zones)
- use of planning and environmental regulations to regulate potential water polluting developments (e.g. urban, agricultural, industrial, mining and forestry)
- use of industry codes of practice and best practice management
- regulation of community and on site wastewater treatment and disposal systems
- stormwater interception.

Groundwater from depth is generally microbiologically safe and chemically stable; however, shallow or unconfined aquifers can be subject to contamination from discharges or seepages associated with agricultural practices (pathogens, nitrates and pesticides), septic tank discharges (pathogens and nitrates) and industrial wastes. Preventive measures for groundwater supplies should include protecting the aquifer and the local area around the borehead from contamination and ensuring the physical integrity of the bore (surface sealed, casing intact etc).

Further information on integrated catchment management is provided in Appendix A6 *Preventive measures and multiple barriers* (Box A1) and the *National Water Quality Management Strategy – Implementation Guidelines* (NWQMS 1998).

Detention in reservoirs or storages

Detention of water in reservoirs can reduce the number of faecal microorganisms through settling and inactivation, including solar (ultraviolet) disinfection. Most pathogenic microorganisms of faecal origin (enteric pathogens) do not survive indefinitely in the environment. Substantial die-off of enteric bacteria will occur over three to four weeks. Enteric viruses and protozoa will survive for longer periods (weeks to months).

Detention also allows suspended material to settle, which makes subsequent disinfection more effective and reduces the formation of disinfection byproducts.

Other preventive measures in reservoirs and storages include:

- reservoir mixing or destratification to reduce growths of cyanobacteria (taste, odour and toxin production)
- excluding or restricting human, domestic animal and livestock access
- diversion of local stormwater flows.

Extraction management

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

Within a single water body, selective use of multiple extraction points can provide protection against localised contamination either horizontally or vertically through the water column (e.g. cyanobacterial blooms).

Coagulation, flocculation, sedimentation and filtration

Coagulation, flocculation, sedimentation (or flotation) and filtration remove particles, including microorganisms (bacteria, viruses and protozoa). It is important that operations are optimised and controlled to achieve consistent and reliable performance.

As an alternative to conventional media-based processes, membrane filtration provides a direct physical barrier and generally achieves a greater removal of microorganisms.

Care should be taken in the selection and use of water treatment chemicals as they may contain undesirable contaminants. In addition, there can be variation in performance between different sources of the same chemical.

Disinfection

The most commonly used disinfection processes are chlorination and chloramination, but ozone, ultraviolet irradiation and chlorine dioxide are also used. These methods are very effective in killing bacteria and can be reasonably effective in inactivating viruses (depending on type) and many protozoa, including *Giardia*. *Cryptosporidium* is not inactivated by the concentrations of chlorine and chloramines that can be safely used in drinking water, and the effectiveness of ozone and chlorine dioxide is limited. However, there is some evidence that ultraviolet light might be effective in inactivating *Cryptosporidium,* and that combinations of disinfectants can enhance inactivation.

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

Providing a disinfectant residual throughout the distribution system can provide protection against contamination and limit regrowth problems; however, the issue of disinfection byproducts needs to be considered. Chloramination has proved successful in controlling *Naegleria fowleri* in water and sediments in long pipelines.

Protection and maintenance of the distribution system

Water distribution systems should be fully enclosed and storages should be securely roofed with external drainage to prevent contamination. Backflow prevention policies should be applied and monitored. Also, there should be effective maintenance procedures to repair faults and burst mains in a manner that will prevent contamination. Positive pressure should be maintained throughout the distribution system. Appropriate security needs to be put in place to prevent unauthorised access to, or interference with, water storages.

Corrosion of pipes, including those on customer premises, can result in leaching of metals with implications for public health (e.g. copper, cadmium and lead) or aesthetic quality (e.g. copper, iron and zinc) and should be monitored.

Growth or persistence of biofilms should be minimised to reduce aesthetic problems, including off-tastes, odours and staining.

Adequate training of maintenance workers, including contractors, responsible for the distribution system is essential because of the potential for contamination during repairs and recommissioning.

3.3.2 CRITICAL CONTROL POINTS

Summary of actions

- Assess preventive measures from catchment to consumer to identify critical control points.
- Establish mechanisms for operational control (see Section 3.4).
- Document the critical control points, critical limits and target criteria.

From among the preventive measures, critical control points should be identified for those hazards that represent a significant risk and require elimination or reduction to assure supply of safe drinking water.

A critical control point is defined as an activity, procedure or process at which control can be applied and which is essential to prevent a hazard or reduce it to an acceptable level.

Not all preventive measures are amenable to selection as critical control points. A critical control point has several operational requirements, including:

- operational parameters that can be measured and for which critical limits can be set to define the operational effectiveness of the activity (e.g. chlorine residuals for disinfection)
- operational parameters that can be monitored frequently enough to reveal any failures in a timely manner (online and continuous monitoring is preferable)
- procedures for corrective action that can be implemented in response to deviation from critical limits.

Critical limits are performance criteria which separate acceptability from unacceptability in terms of hazard control and water safety. As such they should be chosen carefully and not be confused with target criteria (see Section 3.4.2). Critical limits may incorporate both a numerical value as well as a consideration of time (e.g. failure to provide a minimum chlorine residual for a specified time; see Appendix Section A8).

Deviation from critical limits indicates loss of control of the process or activity and should be regarded as representing a potentially unacceptable health risk. Such events should result in immediate notification of the appropriate health regulator. Discussion of target criteria and critical limits is included in Section 3.4.2, and more detailed explanation of critical control points and their requirements is provided in Appendix A7.

3.4 Operational procedures and process control (element 4)

Components: Operational procedures
Operational monitoring
Corrective action
Equipment capability and maintenance
Materials and chemicals

The effectiveness of preventive measures is highly dependent upon the design and implementation of associated process control programs. To consistently achieve a high-quality water supply it is essential to have effective control over the processes and activities that govern drinking water quality.

Periods of sudden change and sub-optimal performance in the drinking water supply system can represent a serious risk to public health, as illustrated by the examples given in Box 3.3. Therefore, it is vital to ensure that all operations are optimised and are continuously controlled, and that barriers are functional at all times.

Process control programs support preventive measures by detailing the specific operational factors that ensure that all processes and activities are carried out effectively and efficiently. This includes a description of all preventive measures and their functions, together with:

- documentation of effective operational procedures, including identification of responsibilities and authorities
- establishment of a monitoring protocol for operational performance, including selection of operational parameters and criteria, and the routine review of data
- establishment of corrective actions to control excursions in operational parameters
- use and maintenance of suitable equipment
- use of approved materials and chemicals in contact with drinking water.

Effective implementation of these programs relies on the skills and training of operations staff. Operators should be proficient, have the ability to interpret the significance of changes in water quality and treatment and be able to respond appropriately in accordance with established procedures (see Section 3.7).

Process control programs should be documented in operations manuals, with controlled copies readily accessible to all appropriate personnel. One option is to organise each manual into sections dealing with the individual components of the water supply system.

Documentation should include a description of:

- preventive measures and their purpose
- operational procedures for relevant activities
- operational monitoring protocols, including parameters and criteria
- schedules and timelines
- data and records management requirements
- corrective actions to be implemented
- maintenance procedures
- responsibilities and authorities
- internal and external communication and reporting requirements.

***Box 3.3** Examples of outbreaks resulting from sub-optimal performance*

Walkerton outbreak (Canada, 2000)

Over 2000 cases of illness were reported, including 26 cases of haemolytic uraemic syndrome and seven deaths. Public health investigations confirmed that the most severe illnesses were caused by *Escherichia* coli 0157 and *Campylobacter*. The shallow groundwater supply appears to have been contaminated by cattle waste following heavy rains and localised flooding. A large number of faults have been proposed as potential contributing factors to the outbreak, including:

- reliance on bores subject to the direct influence of surface runoff, with only chlorination for treatment
- operation and monitoring on the assumption that the bores were secure, deep groundwater sources
- inadequate protection of surface catchments near the water supply bores
- deficient chlorination practice
- inadequate regulatory oversight
- unreliable chlorine residual monitoring
- failure to respond to the detection of contamination
- failure to communicate the results to regulatory authorities
- inadequate operator training and corporate commitment.

A public inquiry into the outbreak and its implications for the safety of drinking water elsewhere in Ontario resulted (O'Connor, 2002a, b).

Box 3.3 *Examples of outbreaks resulting from sub-optimal performance (Continued)*

Milwaukee outbreak (United States, 1993)

Assessments indicate that over 400,000 illnesses were caused, including 4400 hospitalised. Premature deaths of at least 69 immunocompromised persons (most HIV positive) were recorded. The source of the contamination was not identified but it is considered that increased flows in rivers supplying Lake Michigan could have carried *Cryptosporidium* oocysts from livestock wastes or human sewage. Turbidity of the water taken from the lake deteriorated in the weeks preceding the outbreak.

Operation of one of the treatment plants supplying Milwaukee was not under optimal control. Although coagulant doses were adjusted, this did not prevent turbidity fluctuations in filtered water produced at one filtration plant (0.1-2.7 nephelometric turbidity units). Inexperience with the use of polyaluminium chloride, which had been a recent introduction, could have been a contributing factor. In addition, monitors intended to optimise coagulant doses during changes in water quality were not being used due to improper installation, and filtered water turbidimeters were not being used. Turbidity measurements were being taken every eight hours.

Recycling of backwash water through the filtration process could also have had an impact on the numbers of oocysts passing through the plant.

Other water treatment deficiencies associated with outbreaks of cryptosporidiosis have included:

- failure to respond to deterioration in source water quality
- poor coagulation
- poor monitoring of chemical dosing
- inadequate flocculation
- ilters brought on line without backwashing (McKenzie *et al,* 1994).

3.4.1 OPERATIONAL PROCEDURES

Summary of actions

- Identify procedures required for processes and activities from catchment to consumer.
- Document all procedures and compile into an operations manual.

Operational procedures formalise the activities that are essential to ensure the provision of consistently good quality water. Detailed procedures are required for the operation of all processes and activities (both ongoing and periodic) from catchment to consumer, including preventive measures, operational monitoring and verification procedures, and maintenance requirements.

Procedures are most effective when operations staff are involved in their development, documentation and verification. This participation will help to ensure that all relevant activities are included, enhance operator training and awareness, and create commitment to operational and process control.

3.4.2 OPERATIONAL MONITORING

Summary of actions

- Develop monitoring protocols for operational performance of the water supply system, including the selection of operational parameters and criteria, and the routine analysis of results.
- Document monitoring protocols into an operational monitoring plan.

Operational monitoring includes the planned sequence of measurements and observations to assess and confirm the performance of preventive measures. Observations could include activities such as regular inspections of the catchment (e.g. for integrity of fences), plant equipment, wellhead protection areas and bore construction. Measurements are of operational parameters that will indicate whether processes are functioning effectively.

The general intent of operational monitoring is different from that of drinking water quality monitoring (see Section 3.5.1). Operational monitoring is used to confirm that preventive measures implemented to control hazards are functioning properly and effectively. Data from operational monitoring can be used as triggers for immediate short-term corrective actions to improve drinking water quality.

Key elements of operational monitoring include:

- development of operational monitoring plans from catchment to consumer, detailing strategies and procedures
- identification of the parameters and criteria to be used to measure operational effectiveness and, where necessary, trigger immediate short-term corrective actions
- ongoing review and interpretation of results to confirm operational performance.

Further guidance on operational monitoring is provided in Chapter 9.

Operational parameters

Operational parameters should be selected that reflect the effectiveness of each process or activity, and provide an immediate indication of performance. Typically, operational monitoring should focus on parameters that can be readily measured and enable a rapid response. To fulfil these requirements, surrogates are often used as operational parameters rather than direct measurement of the hazards themselves. For example, turbidity may be used as a surrogate for *Cryptosporidium* and *Giardia*. More detail on surrogates is provided in Chapter 9.

Operational parameters should be monitored with sufficient frequency to reveal any failures in good time. Online and continuous monitoring should be used wherever possible, particularly at critical control points (see below). Examples of parameters that can be used for operational monitoring are listed in Chapter 9.

Target criteria and critical limits

Once operational parameters are identified, target criteria (performance goals) should be established for each preventive measure. These criteria can be quantitative (numerical) or qualitative (descriptive). Any deviation of performance from established targets should be regarded as a trend towards loss of control of the process and should result in appropriate actions being taken to resolve potential problems.

For preventive measures identified as critical control points for the water supply system, critical limits must also be defined and validated. A critical limit is a prescribed tolerance that distinguishes acceptable from unacceptable performance at a critical control point. When a critical control point is operating within the prescribed limits, performance in terms of hazard removal is regarded as being acceptable. However, exceedance of or deviation from a critical limit represents loss of control of a process and indicates the existence of an unacceptable health risk. Corrective actions should immediately be instituted to resume control of the process and the health regulator should be notified.

Setting target criteria that are more stringent than critical limits at critical control points will enable corrective actions to be instituted before an unacceptable health risk occurs. Exceedance of a target criterion at a critical control point would generally not require notification of the health regulator providing corrective action successfully prevented deviation from a critical limit.

Chapter 9 provides more explanation of target criteria, critical limits and monitoring at critical control points.

Analysis of results

Results must be reviewed frequently to confirm that records are complete and accurate, and that there are no deviations from critical limits or target criteria. Where results indicate that control has been lost, appropriate corrective actions and process adjustments should be instituted to maintain quality. Those responsible for interpreting and recording operational results should clearly understand how the results should be assessed.

A system should be established for regular reporting of operational monitoring results to relevant staff and departments. Methods such as graphs or trend charts can be used to facilitate the interpretation of operational monitoring results.

3.4.3 CORRECTIVE ACTION

Summary of actions

- Establish and document procedures for corrective action to control excursions in operational parameters.
- Establish rapid communication systems to deal with unexpected events.

Appropriate procedures should be developed for immediate corrective action required to re-establish process control following failure to meet target criteria or critical limits. The procedures should include instructions on required adjustments, process control changes and additional monitoring. Responsibilities and authorities, including communication and notification requirements, should be clearly defined.

Following implementation of a corrective action, effectiveness of the action will need to be verified. This will usually require additional monitoring. Secondary impacts of the corrective action, and whether adjustments or action may be needed further along in the supply system, should also be considered.

Examples of possible corrective actions include:

- selection of an alternative raw water source if available
- altering the plant flow rate (e.g. reducing loading)
- altering the mixing intensity
- changing treatment chemicals
- using auxiliary chemicals such as coagulant aids, flocculant aids, filtration aids
- adjusting pH
- varying chemical feed rates and feed points
- adjusting filtration loading rate or operation
- increasing disinfectant dose
- secondary or booster disinfection
- mains flushing, cleaning and localised disinfection.

Where possible, the underlying cause of the problem should be determined and measures implemented to prevent future occurrences. Analysis of the causes may identify possible solutions, such as modifying an operating procedure or improving training. Details of all incidents should be recorded and reported.

While advance planning is important, it will not always be possible to anticipate every type of event. Rapid communication systems should be established to deal with these events.

Incident and emergency responses should be prepared for times when normal corrective actions cannot re-establish operational performance quickly enough to prevent drinking water of unacceptable quality from reaching consumers.

3.4.4 EQUIPMENT CAPABILITY AND MAINTENANCE

Summary of actions

- Ensure that equipment performs adequately and provides sufficient flexibility and process control.
- Establish a program for regular inspection and maintenance of all equipment, including monitoring equipment.

The capability of equipment is an important consideration in maintaining process control. Equipment and infrastructure in a drinking water supply system need to be adequately designed and of sufficient capacity (size, volume, detention times) to handle all flow rates (peak and otherwise) without limiting performance. Processes should not be hydraulically overloaded or subjected to rapid changes in hydraulic loading, as these conditions may compromise performance.

Design features that can improve performance and process control include:

- online measuring devices that monitor operational parameters continuously
- automated responses to changes in water quality
- 24-hour monitored alarm systems that indicate operational failure
- backup equipment, including power generators
- variable control of flow rates and chemical dosing
- effective mixing facilities.

Design of new equipment and processes should undergo validation through appropriate research and development (see Section 3.9.3).

Equipment used to monitor process performance should also be selected carefully. Monitoring equipment needs to be sufficiently accurate and sensitive to perform at the levels required. Wherever possible, monitoring should be online and continuous, with alarm systems to indicate when operational criteria have been exceeded. Monitoring failures should not compromise the system and in some cases, particularly at critical control points, backup equipment should be considered.

Staff should understand the operation of monitoring equipment so that causes of spurious results can be recognised and rectified.

Regular inspection and maintenance of all equipment from catchment to consumer is required to ensure continuing process capability. A maintenance program should be established and documented, detailing:

- operational procedures and records for the maintenance of equipment, including the calibration of monitoring equipment
- schedules and timelines
- responsibilities
- resource requirements.

3.4.5 MATERIALS AND CHEMICALS

Summary of actions

- Ensure that only approved materials and chemicals are used.
- Establish documented procedures for evaluating chemicals, materials and suppliers.

The selection of materials and chemicals used in water systems is an important consideration as they have the potential to adversely affect drinking water quality. Chemicals added to water include disinfectants, oxidants, coagulants, flocculants, algicides, antioxidants and chemicals for softening, pH adjustment, fluoridation and scale prevention.

All chemicals used should be evaluated for potential contamination. General considerations include data on impurities, chemical and physical properties, maximum dosages, behaviour in water, migration and concentration build-up. In addition, the potential impact of water treatment chemicals on materials used in treatment plants needs to be considered. For example, ferric chloride used as a coagulant is extremely corrosive and can have severe effects on commonly used grades of stainless steel.

Chemical suppliers should be evaluated and selected on their ability to supply product in accordance with required specifications. Documented procedures for the control of chemicals, including purchasing, verification, handling, storage and maintenance should be established to assure the quality of the chemicals at the point of application. Responsibilities for testing and quality assurance of chemicals (supplier, purchaser or both) should be clearly defined in purchase contracts.

Contaminants may also be introduced when water comes into contact with materials such as filter media, protective coatings, linings and liners, joining and sealing products, pipes and fittings, valves, meters and other components. Materials used should comply with Australian Standard AS/NZ 4020 *Products for use in contact with drinking water*.

The products used in water systems should be subjected to an audited system of quality control.

3.5 Verification of drinking water quality (element 5)

Components: Drinking water quality monitoring
Consumer satisfaction
Short-term evaluation of results
Corrective action

Verification of drinking water quality provides an assessment of the overall performance of the system and the ultimate quality of drinking water being supplied to consumers. This incorporates monitoring drinking water quality as well as assessment of consumer satisfaction.

Verification provides:

- a useful indication of problems within the water supply system (particularly the distribution system) and the necessity for any immediate short-term corrective actions or incident and emergency response
- confidence for consumers and regulators regarding the quality of the water supplied.

Chapter 9 provides more information on verification of drinking water quality.

3.5.1 DRINKING WATER QUALITY MONITORING

Summary of actions

- Determine the characteristics to be monitored in the distribution system and in water as supplied to the consumer.
- Establish and document a sampling plan for each characteristic, including the location and frequency of sampling.
- Ensure monitoring data is representative and reliable.

Drinking water quality monitoring is a wide-ranging assessment of the quality of water in the distribution system and, importantly, as supplied to the consumer. It includes regular sampling and testing to assess whether water quality is meeting guideline values and any regulatory requirements or agreed levels of service.

Monitoring of drinking water quality should be regarded as the final check that, overall, the barriers and preventive measures implemented to protect public health are working effectively. The purpose of drinking water quality monitoring is different from that of operational monitoring and the two types of monitoring also differ in what, where and how often water quality characteristics are measured. As it is neither physically nor economically feasible to test for all drinking water quality parameters equally, monitoring effort and resources should be carefully planned and directed at significant or key characteristics.

Key characteristics related to health include:

- microbial indicator organisms
- disinfectant residuals and any disinfection byproducts
- any health-related characteristic that can be reasonably expected to exceed the guideline value, even if occasionally
- potential contaminants identified in analysis of the water supply system (Section 3.2.1) and hazard identification (Section 3.2.3).

Some characteristics not related to health, such as those with significant aesthetic impacts, should also be monitored. Where there is frequent occurrence of unacceptable aesthetic characteristics (e.g. taste and odour), further investigation may be required to determine whether there are problems with significance for health.

Sampling locations will depend on the water quality characteristic being examined. Sampling at the treatment plant or at the head of the distribution system may be sufficient for characteristics where concentrations do not change during delivery; however, for those that can change during distribution, sampling should be undertaken throughout the distribution system, including the point of supply to the consumer.

Frequency of testing for individual characteristics will depend on variability, and whether the characteristics are of aesthetic or health significance. Sampling should be frequent enough to enable the monitoring to provide meaningful information and statistical validity. Sampling and analysis are required most frequently for microbial constituents, and less often for organic and inorganic compounds. This is because even brief episodes of microbial contamination can lead to immediate illness in consumers, whereas, in the absence of a specific event (e.g. chemical overdosing at a treatment plant), episodes of chemical contamination that would constitute an acute health concern are rare. Guideline values for most chemical parameters are based on impacts of chronic exposure.

Once parameters and sampling locations have been identified, these should be documented in a consolidated monitoring plan. Monitoring data should be representative, reliable and fully validated (see Box 3.4). Procedures for sampling and testing should also be documented.

***Box 3.4** Reliability of data*

Monitoring is only as good as the data collected, so every effort should be made to ensure that the data are representative, reliable and fully validated. Appropriate procedures should be in place and the following need to be considered.

Sampling plan:

- parameters measured, sampling locations, sampling frequency
- qualifications and training of personnel
- approved sampling methods and techniques
- quality assurance and validation procedures for sampling
- statistical validity.

Analytical testing:

- qualifications and training of personnel
- suitability of equipment
- approved test methods and laboratories
- quality assurance and validation procedures (e.g. positive and negative control samples, inter-laboratory comparisons)
- accreditation with an external agency such as the National Association of Testing Authorities.

Monitoring equipment:

- calibration and inspection procedures to ensure control of monitoring equipment.

3.5.2 CONSUMER SATISFACTION

Summary of actions

- Establish a consumer complaint and response program, including appropriate training of employees.

Monitoring of consumer comments and complaints can provide valuable information on potential problems that may not have been identified by performance monitoring of the water supply system. Consumer satisfaction with drinking water quality is largely based on a judgment that the aesthetic quality of tap water is 'good', which usually means that it is colourless, free from suspended solids and has no unpleasant taste or odour.

Changes from the norm are particularly noticeable to consumers, who may interpret aesthetic problems as indicating health risks. A consumer complaint and response program operated by appropriately trained personnel should be established. Response targets should be set and regularly reviewed. Complaints and responses should be recorded and in the longer term there should be evaluation of types, patterns and changes in the number of complaints received.

One proactive approach to gauge perception of drinking water quality is to establish a consumer-based taste panel. Participants, who should be sensitive to off-flavours, can be trained with common flavour profile descriptors so that their feedback to the drinking water supplier is more useful for identifying and solving aesthetic water quality problems. This approach can be particularly helpful in identifying recurring seasonal episodes of poor aesthetic quality. The Fact Sheet on *Taste and Odour,* in Part V, discusses consumer panels.

3.5.3 SHORT-TERM EVALUATION OF RESULTS

Summary of actions

- Establish procedures for the daily review of drinking water quality monitoring data and consumer satisfaction.
- Develop reporting mechanisms internally, and externally, where required.

Short-term performance evaluation entails the daily reviewing of drinking water quality monitoring data and consumer satisfaction to verify that the quality of water supplied to consumers conforms with guideline values. If the quality does not conform, then immediate corrective actions and/or incident and emergency response should be implemented.

Those responsible for interpreting and recording results should clearly understand how results should be assessed and, if required, how and where they should be communicated. Monitoring results should be reviewed within appropriate timeframes, and compared with previous results, established guideline values, and any regulatory requirements or agreed levels of service. Procedures for performance evaluation and recording of results should be established and documented. Mechanisms and responsibilities should be identified for the reporting of results internally to operators and senior executives as well as externally, where required, to stakeholders such as regulators and consumers (see Section 3.10.2).

3.5.4 CORRECTIVE ACTION

Summary of actions

- Establish and document procedures for corrective action in response to nonconformance or consumer feedback.
- Establish rapid communication systems to deal with unexpected events.

If the short-term evaluation of drinking water quality monitoring data indicates nonconformance with guideline values or other requirements, an investigation should be initiated and, if necessary, a corrective action implemented as quickly as possible. Failure to take immediate or effective action may lead to the development of a more serious situation, which could require incident and emergency response protocols to be instituted. Implementation of corrective action could also be required in response to consumer feedback.

Corrective actions should be developed in consultation with relevant regulatory authorities and other stakeholders. Examples include:

- disinfection of tanks
- flushing and maintenance of the distribution system
- temporary shutdown of a treatment plant if adequate storage is available
- increased booster or secondary disinfection
- enhanced filtration
- investigative or sanitary surveys of distribution systems.

Significant system failures that could pose a health risk or adversely affect water quality for an extended period should immediately be responded to and reported to the relevant health authority (see Section 3.6).

Corrective actions should be documented, responsibilities and authorities clearly defined, and staff trained in appropriate procedures.

3.6 Management of incidents and emergencies (element 6)

Components: Communication
Incident and emergency response protocols

Considered and controlled responses to incidents or emergencies that can compromise the safety of water quality are essential for protecting public health, as well as maintaining consumer confidence and the organisation's reputation. Although preventive strategies are intended to prevent incidents and emergency situations from occurring, some events cannot be anticipated or controlled, or have such a low probability of occurring that providing preventive measures would be too costly. For such incidents, there must be an adaptive capability to respond constructively and efficiently.

Wherever possible, emergency scenarios should be identified, and incident and emergency protocols, including communication procedures, should be planned and documented. Establishing procedures 'on the run' is a recipe for inefficiency, lack of coordination, poor response times and potential loss of public confidence.

The development of appropriate protocols involves a review of the hazards and events that can lead to emergency situations, such as:

- nonconformance with guideline values and other requirements
- accidents that increase levels of contaminants (e.g. spills in catchments, incorrect dosing of chemicals)
- equipment breakdown and mechanical failure
- prolonged power outages
- extreme weather events (e.g. flash flooding, cyclones)
- natural disasters (e.g. fire, earthquakes, lightning damage to electrical equipment)
- human actions (e.g. serious error, sabotage, strikes).

3.6.1 COMMUNICATION

Summary of actions

- Define communication protocols with the involvement of relevant agencies and prepare a contact list of key people, agencies and businesses.
- Develop a public and media communications strategy.

Effective communication is vital in managing incidents and emergencies. Clearly defined protocols for both internal and external communications should be established in advance, with the involvement of relevant agencies, including health and other regulatory agencies. These protocols should include a contact list of key people, agencies and businesses, detailed notification forms, procedures for internal and external notification, and definitions of responsibilities and authorities. Contact lists should be regularly updated (e.g. six-monthly) to ensure they are accurate.

Maintaining consumer confidence and trust during and after an incident or emergency is essential and is largely affected by how incidents and emergencies are handled. A public and media communication strategy should be developed before any incident or emergency situation occurs. Draft public and media notifications should be prepared in advance and formatted for the target audience. An appropriately trained and authoritative contact should be designated to handle all communications in the event of an incident or emergency. All employees should be kept informed during any incident, because they provide informal points of contact for the community.

Consumers should be told when an incident has ended and be provided with information on the cause and actions taken to minimise future occurrences. This type of communication will help allay community concerns and restore confidence in the water supply. Interviews and surveys of a representative portion of the community are valuable for establishing consumer perceptions of events and how they were managed.

3.6.2 INCIDENT AND EMERGENCY RESPONSE PROTOCOLS

Summary of actions

- Define potential incidents and emergencies and document procedures and response plans with the involvement of relevant agencies.
- Train employees and regularly test emergency response plans.
- Investigate any incidents or emergencies and revise protocols as necessary.

Incident and emergency response protocols should be regarded as a priority. Potential incidents and emergencies should be defined and response plans should be developed and documented in advance to respond to these events.

Plans should be developed in consultation with relevant regulatory authorities and other key agencies, and should be consistent with existing government emergency response arrangements. In an emergency situation there will not be time to establish confidence and goodwill if these have not been established during normal operation. An investment in advance for building trust and understanding with parties who will be partners in responding to an emergency will pay important dividends in the form of more effective action when an emergency arises.

Key areas to be addressed in incident and emergency response plans include clearly specified:

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

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

Following any incident or emergency situation, an investigation of the incident or emergency should be undertaken and all involved staff should be debriefed to discuss performance and address any issues or concerns. The investigation should consider factors such as:

- What was the initiating cause of the problem?
- How was the problem first identified or recognised?
- What were the most critical actions required?
- What communication problems arose and how were they addressed?
- What were the immediate and longer-term consequences?
- How well did the protocol function?

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

Box 3.5 provides a summary of an emergency response protocol.

***Box 3.5** Water incident communication and notification protocol*

In South Australia, a protocol has been established between the Department of Health, South Australia Water, the Environmental Protection Agency (EPA) and the Department of Water Resources to ensure effective communication between government agencies in the event of incidents associated with reticulated water supplies. The protocol includes notification to other relevant bodies such as catchment water management boards and local authorities.

Incidents are classified as:

- Type 1 – potentially serious with either human health or environmental risks, or
- Type 2 – lesser incidents representing a low risk to human health or possible low impact and localised environmental harm.

The protocol includes agreed criteria for both raw water (e.g. cyanobacterial blooms, high numbers of Cryptosporidium, unacceptable concentrations of health-related chemicals and detection of pesticides) and treated drinking water (e.g. high turbidity in filtered water, chlorinator failure, detection of high concentrations of health-related chemicals, pesticides, *Cryptosporidium, Naegleria fowleri* and persistent *E.coli*/coliform bacteria).

The protocol defines the role of a water incident coordinator placed in the Department of Human Services and specifies which minister and agency will take the lead in dealing with and communicating incidents (incidents with health concerns are led by Department of Health, those with environmental concerns by the EPA and those with operational concerns by South Australia Water).

Reporting requirements for individual agencies are defined, as well as communication requirements and protocols for the agencies, the water incident coordinator, offices of the ministers and the lead minister.

The testing agency is required to report all Type 1 incidents immediately to the water incident coordinator and provide written confirmation within 24 hours by email or fax. The water incident coordinator ensures that all appropriate agencies have been notified and that relevant ministers are notified by their agencies as soon as possible and in any event within 24 hours.

Type 2 incidents are normally only notified to relevant agencies and generally do not require ministerial advice.

The protocol includes a list of 24-hour contacts for all agencies. Copies of the protocol are provided to all emergency contacts and relevant officers. The protocol is updated and reissued every six months.

3.7 Employee awareness and training (element 7)

Components: Employee awareness and involvement
Employee training

The knowledge, skills, motivation and commitment of employees and contractors ultimately determine a drinking water supplier's ability to successfully operate a water supply system. It is vital that awareness, understanding and commitment to performance optimisation and continuous improvement are developed and maintained within the organisation.

3.7.1 EMPLOYEE AWARENESS AND INVOLVEMENT

Summary of actions

- Develop mechanisms and communication procedures to increase employees' awareness of and participation in drinking water quality management.

An understanding of drinking water quality management is essential for empowering and motivating employees to make effective decisions. All employees of the drinking water supplier should be aware of:

- the organisation's drinking water quality policy
- characteristics of the water supply system and preventive strategies in place throughout the system
- regulatory and legislative requirements
- roles and responsibilities of employees and departments
- how their actions can impact on water quality and public health.

Mechanisms and communication procedures should be developed to ensure awareness of, and commitment to, drinking water quality management throughout the organisation. Methods to increase employee awareness can include employee education and induction programs, newsletters, guidelines, manuals, notice boards, seminars, briefings and meetings.

Employee participation and involvement in decision making is an important part of establishing the commitment necessary for the continuous improvement of drinking water quality management. Employees should be encouraged to participate in decisions that affect their jobs and areas of responsibility. Such participation provides a sense of ownership for decisions made and their implications. Open and positive communication is a foundation to creating a participatory culture, and employees should be encouraged to discuss issues and actions with management.

3.7.2 EMPLOYEE TRAINING

Summary of actions

- Ensure that employees, including contractors, maintain the appropriate experience and qualifications.
- Identify training needs and ensure resources are available to support training programs.
- Document training and maintain records of all employee training.

Employees and contractors must be appropriately skilled and trained in the management and operation of water supply systems, as their actions can have a major impact on drinking water quality and public health (see Box 3.6).

Employees should have a sound knowledge base from which to make effective operational decisions. This requires training in the methods and skills required to perform their tasks efficiently and competently, as well as knowledge and understanding of the impact their activities can have on water quality. For example, treatment plant operators should understand water treatment concepts and be able to apply these concepts and adjust processes appropriately to respond to variations in water quality.

Training needs should be identified and adequate resources made available to support appropriate programs. Examples of relevant areas to address are:

- general water quality
- water biology and water chemistry
- specific training to optimise system performance such as
  - coagulant control testing
  - proper filtration operation
  - disinfection system operation
  - reticulation management
  - sampling, monitoring and analysis
  - interpretation and recording of results
  - maintenance of equipment.

Employees should also be trained in other aspects of drinking water quality management, including incident and emergency response, documentation, record keeping, reporting, and research and development.

Commonly used training techniques and methods include formal training courses accredited by a national training body, in-house training, on-the-job experience, mentor programs, workshops, demonstrations, seminars, courses and conferences. Training programs should encourage employees to communicate and think critically about the operational aspects of their work.

Training should be documented, and records of all employees who have participated in training maintained. Mechanisms for evaluating the effectiveness of training should also be established and documented. Training is an ongoing process and requirements should be regularly reviewed to ensure that employees maintain the appropriate experience and qualifications. For those activities that have a significant impact on drinking water quality, periodic verification of the capability of operations staff is necessary.

Where possible, accredited training programs and certification of operators should be employed.

***Box 3.6** Contractors*

Given the considerable restructuring of the water industry in recent years, there is now a heavy reliance on contractors to undertake work for drinking water suppliers. These include contractors for construction, operations and maintenance of bulk water, treatment and distribution systems, and sampling and analytical work.

Contractors need to have the same awareness, training and culture as the organisation's employees. Requirements for contract or acceptability should be established, and contractors should be evaluated and selected on the basis of their ability to meet the specified requirements.

A drinking water supplier should ensure that contractors are qualified and have undergone appropriate training related directly to their task or role. When contracting labour, provisions should be made within the organisation to conduct the necessary education and training of contractors on the requirements for adherence to the organisation's policy and protocols.

Conditions under which the contractor operates should be clear, accurate and achievable, with scope for ongoing review and improvement. Partnerships will be more successful where the drinking water supplier retains sufficient knowledge and technical expertise to manage the contract efficiently.

3.8 Community involvement and awareness (element 8)

Components: Community consultation
Communication

Community consultation, involvement and awareness can have a major impact on public confidence in the water supply and the organisation's reputation. A communication program is a long-term commitment, including both consultation and education, and should be designed to provide an active, two-way exchange of information. This will help to ensure that consumers' needs and expectations are understood and are being satisfied.

3.8.1 COMMUNITY CONSULTATION

Summary of actions

- Assess requirements for effective community involvement.
- Develop a comprehensive strategy for community consultation.

Decisions on drinking water quality made by a drinking water supplier and the relevant regulatory authorities must be aligned with the needs and expectations of consumers. Therefore, the community and appropriate industry sectors should be consulted and involved during decision-making processes.

Discussions should include the establishment of levels of service, costs, existing water quality problems and the options for protection and improvement of drinking water quality, including constraints on land use and changes in treatment or infrastructure. Consumers should also be consulted on monitoring requirements and mechanisms for public reporting of system performance.

Decisions and agreed levels of service should be based primarily on estimates of risk and cost, together with local knowledge of the source water (including the degree of catchment protection), treatment processes employed, history of the distribution system and the management of water quality. Consumer needs and expectations will influence the extent to which each community will adopt guideline values. For example, one community may choose to tolerate aesthetic problems, while another may choose to pay for treatment to bring water quality within commonly accepted limits.

Decisions about drinking water quality cannot be taken in isolation from other aspects of water supply that compete for limited financial resources. Two major decisions to be made are the levels of service to be provided, and the timeframe within which those levels can be achieved. Priorities will depend on the impact of water quality improvements on public health and on aesthetic considerations (taste, colour and odour). Public health should take a higher priority than aesthetics.

Assessing what is required for effective community involvement can be a complex task, depending on the issues and the community involved. The development of community consultation strategies requires:

- Definition of the scope of the issue and the potential links with wider issues or problems. This will provide an indication of the extent of consultation or education required.
- Identification of specific interest and stakeholder groups that may be affected, and their needs, existing level of knowledge and attitudes on the issues. All groups should be able to participate in the consultation process irrespective of barriers of language, distance, technical knowledge or lack of resources.
- Presentation of factual information to the community, consumers and groups in a form that is accessible, understandable and suitable as a basis for informed discussion.
- Provision of adequate time for consultation. The community should understand and agree to the process proposed for the consultation.
- Inclusion of measures to evaluate the effectiveness of the community consultation process.

Community consultation might include:

- briefings targeted to specific groups with interests or responsibilities
- workshops or seminars on key issues or for special groups
- focus groups and market research or surveys to determine community views, knowledge and attitudes
- customer councils or customer panels
- informative media programs targeting print media, radio and television
- community education or information exchange programs
- school programs
- preparation of technical issues papers
- media advertising of activities and available papers
- public hearings for major and controversial initiatives.

Communications and community involvement should be considered when setting up a community consultation process or when working with, or seeking advice from, professionals in the areas of survey research. Records should be kept of all community consultation.

3.8.2 COMMUNICATION

Summary of actions

- Develop an active two-way communication program to inform consumers and promote awareness of drinking water quality issues.

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

Management of communication is particularly important in the event of an incident or emergency (see Section 3.6).

A coordinated consumer information program should include:

- discussion of issues on drinking water quality, public health and risk assessment, cost of treatment and levels of service
- details of the water supply system and the drinking water quality management system
- incident and emergency response plans, including procedures for notification when drinking water quality poses a health risk
- consumer responsibilities beyond the meter and how drinking water quality may be affected in household distribution and use (e.g. use of suitable plumbing materials, point-of-use treatment devices, prevention of backflow)
- the need for further treatment of water for special purposes (e.g. renal dialysis, some industrial uses)
- the role and responsibility of the community in protecting water supply catchments and water conservation
- commercial and industrial consumer responsibilities beyond the meter (e.g. the responsibility for design, maintenance, education of managers, and development of codes of practice that include reporting procedures in the event of contamination in large buildings).

Although a drinking water supplier is generally only responsible for delivery of water to the consumer's meter, consumers should be informed about how drinking water quality may be affected in household distribution and use.

Procedures for disseminating information to promote awareness of drinking water quality issues to the community should be established. Possible methods include annual or other periodic water quality reports, newsletters, notices in bills, workshops, seminars or briefings, media programs targeting radio and television, websites, treatment plant tours, catchment signage and school education programs.

Additionally, mechanisms such as a service line or complaint handling system should be established to provide opportunities for consumers to communicate their needs and expectations.

3.9 Research and development (element 9)

Components: Investigative studies and research monitoring
Validation of processes
Design of equipment

A corporate commitment to conduct and participate in research and development activities on drinking water quality issues is important. Such a commitment helps to ensure continual improvement and the ongoing capability to meet drinking water quality requirements.

Applied research and development may be directed towards:

- increasing the understanding of a water supply system and potential hazards
- investigating improvements, new processes, emerging water quality issues and new analytical methods
- validation of operational effectiveness of new products and processes
- increasing the understanding of the relationship between public health outcomes and water quality.

Research at a local level increases understanding of the specific characteristics of individual water supply systems. Local research could include, for example, detailed analysis of temporal and spatial variations in source water quality parameters. Research and development activities should also investigate mechanisms to improve and optimise plant performance, evaluate treatment processes (including the validation of critical limits and target criteria) and design new equipment. These activities should be carried out under controlled conditions by qualified staff, and all protocols and results should be documented and recorded.

Additionally, participation in research and development activities through partnerships and industry-wide cooperation can be a cost-effective way to address broader issues associated with water quality and treatment, including the development and evaluation of new technologies. Box 3.7 describes an example of a research activity. Opportunities for collaboration and initiation of joint research and development projects should be identified. Partnership organisations may include health and environment agencies, industry associations, other drinking water suppliers, university departments, cooperative research centres and community groups.

***Box 3.7** The Melbourne water quality study*

The Melbourne water quality study is an example of a large-scale, high-quality research study made possible through the collaboration of several organisations. The study was carried out by university researchers with the involvement of four water utilities, and was funded jointly by the water industry and the health regulator.

The study investigated the effect of microbial water quality on rates of community gastroenteritis in Melbourne by measuring the difference in the levels of illness among two population groups, each comprising approximately 300 households. One group consumed normal tap water and the other consumed water that was filtered and disinfected with ultraviolet radiation.

The principal aim of the study was to determine whether additional treatment of drinking water was necessary for an area served by a disinfected but unfiltered water supply drawn from protected catchments. The study used stringent epidemiological methodology and found no measurable difference in illness rates between the normal tap water group and the filtered water group, thus demonstrating that Melbourne's unfiltered drinking water does not make a significant contribution to gastroenteritis rates.

This groundbreaking project successfully addressed a water quality issue of international importance by shifting the focus from testing the microbial quality of drinking water to studying the health effects of drinking water. The study was a major undertaking but was completed for less than 1 per cent of the cost of building a water treatment plant.

Information from this research will enable better informed decisions about the management of Melbourne's water. Furthermore, the study has established a new methodology to assess the health effects of drinking water quality that is being employed in other cities to answer similar questions for different types of water supplies.

Source: Hellard *et al* (2001)

3.9.1 INVESTIGATIVE STUDIES AND RESEARCH MONITORING

Summary of actions

- Establish programs to increase understanding of the water supply system.
- Use information to improve management of the water supply system.

Investigative studies and research monitoring include strategic programs designed to increase understanding of a water supply system, to identify and characterise potential hazards, and to fill gaps in knowledge. Improved understanding of the factors affecting water quality characteristics allows suppliers to anticipate periods of poor water quality and respond to them in an effective way.

Examples could include:

- baseline monitoring of parameters or contaminants or testing of potential new water sources to identify water quality problems
- source water monitoring to understand the temporal and spatial variability of water quality parameters
- developing early warning systems to improve the management of poor water quality
- event-based monitoring to determine the magnitude of impacts (duration and maximum concentrations)
- examining mixing effects within a water storage
- evaluating characteristics of an aquifer through pumping tests and analyses
- studying the movement of water within reservoirs to determine short-circuiting effects
- examining backwash return water and its effect in increasing microorganism load.

In addition, monitoring could provide input into predictive modelling of source water quality or assist in the selection of management and treatment approaches.

Careful consideration should be given to the selection of water quality characteristics to be analysed, use of statistical techniques, collection of samples (frequency and location), use of appropriate sampling and testing procedures, evaluation and management of results.

Tracing the cause of taste and odour problems often initiates investigations. Box 3.8 illustrates one such investigation and highlights the importance of investigative studies in assisting with evaluating risk to public health.

Box 3.8 *Cyanotoxin investigation in South Australia*

In April 2000, water quality problems were experienced at the Upper Paskeville Reservoir, a key water supply facility to the Yorke Peninsula in South Australia. Complaints of poor tastes and odours in the drinking water supplied to consumers were investigated. The problem was traced to the presence of high concentrations of 2-methyl isoborneol produced by the blue-green benthic cyanobacterium Phormidium, which was found in the reservoir entangled in strands of a submerged aquatic plant, water milfoil.

In view of the taste and odour complaints, Paskeville Reservoir was taken out of service. At the time, existing knowledge of Phormidium toxicity suggested that there would be no health concerns to the consumers of the Yorke Peninsula, but scientists at the Australian Water Quality Centre recommended that toxicity tests of cyanobacterial material be carried out as a precaution. The material was found to be toxic.

Following these results, the South Australian Department of Human Services issued advice that, due to the potential health risk, people should not use the mains water for drinking or cooking. Temporary supplies of bottled water were distributed to Yorke Peninsula communities by South Australia Water. Hospitals, nursing homes, caravan parks, food businesses etc were notified individually and in some cases provided with carted water. The state primary industries department advised that the mains supply should not be used for stock water.

Subsequent testing confirmed that chlorination and boiling inactivated the toxin. On this basis the public was advised that the water could be used after boiling, and the strategy for cleaning the supply was changed from flushing to a mixture of chlorination and flushing. Chloramination, which is normally used to disinfect the supply, did not inactivate the toxin.

In addition to extending monitoring in similar storages in South Australia to determine the presence of Phormidium in benthic cyanobacterial growths, research is being undertaken to further characterise the toxin. Results so far have shown that the toxic effect is associated with cell-bound material and that the toxin is only sparingly soluble, thereby reducing its potential risk to human health.

Source: Baker *et al* (2001)

3.9.2 VALIDATION OF PROCESSES

Summary of actions

- Validate processes and procedures to ensure that they are effective at controlling hazards.
- Revalidate processes periodically or when variations in conditions occur.

Validation involves evaluating scientific and technical information available on processes and then undertaking investigations, where necessary, to validate system-specific operational procedures, critical limits and target criteria. The aim of process validation is to ensure effective operation and control. Historical data and operational experience can also be useful sources of information.

Processes should be revalidated on a regular basis or when variations occur (e.g. seasonally). Any new processes should be tested using benchtop, pilot-scale or full-scale experimental studies to confirm that the process and operational criteria produce the required results under the conditions specific to the individual water supply system.

3.9.3 DESIGN OF EQUIPMENT

Summary of actions

- Validate the selection and design of new equipment and infrastructure to ensure continuing reliability.

Research and development should be undertaken to validate the selection and design of new equipment and infrastructure, or to confirm design changes necessary to improve plant performance and control systems. New technologies require pilot-scale research and evaluation before full-scale implementation. Design specifications should be established to ensure that new equipment will be able to meet the intended requirements and provide necessary process flexibility and controllability (see Section 3.4.4).

Other considerations for ensuring the reliability of water treatment systems include designing equipment and facilities to withstand natural disasters (e.g. earthquakes and flooding) and providing backup systems for emergency use (e.g. alternative power generation). Appropriate consideration of these factors during the design phase will reduce the risk that equipment failures will cause major disruptions in service.

3.10 Documentation and reporting (element 10)

Components: Management of documentation and records
Reporting

Appropriate documentation provides the foundation for the establishment and maintenance of effective drinking water quality management systems. Documentation should:

- demonstrate that a systematic approach is established and is implemented effectively
- develop and protect the organisation's knowledge base
- provide an accountability mechanism and tool
- facilitate review and audits by providing written evidence of the system
- establish due diligence and credibility.

Documentation provides a basis for effective communication within the organisation as well as with the community and various stakeholders. A system of regular reporting, both internal and external, is important to ensure that the relevant people receive the information needed to make informed decisions about the management or regulation of drinking water quality.

3.10.1 MANAGEMENT OF DOCUMENTATION AND RECORDS

Summary of actions

- Document information pertinent to all aspects of drinking water quality management.
- Develop a document control system to ensure current versions are in use.
- Establish a records management system and ensure that employees are trained to fill out records.
- Periodically review documentation and revise as necessary.

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

- preventive measures
- critical control points, including specific operational procedures and criteria, monitoring and corrective actions
- incident and emergency response plans
- training programs
- procedures for evaluating results and reporting
- communication protocols.

Documentation should be visible and readily available to employees. Mechanisms should be established to ensure that employees read, understand and adhere to the documents.

Operation of systems and processes leads to the generation of large amounts of data that need to be recorded. Efficient record keeping is an essential tool for indicating and forewarning of potential problems, and providing evidence that the system is operating effectively.

Activities that generate records include:

- operational and drinking water quality monitoring
- corrective actions
- incident and emergency responses
- training
- research and development
- assessment of the water supply system (flow diagrams, potential hazards etc)
- community consultation
- performance evaluations, audits and reviews.

Documentation and records systems should be kept as simple and focused as possible. The level of detail in the documentation of procedures should be sufficient to provide assurance of operational control when coupled with a suitably qualified and competent operator. Retention of corporate memory should also be considered in documentation of procedures.

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

Records of all activities pertaining to the performance of drinking water quality management should be stored so that they can be easily accessed and reviewed. Storage should provide protection against damage, deterioration or loss. A system should be in place to ensure that employees are properly trained to fill out records, and that records are regularly reviewed by a supervisor, signed and dated.

Documents and records can be stored in a variety of forms, such as written documents, electronic files and databases, video and audiotapes, and visual specifications (flow charts, posters etc). Computer-based documentation should be considered to allow for faster and easier access as well as to facilitate updating.

3.10.2 REPORTING

Summary of actions

- Establish procedures for effective internal and external reporting.
- Produce an annual report to be made available to consumers, regulatory authorities and stakeholders.

Reporting includes the internal and external reporting of activities pertinent to the implementation and performance of drinking water quality management.

Internal reporting supports effective decision making at the various levels of the organisation, including operations staff and management, senior executive and the board of directors. It also provides a way to communicate information on decisions to employees throughout the organisation.

Internal reporting requirements should be defined and a system developed for communication between the various levels and functions of the organisation. Documented procedures (including definition of responsibilities and authorities) should be established for regular reporting (daily, weekly, monthly etc). These reports should include summaries of monitoring data, performance evaluation and significant operational problems that occurred during the reporting period. Results from audit and management reviews should also be communicated to those within the organisation responsible for performance.

External reporting ensures that drinking water quality management is open and transparent. It includes reporting to regulatory bodies, consumers and other stakeholders in accordance with requirements. External reporting requirements should be established in consultation with consumers and the relevant regulatory authorities; procedures for information dissemination should also be developed.

Agreement should be reached with health and other relevant regulators on requirements for:

- regular reports summarising performance and water quality data
- event reports on significant system failures that may pose a health risk or adversely affect water quality for an extended period (see Section 3.6.2).

Reports should be provided to regulatory authorities on incidents defined in agreed incident and emergency response protocols. If necessary, the health authority can then ensure that public health concerns are reported to the community.

An annual report should be produced and made available to consumers, regulatory authorities and stakeholders. The annual report should:

- summarise drinking water quality performance over the preceding year against numerical guideline values, regulatory requirements or agreed levels of service, and identify water quality trends and problems
- summarise any system failures and the action taken to resolve them
- specify to whom the drinking water supplier is accountable, statutory or legislative requirements, and minimum reporting requirements
- indicate whether monitoring was carried out in accordance with the principles of risk management set out in the *Australian Drinking Water Guidelines*, standards set by the regulator and any requirements contained in agreed levels of service.

Annual reports should contain sufficient information to enable individuals or groups to make informed judgments about the quality of drinking water and provide a basis for discussions about the priorities that will be given to improving drinking water quality. The annual report represents an opportunity to canvass feedback, and it should therefore encourage consumers and stakeholders to provide comment.

3.11 Evaluation and audit (element 11)

Components: Long-term evaluation of results
Audit of drinking water quality management

Long-term evaluation of drinking water quality results and audit of drinking water quality management are required to determine whether preventive strategies are effective and whether they are being implemented appropriately. These reviews enable performance to be measured against objectives and help to identify opportunities for improvement.

3.11.1 LONG-TERM EVALUATION OF RESULTS

Summary of actions

- Collect and evaluate long-term data to assess performance and identify problems.
- Document and report results.

The systematic review of monitoring results over an extended period (typically the preceding 12 months or longer) is needed to:

- assess overall performance against numerical guideline values, regulatory requirements or agreed levels of service
- identify emerging problems and trends
- assist in determining priorities for improving drinking water quality.

There will inevitably be occasions of nonconformance with operational criteria or numerical guideline values. Each event will need to be assessed and responses determined.

Mechanisms for evaluation of results should be documented, with responsibilities, accountabilities and reporting requirements defined. Useful tools to enhance the interpretation of data sets include statistical evaluation of results and graphs or trend charts using a 'control chart' format.

Evaluation of results should be reported internally to senior executive, and externally to consumers, stakeholders and regulatory authorities in accordance with established requirements (see Section 3.10.2). Providing assurance that data are reviewed regularly and that improvements are made in response to identified problems will contribute to consumer confidence.

3.11.2 AUDIT OF DRINKING WATER QUALITY MANAGEMENT

Summary of actions

- Establish processes for internal and external audits.
- Document and communicate audit results.

Auditing is the systematic evaluation of activities and processes to confirm that objectives are being met. It includes assessment of the implementation and capability of management systems. Auditing provides valuable information on those aspects of the system that are effective, as well as identifying opportunities for improvement of poor operational practices.

Periodic auditing of all aspects of the drinking water quality management system is needed to confirm that activities are being carried out in accordance with defined requirements and are producing the required outcomes.

Effective internal audits are important for maintaining a functional drinking water quality management system and for identifying areas for improvement. Internal audits will involve trained staff and should include a review of the management system and associated operational procedures, monitoring programs, and the records generated in order to ensure that the system is being implemented correctly and is effective.

The frequency and schedule of audits as well as the responsibilities, requirements, procedures and reporting mechanisms should be defined. The audit process can take place over time but it should be comprehensive.

Drinking water agencies should consider mechanisms for establishing external auditing. Such auditing can be useful in establishing credibility and maintaining consumer confidence. External auditing could be achieved by peer review or be undertaken by an independent third party. External audits should focus on confirming implementation and results of internal audits.

External audits could be conducted on:

- the management system
- operational activities
- drinking water quality performance
- the effectiveness of incident and emergency response or other specific aspects of drinking water quality management.

Audit results should be appropriately documented and communicated to management and personnel responsible for the department or function being audited. Results of audits should also be considered as part of the review by senior executive.

3.12 Review and continual improvement (element 12)

Components: Review by senior executive
Drinking water quality management improvement plan

Senior executive support, commitment and ongoing involvement are essential to the continual improvement of the organisation's activities relating to drinking water quality. Senior executive should regularly review its approach to drinking water quality management, develop action plans and commit the resources necessary to improve operational processes and overall drinking water quality performance.

3.12.1 REVIEW BY SENIOR EXECUTIVE

Summary of actions

- Senior executive review of the effectiveness of the management system.
- Evaluate the need for change.

In order to ensure continual improvement, the highest levels of the organisation should maintain oversight of the effectiveness of the drinking water quality management system and evaluate needs for change.

Senior executive should review reports from audits, drinking water quality performance and previous management reviews. The review should also consider concerns of consumers, regulators and other stakeholders, and evaluate the suitability of the drinking water quality policy, objectives and preventive strategies in relation to changing internal and external conditions such as:

- changes to legislation, expectations and requirements
- changes in the activities of the organisation
- advances in science and technology
- outcomes of drinking water quality incidents and emergencies
- reporting and communication.

The review by senior executive should be documented.

3.12.2 DRINKING WATER QUALITY MANAGEMENT IMPROVEMENT PLAN

Summary of actions

- Develop a drinking water quality management improvement plan.
- Ensure that the plan is communicated and implemented, and that improvements are monitored for effectiveness.

An improvement plan should be developed to address identified needs for full implementation of the drinking water quality management system. The improvement plan should be endorsed by senior executive. Improvement plans may encompass a wide range of issues such as:

- capital works
- training
- enhanced operational procedures
- consultation programs
- research and development
- incident protocols
- communication and reporting.

Improvement plans can include short-term (e.g. one year) or long-term programs. Short-term improvements might include actions such as enhanced mains flushing programs, increased staffing and the development of community awareness programs. Long-term capital works projects could include covering of water storages or enhanced coagulation and filtration.

Improvement plans should include objectives, actions to be taken, accountability, timelines and reporting. They should be communicated throughout the organisation and to the community, regulators and other agencies.

Implementation of improvement plans will often have significant budgetary implications and therefore may require detailed cost-benefit analysis and careful prioritisation in accord with the outcomes of risk assessment (see Section 3.2.3). Implementation of plans should be monitored to confirm that improvements have been made and are effective.

3.13 References

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Chapter 4 Framework for Management of Drinking Water Quality – application to small water supplies

Chapter 4 Framework for the Management of Drinking Water Quality: application to small water supplies

4.1 Introduction

For the purposes of this document, small water supplies are those serving fewer than 1000 people; they include supplies to facilities such as caravan parks, school camps, tourist attractions, roadhouses, and individual household supplies. The sources of these supplies can include groundwater, surface water and rainwater.

For small supplies, it may not be economically feasible or practical to carry out all the recommendations of the *Australian Drinking Water Guidelines* (ADWG); however, there is a range of basic measures that can be implemented to provide reasonable assurance of safety. This chapter provides guidance on methods that are suited to small communities and should give an adequate degree of confidence that safe water is being supplied.

4.2 Applying the Framework

The ADWG provide a Framework for management of drinking water quality based on a preventive, risk management approach; Chapter 2 gives an overview and Chapter 3 details the 12 elements that make up the Framework. Those responsible for small water supplies should adhere to this approach as far as possible; however, it may not be practical or necessary to implement all aspects of the Framework. One of the major difficulties for small communities, particularly those in remote areas, is the implementation of regular monitoring programs (both in terms of cost and the practicalities of transporting samples to testing laboratories). The advantage of the Framework is that it places increased emphasis on a preventive approach to managing water quality, with decreased reliance on water testing.

The principal risk to human health from drinking water is the presence of pathogenic microorganisms. Thus, to ensure safe water, the focus in small supplies should be on regular inspection of the system to check for any direct or potential sources of contamination, and on the use of a clean and unpolluted water source. The following sections explain how these requirements for small water supplies can be achieved in the context of the Framework.

4.2.1 ASSESSMENT OF THE DRINKING WATER SUPPLY

Analysis of the water supply system, identification of potential hazards and risk assessment (described in detail in Section 3.2) are essential for good management of all supplies.

In the case of small supplies, initial steps would be to develop a simple flow diagram of the main features of the system (water sources, treatment or disinfection, service tanks and major piping) and to determine basic water quality characteristics. If groundwater is the source of supply, then chemical quality should be assessed as a priority. In some parts of Australia, concentrations of naturally occurring elements such as arsenic, fluoride and uranium, or nitrates from agricultural land uses, may exceed safe levels.

The water system should be inspected to identify likely sources of hazards. The greatest sources of microbial hazards are human and livestock wastes, and water systems should be inspected to determine the likelihood that this type of contamination will affect water quality. The discharge of septic waste and access of livestock to watercourses, or the proximity of either to supply bores, are likely sources of contamination.

Potential sources of hazards for water supplies can include:

- septic waste from on site or communal wastewater systems
- human wastes from tourists, campers and others having access to water catchments
- animal faeces or dumped animal carcases
- effluent from factories, milking sheds and urban stormwater drains (which may contain partially treated sullage and toilet wastes)
- leakage or seepage from rubbish tips and landfill sites
- agricultural pesticides and fertilisers
- naturally occurring elements
- mining industry wastes.

Risk assessment, described in detail in Section 3.2.3, involves estimating the likelihood that a hazard will occur and the consequences if it does. The aim is to distinguish between high and low risks so that attention and resources can be directed towards those hazards that are most threatening. The risks associated with all hazards identified for a small water supply system should be assessed.

4.2.2 PREVENTIVE MEASURES FOR DRINKING WATER QUALITY MANAGEMENT

Where there are hazards that represent high risks, preventive measures (described in detail in Section 3.3) will be required to remove the hazard or to reduce it to an acceptable level. The effectiveness of existing measures should be assessed, but if these are not sufficient, alternative measures will need to be identified. As with all systems, assessment of preventive measures should include consideration of the important principle of the multiple barrier approach. The types of barriers and the preventive measures required will depend on the characteristics of the source water and the associated catchment.

Groundwater

In most cases, contamination of groundwater supplies can be prevented by a combination of simple measures. Groundwater in confined or deep aquifers will generally be free of pathogenic microorganisms and, providing the water is protected during transport from the aquifer to consumers, microbial quality should be assured. The local vicinity of the borehead should be protected from livestock access, and buffer zones should be established between the bore and disposal or discharge of septic wastes. Bores should be encased to a reasonable depth and boreheads should be sealed to prevent ingress of surface water or shallow groundwater.

Once the groundwater is pumped out of the aquifer, protection can be achieved by delivering the water through enclosed water systems. Storage tanks should be roofed, pipelines should be intact and cross-connections should be protected by the installation of backflow prevention devices.

Rainwater

Rainwater systems, particularly those involving storage in above-ground tanks, generally provide a safe supply of water. The principal sources of contamination are birds, small animals and debris collected on roofs. The impact of these sources can be minimised by a few simple measures: guttering should be cleared regularly; overhanging branches should be kept to a minimum, because they can be a source of debris and can increase access to roof catchment areas by birds and small animals; and inlet pipes to tanks should include leaf litter strainers. First flush diverters, which prevent the initial roof-cleaning wash of water (20-25 L) from entering tanks, are recommended. If first flush diverters are not available, a detachable downpipe can be used to provide the same result.

Further information on rainwater tanks is provided in *Guidance on the use of rainwater tanks* (enHealth, 2004).

Surface water

Assurance of quality from surface water sources is more difficult than from most groundwater or rainwater systems. In general, surface waters will require at least disinfection, and in some cases filtration, to assure microbial safety. However, as for groundwater systems, the first barrier is to prevent contamination at source by minimising contamination from human waste, livestock and other hazards as discussed above. The greater the degree of protection of the water source, the less the reliance on treatment and disinfection. After treatment or disinfection, water should be protected during delivery to consumers in the same manner as groundwater, by ensuring that distribution systems are enclosed.

4.2.3 IMPLEMENTATION OF OPERATIONAL PROCEDURES AND PROCESS CONTROL

Section 3.4 provides a detailed description of the implementation of operational processes and process control.

Operational procedures

Operational procedures should be developed and clearly documented. The procedures should provide clear protocols for activities and processes such as:

- regular inspections of raw water sources and storages for sources of contamination (animals, birds, drainage inflows)
- checking the integrity of groundwater bores and protection of bores from surface contamination
- inspection and cleaning of rainwater catchments and tanks
- inspection and maintenance of all equipment and plant.

Operational monitoring

Operational monitoring includes both regular inspections and testing. In small and remote systems, greater attention should be given to inspections of systems, to check that the preventive measures used to protect water supplies (e.g. denying livestock access and keeping out human waste) are functioning.

The frequency of sanitary inspections of a catchment will depend on the characteristics of each site, the source of raw water, the time the water remains in storage (allowing natural die-off of pathogens to occur), and the subsequent treatment that is provided. As well as regular inspections in the immediate vicinity of the off-take site, every catchment where there is habitation or free public access should be comprehensively inspected at least once a year for potential sources of pollution. Wherever possible, measurements should be undertaken at the site. Test kits are available for a range of parameters, including disinfectant residuals and pH. In some cases, online monitoring might be used; for example, the operation of pumps and disinfection equipment can be monitored using 24-hour telemetry systems that include remote alarms.

Where catchments and supplies are beyond the water supplier's jurisdiction, exchange of information and collaborative assessment of the quality of source waters is advocated.

Corrective action

Where problems occur, corrective action should be taken as quickly as possible. Potential impacts on water quality will need to be assessed and, where necessary, discussed with the local health authority.

If health risks are considered unacceptable, responses could include using an alternative source of water (if available), or issuing advice to the public to either to boil water before consumption (in the case of microbial contamination) or avoid use (in the case of chemical contamination). In the latter case, an alternative water supply will be needed.

Equipment capability and maintenance

The equipment and plant incorporated in the water supply system should be maintained in good condition. In particular, equipment used in water treatment (e.g. for disinfection or microfiltration) should be inspected regularly and should be adequately maintained.

Materials and chemicals

Materials and chemicals used in water systems should be suitable for use with drinking water. Chemicals such as disinfectants and coagulants should be evaluated for suitability. Where expertise is limited, small communities are encouraged to seek advice from larger suppliers, or State/Territory or local governments. All materials should comply with Australian Standard AS/NZ 4020 *Products for use in contact with drinking water.*

4.2.4 VERIFICATION OF DRINKING WATER QUALITY

Verification of drinking water quality is described in detail in Section 3.5. Testing of water in small and remote supplies can present both economic and logistic difficulties, particularly for microbial samples that need to be transported to testing laboratories within 12-24 hours of collection. Application of the Framework decreases reliance on drinking water quality testing; however, testing is still important as a means of verifying that, overall, the barriers and preventive measures implemented to protect public health are working effectively.

Small systems should be monitored on the basis that it is more effective to test for a narrow range of characteristics as frequently as possible than to analyse comprehensively less often.

Microbial quality is the most important factor in determining the ongoing safety of water supplies for human consumption. Therefore, wherever possible, a regular testing program should be instituted for the indicator *E. coli* (or thermotolerant coliforms). As stated in Chapter 9, a minimum of one microbial sample per week is generally recommended; however, in small systems this is not always practical. Where sampling is less frequent than recommended, sanitary inspections should be more frequent, to provide assurance on the integrity and normal operation of the system.

In systems where disinfection is used, evidence of continuous operation is very important in providing assurance of microbial quality. Disinfection is very effective against bacterial pathogens but less so against viruses and enteric protozoa (e.g. *Giardia* and *Cryptosporidium*). The presence of viruses and protozoa can be minimised by protecting water supplies from human and livestock waste.

If chlorination is used, the presence of a free chlorine residual in the distribution system provides evidence of initial disinfection and protection against recontamination from backflow, pipeline breaks or other causes. The amount of chlorine required varies with the flow rate, the quality of the raw water and other factors. Generally, a free chlorine residual of between 0.2 and 0.5 mg/L is adequate.

At least daily testing of chlorine residuals should be carried out to check the effectiveness of the disinfection system. This can be done using a simple diethyl-phenylenediamine (DPD) colour comparator.

4.3 Individual household supplies

For an individual household supply, the emphasis should be on selecting the best quality source water available, and on protecting its quality by the use of barrier systems and maintenance programs. Whatever the source (ground, surface or rainwater tanks), householders should assure themselves that the water is safe to drink. Generally, surface water or shallow groundwater should not be used as a source of drinking water without treatment. Information on the quality of surface and groundwater may be available from state or local governments, which may monitor the particular source water as part of a water monitoring program. Alternatively, an individual household should consider having the water tested for any key health characteristics identified as being of local concern. Where the raw water quality does not meet the ADWG, a point-of-use device may be useful.

The quality of water from rainwater tanks can be affected by roofing and tank materials, paints, atmospheric contaminants, leaves, dust, and animal and bird droppings. However, providing that the system is reasonably well maintained, rainwater can generally provide a safe supply of drinking water. Further information on rainwater tanks is provided in *Guidance on the use of rainwater tanks* (enHealth, 2004), and brochures and other material are provided by state and local government authorities.

4.4 Reference

enHealth Council (2004) *Guidance on use of rainwater tanks,* National Public Health Partnership, Canberra.

PART II DESCRIPTION OF WATER QUALITY

Chapter 5 Microbial quality of drinking water

Chapter 5 Microbial quality of drinking water

5.1 Introduction

This chapter discusses the microbial characteristics of water quality. It describes the microorganisms found in drinking water that can be harmful to health, gives a historical overview of the control of waterborne infection and discusses the risk of disease from waterborne pathogens. It also discusses the 'nuisance organisms' that may affect the taste, odour or appearance of water but do not cause disease. Advice on when and how to measure the characteristics and how to interpret the results is provided in Part III.

5.2 Microorganisms in drinking water

The microbial guidelines seek to ensure that drinking water is free of microorganisms that can cause disease. The provision of such a supply is of paramount importance to the health of a community.

The most common and widespread health risk associated with drinking water is contamination, either directly or indirectly, by human or animal excreta and the microorganisms contained in faeces. If the contamination is recent, and those contributing to the contamination include carriers of communicable enteric diseases (diseases of the gut), some of the microorganisms that cause these diseases may be present in the water. Drinking such contaminated water or using it in food preparation may cause new cases of infection. Those at greatest risk of infection are infants and young children, people whose immune system is suppressed, the sick, and the elderly.

Pathogenic (disease-causing) organisms of concern include bacteria, viruses and protozoa; the diseases they cause vary in severity from mild gastroenteritis to severe and sometimes fatal diarrhoea, dysentery, hepatitis, cholera or typhoid fever.

The classic waterborne diseases are caused by organisms originating in the gut of humans or other animals. However, many organisms of environmental origin that are not normally associated with the gastrointestinal system are found in water, and some of these organisms may, under certain circumstances, cause disease in humans. Such organisms include the protozoan *Naegleria fowleri,* a number of bacteria, including *Pseudomonas, Klebsiella and Legionella* spp, and some species of environmental mycobacteria.

Infection is the main, but not the only, problem associated with microorganisms in drinking water. For instance, certain algae and bacteria can produce toxins that affect humans; the toxins may remain in the water even when the organisms responsible have been removed. Other 'nuisance organisms' can cause problems of taste, odour or colour, or promote deposition and corrosion.

The supply of safe drinking water involves the use of multiple barriers to prevent the entry and transmission of pathogens. The effectiveness of these barriers should be monitored by a program based on operational characteristics and testing for microbial indicators (see Sections 3.4 and 3.5).

This chapter presents a brief historical overview of waterborne infection, demonstrating the dramatic effectiveness of simple control measures and the use of indicator organisms to detect faecal pollution. It then discusses the characteristics and behaviour of the various groups of microorganisms and factors influencing the risk of disease. The chapter ends with a summary of nuisance organisms.

5.3 Controlling waterborne infection: a historical overview

The value of pure water supplies has been recognised, at least in some quarters, for millennia. Hippocrates described an association between water supplies and disease[1] and Roman engineers went to great lengths to provide water suitable in both quantity and quality for major cities.

Urbanisation and industrialisation increased the pressure on water supplies and systems of waste disposal, and by the middle of the 19th century, Britain was affected by major epidemics of cholera and endemic typhoid. John Snow and William Budd provided incontrovertible evidence of the role of water in transmission of these two diseases. Snow's case rested very simply on a comparison of cholera incidence among the customers of three London water companies (Snow 1855): one supplied filtered water; the second moved the source of its supply to a cleaner area of the Thames; the third persisted in supplying polluted Thames water. Budd appreciated that the sewer was merely the continuation of the diseased gut (Budd 1856), and applied what are now classic epidemiological concepts to the investigation of water as a vehicle for spreading typhoid. As a result, filtration of river-derived water became a legal requirement in London in 1859, and the practice gradually spread through Europe. By 1917, Sir Alexander Houston could draw attention to the effectiveness of London's systems of water treatment and delivery in stopping the waterborne transmission of typhoid. He pointed out that in America an annual mortality rate from typhoid of 20 or more per 100 000 people was considered normal (e.g. the rate in Minneapolis was 58.7); however, in London the annual mortality from typhoid was 3.3 per 100 000 (Houston 1917).

Budd's relatively simple precautions against typhoid were remarkably successful (Budd 1856). A century later, Hornick's experiments on volunteers helped to explain this success by showing typhoid to be relatively difficult to catch (Hornick *et al* 1966): around 10^7 *Salmonella enterica* serovar Typhi caused disease in only 50 per cent of his volunteer subjects. Kehr and Butterfield (1943), however, showed that a small minority of the population (about 1.5 per cent) need to ingest only a single typhoid organism to contract typhoid; to protect such individuals, more elaborate precautions are needed.

When the need to protect drinking water from faecal material was first recognised, the techniques available for the isolation of organisms such as *Salmonella enterica* serovar Typhi and *Vibrio cholerae* were quite inadequate for practical purposes. Surrogates were needed, and the obvious candidates were the coliforms, common flora from the gut. Thus, the use of indicator organisms became established. A consensus rapidly developed about the use of coliform organisms, and the work of Alexander Houston (1917), Doris Bardsley (1934) and many others helped to establish the validity of *Escherichia coli* as an indicator of faecal contamination.

Kehr and Butterfield (1943) showed the coliform test to be a useful indicator of *S. enterica* serovar Typhi. The authors concluded that the presence of even moderate numbers of coliforms presented a high risk, citing an outbreak in Detroit, Michigan, where mean coliform counts in the water supply of only 3 and 10 colony forming units (CFU) in every 100 mL of water on two successive days were the indicator for an outbreak of waterborne typhoid. Kehr and Butterfield also noted the much greater risk of gastroenteritis associated with this low coliform count: for the eight cases of typhoid recorded in this outbreak, there were 45 000 cases of gastroenteritis.

Endemic and epidemic cholera and typhoid both still occur, transmitted through contaminated drinking water. For example, this has been demonstrated in recent years in Priština (Yugoslav Typhoid Commission 1964), South Africa (Küstner *et al* 1981) and Peru (Anderson 1991). In Australia, fortunately cholera and typhoid are rare.

1. ***On Airs, Waters and Places***, available online at classics.mit.edu/Hippocrates/airwatpl.8.8.html

5.4 Waterborne pathogens

5.4.1 BACTERIAL PATHOGENS

Excreted pathogens

The human bacterial pathogens that can be transmitted by consuming contaminated drinking water, and that present a serious risk of disease, include *Salmonella* spp, *Shigella* spp, enterovirulent *E. coli, Vibrio cholera, Yersinia enterocolitica, Campylobacter jejuni* and *C. coli*.

After being excreted in faeces from the body of their host, bacterial pathogens gradually lose viability and the ability to cause infection. The rate of decay varies with different bacteria; it is usually exponential, and after a certain period a pathogen will become undetectable. The most common waterborne pathogens are those that are highly infectious or highly resistant to decay outside the body. Pathogens with a low persistence (i.e. those that do not survive long outside the host) must rapidly find a new host and are more likely to be spread by person-to-person contact or by poor personal or food hygiene than by drinking water.

If drinking water is faecally contaminated, bacterial pathogens are likely to be widely and rapidly dispersed. Outbreaks of waterborne disease are therefore frequently characterised by infection across a whole community.

Pathogens growing in water supplies

Various bacteria that occur naturally in the environment may cause disease opportunistically in humans. Those most at risk are people with impaired local or general defence mechanisms, such as the elderly, the very young, people with burns, people who have undergone recent surgery or who have suffered serious injury, and people with severely compromised immune systems. In such individuals, if water used for drinking or bathing contains large numbers of opportunistic pathogens it can occasionally produce infections of the skin, and of the mucous membranes of the eye, ear, nose and throat. Examples of such opportunistic agents are *Pseudomonas aeruginosa*, species of *Klebsiella* and *Aeromonas*, and certain slow-growing mycobacteria.

Legionellosis, commonly caused by the free-living bacterium *Legionella pneumophila*, is a serious illness resulting from inhalation of water in which the causative organisms have been able to multiply because of warm conditions and the presence of nutrients.

Part V contains fact sheets on the bacterial pathogens that may contaminate the water supply.

5.4.2 PROTOZOA

The great majority of protozoa in freshwater are natural aquatic organisms of no significance to health. They generally feed on other microorganisms such as bacteria, cyanobacteria or algae. The greatest diversity of protozoa is found in open surface waters, including water supply sources, but some species can colonise piped water supplies; the extent to which this occurs depends on bacterial activity in these supplies.

The protozoa that may occur in drinking water and cause adverse health effects fall into two functional groups:

- enteric protozoa that occur widely as parasites in the gut of humans and other mammals
- free-living organisms that are opportunistic pathogens in humans and are responsible for serious cerebral and eye diseases (there are very few such organisms).

Since pathogenic protozoa are of both enteric and environmental origin, and since different species vary in their responses to water treatment, control strategies need to be specifically tailored to the biology of individual species.

Enteric protozoa

Enteric protozoa, like enteric bacteria and viruses, may be found in water following direct or indirect contamination with human or animal faeces. Transmission by drinking water is one of several mechanisms for completing the faecal-oral cycle for these organisms. Enteric protozoa occur in water as dormant infectious cysts; the cysts have natural mortality rates that are probably determined by temperature and incident ultraviolet light.

In principle, removal or disinfection at the water source should be sufficient to prevent contamination of drinking water by enteric protozoa, provided adequate measures are in place to prevent later recontamination. In practice, this may be difficult because protozoan cysts are generally more resistant to water disinfectants than most bacteria and viruses.

Cryptosporidium and Giardia species are likely to be the most important enteric protozoa in water in Australia, although infection by *Entamoeba histolytica* is also endemic in some communities. All these organisms cause moderate to severe enteritis in susceptible people; in Australia, they seem to be transmitted mostly by direct contact with a carrier. Outbreaks of *Cryptosporidium* in humans are associated with contamination from by human or livestock (particularly cattle), and faulty or inadequate treatment. There is evidence that *Giardia* infections in Australia may result from contact with septic-tank waste or from recent faecal contamination of drinking water.

Free-living protozoa

Two groups of free-living amoebae, *Naegleria* and *Acanthamoeba,* have been responsible for human infections in Australia. Infection is opportunistic, and generally results from contact during recreational bathing, or domestic uses of water other than drinking. Public water supplies can contaminate swimming pools. The occurrence of these organisms is unrelated to faecal contamination, and their ecology in aquatic environments is more complex than that of enteric protozoa.

Cerebral infection by *Naegleria fowleri* is strictly waterborne and, although rare, is usually fatal. Since these amoebae are able to colonise piped water supplies, disinfection at the water source may not adequately control them unless the disinfectant pervades the whole distribution system.

Acanthamoeba species cause both cerebral and corneal disease. An environmental source of infection has rarely been identified with certainty. Since *Acanthamoeba* species are among the most common protozoa in soil, as well as occurring in freshwater and seawater, the source of infection may often be soil or airborne dust.

Both *Acanthamoeba* and *Naegleria* species are known to support symbiotic growth of *Legionella* species within the cell, and the presence of these amoebae in cooling-tower water can indicate conditions that favour *Legionella.*

Part V contains fact sheets on the protozoan pathogens that may contaminate the water supply.

5.4.3 VIRUSES

Viruses are among the smallest of all infectious agents. In essence they are molecules of nucleic acid that can enter cells and replicate in them. The virus particle consists of a genome, either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA), surrounded by a protective protein shell, the capsid. Frequently this shell is itself enclosed within an envelope that contains both protein and lipid. Viruses replicate only inside specific host cells, and they are absolutely dependent on the host cell's synthetic and energy-yielding apparatus for producing new viral particles.

The viruses of most significance for drinking water are those that multiply in the human intestine and are excreted in large numbers in the faeces of infected individuals. Although they cannot multiply outside the tissues of infected hosts, some enteric viruses can survive in the environment and remain infective for long periods. Human enteric viruses occur in water largely as a result of contamination with sewage and human excreta. The numbers of viruses present and their species distribution will reflect the extent to which they are being carried by the population; however, the use of different analytical methods can also lead to wide variations in calculations of the numbers of viruses found in sewage. Sewage treatment may reduce numbers by a factor of 10 to 10 000, depending upon the nature and degree of treatment; however, even tertiary treatment of sewage will not eliminate all viruses. As sewage mixes with receiving water, viruses are carried downstream; the length of time they remain detectable depends on temperature, their degree of adsorption to particulate matter, penetration of sunlight into the water and other factors. Consequently, enteric viruses can be found at the intakes to water treatment plants if the water is polluted by sewage. However, proper treatment and disinfection should produce drinking water that is essentially virus free.

Recent methodological advances have revolutionised the diagnosis of viral diarrhoeal diseases, and waterborne outbreaks due to viruses have now been identified in both developed and developing countries all over the world, with many different strains of viruses isolated from raw and treated drinking water. Isolation of viruses from water indicates that a hazard exists, but it does not prove beyond doubt that water is a vehicle for transmission of disease.

Epidemiological proof of waterborne transmission of viral diseases is very difficult to establish, for a variety of reasons. Symptoms may not resemble those of typical waterborne diseases, and many of those infected will show no symptoms. Some infections, for example the hepatitis A virus, are difficult to trace to a source because of long incubation periods. Water is often only one of various routes of transmission, it is not always the major route, and adequately sensitive methods for detecting the infectious agent in water are often not available.

Part V contains fact sheets on the viral pathogens that may contaminate the water supply.

5.4.4 HELMINTHS

The major helminth (worm) parasites of humans listed by the World Health Organization as being transmitted by water do not occur in Australia, apart from their rare incidence in recent immigrants or Australians returning from areas where the organisms are endemic. The eggs of enteric nematodes such as *Trichurus* may enter water, but waterborne transmission is generally regarded as unimportant. Nematodes seen as adult worms or larvae in microscopic examination of material from water supplies are likely to belong to free-living groups such as *Turbatrix or Rhabditis,* which, like free-living protozoa, colonise systems that support other microorganisms.

Infective enteric helminths should not be present in drinking water; however, it is impracticable to set guidelines due to the low prevalence of these agents in Australia.

5.4.5 CYANOBACTERIA

Cyanobacteria are true bacteria, although they are often called 'blue-green algae' because they resemble green algae in morphology, habitat and photosynthetic ability. They occur as single cells, filaments or colonies, and their buoyancy enables them to migrate towards the surface of water in response to light. Cyanobacteria inhabit all natural waters, and become a problem only when present in excessive numbers (blooms). This is more likely to occur when temperatures are high, with long sunny days, high levels of plant nutrients in the water, low stream flows, and calm conditions that permit the cells to migrate to the surface. These conditions occur sporadically in late spring through to autumn in many parts of Australia. In addition, eutrophication (nutrient enrichment) associated with increased agriculture and urbanisation has increased the occurrence of cyanobacterial blooms.

They are of concern in drinking water primarily because of the intracellular toxins they produce, which are of three main types:

- hepatotoxins, which damage liver cells
- neurotoxins, which damage nerve cells
- cylindrospermopsin which can damage the liver, kidney, gastrointestinal tract and blood vessels.

No human deaths have been recorded from ingesting the toxins of cyanobacteria but gastroenteritis may result from drinking water containing toxic species and extended exposure may lead to more serious impacts. Deaths have been attributed to the presence of microcystin in water used for renal dialysis in Caruara, Brazil (Jochimsen *et al* 1998).

Direct contact with toxic or non-toxic species of cyanobacteria may cause skin rashes or eye irritation due to adverse reactions to components in the cell walls of the organisms. This could occur through showering or bathing in water containing blooms or scums.

Part V contains fact sheets on cyanobacteria.

5.5 Risk of disease from waterborne pathogens

Drinking water is only one of several means by which many infectious agents can be transmitted. It can, however, be of considerable importance, and many pathogens that are excreted in faeces have caused epidemics through contaminated water. The significance of a particular organism in water can vary considerably; for example, a potentially pathogenic organism will not always cause symptomatic disease in a particular individual. The chances of waterborne infections occurring in a community depend on:

- the concentration of pathogenic organisms in the water
- the virulence of the strain
- the per capita intake of contaminated water
- the infectious dose of the particular pathogen
- the susceptibility of individuals
- the incidence of the infection in the community (which will determine the numbers of pathogens being excreted).

The occurrence of disease is also related to the relative level of immunity in the community. If, for example, the water supply has been repeatedly contaminated, the community may have become immune to some waterborne pathogens. Such a situation can be seen in some developing countries where the prevalence of pathogens is high and the standard of tap water is less than optimal. Visitors who drink the water frequently become ill, while the local community, especially adults, appear to suffer minimal morbidity. The immunity of the local population may, however, be acquired at the expense of the health of more susceptible individuals in that community, including children, the aged and people already in poor health.

Thus, a community consuming water with indicators of faecal pollution may show no discernible disease. Such a situation, however, is unstable. Apart from the risk to visitors, faecal pathogens affecting the locals may be introduced from, for instance, an immigrant or a seasonal outbreak of a disease such as cryptosporidiosis resulting from cattle in the catchment.

When illness occurs in a community, the route of infection needs to be confirmed by epidemiological investigation, even when the disease-causing organism is found in a suspect water supply.

5.6 Nuisance organisms

Nuisance organisms comprise a morphologically and physiologically diverse collection of organisms. They include:

- procaryotic bacteria such as planktonic and benthic cyanobacteria (blue-green algae)
- iron, manganese and sulfur bacteria
- actinomycetes and fungi
- eucaryotic organisms such as algae, crustacea and protozoa.

Problems occur when the conditions in source waters, reservoirs or distribution systems support the growth of a particular nuisance organism or group of nuisance organisms. Excessive quantities of organic matter, for instance, will support the growth of bacteria and fungi, and these will maintain populations of protozoa and crustacea. Many invertebrate animals can feed on bacteria, fungi and protozoa.

In addition, a particular nuisance organism may show morphological characteristics or produce some extracellular product that gives the organism a competitive advantage over other aquatic inhabitants. This may include a 'holdfast' (i.e. a mechanism for anchoring the organism) or sheath (in the case of some iron bacteria) or the ability to produce antibiotic substances (as in some fungal species).

Raw water does not usually contain sufficient numbers of nuisance organisms to create problems; however, the water treatment process may assist their growth. Nuisance organisms concentrate on the surface of filters and inside the filter bed, and on mains and water reservoir surfaces, where they lyse and release cellular compounds responsible for colour, turbidity, taste and odour. Activated carbon filters will, after a period, contain high amounts of organic matter; this may affect taste and odour, and increase turbidity, providing an excellent substrate for bacteria. Poorly operated filter systems, including activated carbon-based domestic filter systems, can be the source of tastes and odours.

It is not practicable to specify a quantitative limit for nuisance microorganisms.

5.6.1 ORGANISMS CAUSING TASTE AND ODOUR PROBLEMS

Objectionable tastes and odours can result from compounds produced by certain types of algae, cyanobacteria (blue-green algae), bacteria and sometimes protozoa. Actinomycetes and cyanobacteria, for instance, produce geosmin and methylisoborneol (MIB), which have an earthy taint, and a taste and odour threshold of approximately 0.00001 mg/L (10 ng/L).

Several groups of protozoa produce odorous compounds in culture. Certain species of the amoeba genera *Vannella, Saccamoeba* and *Ripidomyxa* that carry rather dense bacterial symbionts also produce either geosmin or MIB. Most previously described sources of these compounds have been cyanobacteria or actinomycetes, so it seems likely that the symbionts are the immediate source. While the mechanism of symbiont contribution to odours in waters is unknown, they should be considered as the likely source of a problem if no other biological source of these strongly smelling compounds can be identified.

Free-swimming ciliates, such as *Climacostomum* and certain *Stentor* species that bear the algal symbionts zoochlorelle, can contribute to odours in water if they reach high densities, although such incidents are not often reported.

Consumers often detect taste and odour problems before analytical methods have detected the compounds responsible. It is therefore advisable to use trained panels to detect taste and odour, and undertake remedial measures before a problem becomes significant. Section 3.5.2 and Fact Sheet on *Taste and odour* in Part V discuss such panels.

Another method to pre-empt taste and odour problems is to use microscopy to examine regularly the type and number of organisms present in the water. When a group of organisms known to cause taste or odour problems is dominant, measures should be taken to overcome the problem.

5.6.2 ORGANISMS CAUSING COLOUR PROBLEMS

Excessive growths of some algae, cyanobacteria and other bacteria can produce undesirable 'blooms' in source waters, and this may affect colour in the distribution system.

Blooms of algae and cyanobacteria may be controlled by judicious application of copper sulfate or other algicides to the source water, provided that the cyanobacterial genus is not toxic.

When pigmented organisms such as cyanobacteria and algae are crushed on filters, colour problems can result. This type of problem can be exacerbated by the passage of microalgae through the filters causing an increase in turbidity.

5.6.3 DEPOSITS DUE TO IRON AND MANGANESE BACTERIA

Nuisance iron oxidising organisms may cause problems in groundwater sources by encrusting bore screens, causing loss of yield and impairing the aesthetic quality of the supply. The presence of these organisms may also indicate organic pollution of the aquifer.

Manganese-oxidising organisms (bacteria, fungi and, very rarely, protozoa) may be responsible for deposits in aquifers, wells and water conduits. The deposits can reduce yield, clog slots in the bore pipes, slow the flow in pipes by increasing turbulence, damage equipment for measuring water flows, and produce black water that stains laundry and disrupts food-handling establishments. Bacteria can attach to the deposits; if disturbed, these will increase the heterotrophic colony count of the water. These problems will generally not occur if the concentration of manganese is below 0.1 mg/L. (See Fact Sheet on *Manganese*)

In water containing ferrous or manganous salts, iron or manganese bacteria can oxidise these compounds to form rust-coloured or black deposits in tanks and on the walls of pipes in slow-flowing parts of the distribution system. Changes in water flow can then release the deposits into the supply system, staining laundry and plumbing fittings, and adversely affecting the appearance of drinking water. The slurry may also contain organic deposits that can break down to cause odour problems. (See Fact Sheets on *Colour, Iron, and Manganese*.)

Although these nuisance organisms can impair water quality, it is not practicable to monitor for them routinely because of their diverse nature and unpredictable occurrence. Consumer complaints, together with local knowledge of the water supply system and water sources, should be a trigger for action.

5.6.4 CORROSION PROBLEMS DUE TO IRON AND SULFUR BACTERIA

Iron and sulfur bacteria contribute to the corrosion of iron and steel well pipes and drinking-water mains, with corrosion starting from either inside or outside. Microorganisms may cause corrosion by:

- depleting dissolved oxygen
- preventing corrosive metabolites
- producing sulfuric acid from sulfides or elemental sulfur
- participating in the cathodic process.

The presence of these organisms in water may indicate a potential for corrosion of cast iron mains and storage tanks. It can also indicate biodeterioration of certain construction materials, including nonmetallic materials such as plastics, rubber jointing compounds and pipe lining materials, which provide organic nutrients and thus encourage the growth of microorganisms such as *Pseudomonas aeruginosa*.

5.6.5 PROBLEMS CAUSED BY LARGE NUMBERS OF MICROORGANISMS

Large numbers of aerobic heterotrophic bacteria in treated water can interfere with the interpretation of tests for the coliform group by masking their presence, thus yielding false-negative results. Strains of *Aeromonas* species that produce acid and gas with coliform media, even at 44°C, present a particular problem.

Most of these organisms can be controlled relatively easily by water treatment processes, including disinfection. Nutrient-rich raw water should be avoided if water treatment cannot be applied.

5.6.6 NUISANCE INVERTEBRATES

Invertebrate animals often infest shallow open wells, warm shallow storage tanks and small supplies, but problems are uncommon in large public supplies. These invertebrates derive their food from bacteria, algae and protozoa that are present in the water or on slimes. They include freshwater sponges of the phylum Porifera (*Spongilla* spp and *Ephydatia* spp), a coelenterate (*Cordylophora* spp), bryozoans (*Plumatella* spp and *Fredericella* spp) and molluscan bivalves and snails (e.g. *Corbiculina* spp).

For control purposes, the types of animal can be divided into two groups:

- free-swimming organisms, such as the crustacea *Gammarus pulex* (freshwater shrimp), *Crangonyx pseudogracilis,* Cyclops species and *Chydorus sphaericus*
- animals that either move along surfaces or are anchored to them, such as *Asellus aquaticus* (water louse), snails, *Dreissena polymorpha* (the zebra mussel) and other bivalve molluscs, the bryozoan *Plumatella* species, or animals that inhabit slimes, such as *Nais* species, nematodes, and larvae of chironomids.

In warm weather, slow sand filters can sometimes discharge larvae of midges and mosquitoes into the water. This occurs if the top layer of the bed collapses, causing unfiltered water to be drawn down.

Nuisance invertebrates are more likely to penetrate water filtration plant and mains when low-quality raw waters and high-rate filtration processes are used. Prechlorination destroys the invertebrates and thereby assists their removal by filtration; however, the use of high concentrations of chlorine may produce high levels of chlorination byproducts. Infestation can usually be prevented by maintaining chlorine residuals in the distribution system, producing high-quality water and cleaning water mains regularly by flushing or swabbing.

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Chapter 6 Physical and chemical quality of drinking water

Chapter 6 Physical and chemical quality of drinking water

6.1 Introduction

This chapter discusses both the physical characteristics of water quality and the chemical characteristics, including organic and inorganic chemicals and pesticides. It explains the rationale for deriving guideline values. The principles used in both cases are very similar and a number of common assumptions have been made.

6.2 Physical quality of drinking water

6.2.1 AN OVERVIEW OF PHYSICAL CHARACTERISTICS

The appearance, taste, odour, and 'feel' of water determine what people experience when they drink or use water and how they rate its quality; other physical characteristics can suggest whether corrosion and encrustation are likely to be significant problems in pipes or fittings. The measurable characteristics that determine these largely subjective qualities are:

- true colour (i.e. the colour that remains after any suspended particles have been removed)
- turbidity (the cloudiness caused by fine suspended matter in the water)
- hardness (the reduced ability to get a lather using soap)
- total dissolved solids (TDS)
- pH
- temperature
- taste and odour
- dissolved oxygen.

Colour and turbidity influence the appearance of water. Taste can be influenced by temperature, TDS, and pH. The 'feel' of water can be affected by pH, temperature, and hardness. Rates of corrosion and encrustation (scale build-up) of pipes and fittings are affected by pH, temperature, hardness, TDS and dissolved oxygen.

Each of the physical characteristics is discussed separately in the fact sheets in Part V. However, there is some overlap with organic compounds, microorganisms and, most notably, the inorganic constituents of water; when this occurs, it is noted and cross-referenced.

6.2.2 APPROACH USED IN DERIVATION OF GUIDELINES VALUES FOR PHYSICAL CHARACTERISTICS

In general, the physical characteristics of water are not of direct public health concern, but they do affect the aesthetic quality of the water, which largely determines whether or not people are prepared to drink it. If water is unpalatable or appears to be of poor quality, even though it may be quite safe to drink, the consumer may seek other water sources that may not be as safe.

Each guideline value is set at a level that ensures good quality water – that is, water that is aesthetically pleasing and safe, and that can be used without detriment to fixtures and fittings. The values are determined by considering water quality guidelines used by other countries and international bodies, assessing any health implications and then deciding on a point beyond which the quality of the water might no longer be regarded as good. Factors taken into account include:

- taste and odour thresholds (i.e. the smallest concentration or amount that would be just detected by a trained group of people)
- the concentration or amount that would produce noticeable stains on laundry or corrosion and encrustation of pipes or fittings
- the concentration or amount that would be just noticeable in a glass of water and lead to a perception that the water was not of good quality.

The physical guideline values are not absolute; they are value judgments determined from an often wide range of values that may be broadly classed as acceptable – that is, there is no one right answer. Consequently, small, short-term excursions beyond a physical guideline value do not necessarily mean that the water will be unacceptable. What is aesthetically acceptable or unacceptable depends on public expectations, and must ultimately be determined by water authorities in consultation with consumers, taking into account the costs and benefits of further treatment. The *Australian Drinking Water Guidelines* (ADWG) provide a starting point for this process.

6.3 Chemical quality of drinking water

A number of chemicals, both organic and inorganic, including some pesticides, are of concern in drinking water from the health perspective because they are toxic to humans or are suspected of causing cancer; some can also affect the aesthetic quality of water.

6.3.1 INORGANIC CHEMICALS

Inorganic chemicals in drinking water usually occur as dissolved salts such as carbonates and chlorides, attached to suspended material such as clay particles, or as complexes with naturally occurring organic compounds. Their presence may result from:

- natural leaching from mineral deposits into source waters
- land-use activities in catchments leading to exacerbation of natural processes such as mobilisation of salts
- carryover of small amounts of treatment chemicals
- addition of chemicals such as chlorine and fluoride
- corrosion and leaching of pipes and fittings.

Unless otherwise stated, the guideline value refers to the total amount of the substance present, regardless of its form (e.g. in solution or attached to suspended matter).

6.3.2 ORGANIC COMPOUNDS

Organic compounds are usually present in drinking water in very low concentrations; they may occur either naturally or as a result of human activities. Byproducts of disinfection are the most commonly found organic contaminants in Australian drinking water supplies, and the guideline values for organic compounds have therefore been divided into two sections:

- disinfection byproducts
- other organic compounds.

Disinfection byproducts

The byproducts of disinfection are the products of reactions between disinfectants, particularly chlorine, and naturally occurring organic material such as humic and fulvic acids, which result from the decay of vegetable and animal matter. Of these disinfection byproducts, the trihalomethanes (THMs) are produced in the highest concentrations.

Most disinfectants used to render drinking water safe from pathogenic microorganisms will produce byproducts in the disinfection process. Factors affecting the formation of disinfection byproducts include:

- the amount of natural organic matter present
- the disinfectant used
- the disinfectant dose
- pH
- temperature
- the time available for reaction (C.*t* or contact time).

Chlorine is the most common disinfectant; in the chlorination process it reacts with naturally occurring organic matter to produce a complex mixture of byproducts, including a wide variety of halogenated compounds (i.e. organic byproducts of chlorination). The main byproducts are the THMs and chlorinated acetic acids. Many other byproducts can be produced, but concentrations are generally very low (usually < 0.01 mg/L and often < 0.001 mg/L).

Other disinfectants can produce different types of byproducts: for example, ozone is known to produce formaldehyde and other aldehydes.

Known disinfection byproducts are considered individually in the fact sheets in Part V. It is possible, however, that other disinfection byproducts for which no health data are available are present at extremely low concentrations. It is also possible that when these compounds (both known and unknown) are ingested together, their combined effects on health may be different from their individual effects. Epidemiological studies examine disinfection byproducts as a generic group, and can be useful in determining overall effects.

A number of epidemiological studies have suggested an association between water chlorination byproducts and various cancers. This association has been most consistent in relation to cancer of the bladder and rectum, but there are insufficient data to determine concentrations at which chlorination byproducts might cause an increased risk to human health.

In experiments with laboratory mice, when concentrates derived from chlorinated drinking water were applied to the skin, there was no increase in the incidence of skin tumours compared with concentrates derived from unchlorinated supplies. Similarly, oral administration of chlorinated humic acids in drinking water did not increase the incidence of tumours compared with animals receiving unchlorinated humic acids, or with saline-treated controls.

Studies have shown that concentrates of some chlorinated drinking water supplies are mutagenic to some strains of test bacteria. These effects were consistently found with samples of surface water that had a high content of natural organic compounds at the time of chlorination. A significant proportion of the increased mutagenicity has been attributed to a chlorinated furanone known as MX.

The International Agency for Research on Cancer has reviewed the available data and concluded that there is inadequate evidence to determine the carcinogenicity of chlorinated drinking water to humans (IARC 1991).

Action to reduce the concentration of disinfection byproducts is encouraged, but disinfection itself must not be compromised: the risk posed by disinfection byproducts is considerably smaller than the risk posed by the presence of pathogenic microorganisms in water that has not been disinfected.

Further information on disinfection of drinking water is contained in the Procedures Sheets (Part IV) and Fact Sheets (Part V).

Other organic compounds

Naturally occurring organic compounds are not generally of human health concern, except for certain specific toxins (see Fact Sheet on *algal toxins*). Other than disinfection byproducts, organic contaminants resulting from human activity are not normally detected in Australian drinking water. They have, however, been detected at times in supplies in North America and Europe, usually following an accidental spill or discharge into a water source or, on rare occasions, from airborne contamination of rain. Fact sheets and guideline values are provided in case similar incidents should occur in Australia.

6.3.3 PESTICIDES

For the purpose of the ADWG the term 'pesticides' includes agricultural chemicals such as insecticides, herbicides, nematicides, rodenticides and miticides.

The Australian Pesticides and Veterinary Medicines Authority is responsible for assessing all pesticides prior to registration to allow sale and use in Australia. For registration, data required on the pesticide include information on the proposed use, the toxicity and the residues that might result from proper use. When the pesticide is registered, a safe level of exposure, conditions of use and maximum levels of residues for water are determined. This mechanism allows the formulation of appropriate guideline values for pesticides in drinking water and a process for their revision, which includes public consultation.

Pesticides should be authorised for use in water or water catchment areas only where necessary. Pesticides not authorised for such use should not be present in drinking water. Where pesticides are registered for use in water catchment areas, levels are set that take into account safety and good water management practice.

Contamination of drinking water by pesticides may occur occasionally as a result of accidental spills, misadventure, or emergency use of pesticides. In such cases, prompt action may be required by public health officials. There may also be times when persistent or widespread contamination occurs.

Values for pesticides have been divided into two categories – guideline values and health values.

Guideline values

These values are intended for use by regulatory authorities for surveillance and enforcement purposes; they provide a mechanism to measure compliance with approved label directions.

For pesticides that are not approved for use in water or water catchment areas, the guideline value is set at or about the limit of determination (LOD). This value is the level at which the pesticide can be reliably detected using practicable, readily available, validated analytical methods.

Where a pesticide is approved for use in water or water catchment areas, the guideline value is set at a level that is consistent with good water management practice and that would not result in any significant risk to the health of the consumer over a lifetime of consumption.

If a pesticide is detected at or above the guideline value, steps should be taken to determine the source and to stop further contamination. Exceeding the guideline value indicates that undesirable contamination of drinking water has occurred; it does not necessarily indicate a hazard to public health. If contamination occurs, the advice of the relevant health authority should be sought.

Health values

These values are intended for use by health authorities in managing the health risks associated with inadvertent exposure, such as a spill or misuse of a pesticide.

The values are derived from the acceptable daily intake (ADI) and set at about 10 per cent of the ADI for an adult weight of 70 kg for a daily water consumption of 2 litres. The health values are very conservative, include a range of safety factors and always err on the side of safety.

6.3.4 APPROACH USED IN DERIVATION OF GUIDELINE VALUES FOR CHEMICALS

The guideline value for each organic and inorganic chemical is the concentration that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption and is consistent with water of good quality.

The health-related guideline values are very conservative, and are calculated using a range of safety factors. They always err on the side of safety, particularly where scientific data are inconclusive or where the only data available are from animal studies.

Where aesthetic considerations, including taste and odour, corrosion, and stains on sanitary ware and laundry, dictate a more stringent guideline than that required to protect health, both values are quoted. Health considerations may be of less concern in such cases (although they must still be considered), because water that is aesthetically unacceptable is less likely to be consumed.

For most chemicals, it has not been possible to estimate the higher concentrations that would affect health over shorter periods, so short-term guideline values have generally not been set. However, given the very conservative nature of the guidelines, deviations from the guideline values over a short period do not necessarily mean that the water is unsuitable for consumption. The amount by which and the period for which any guideline value could be exceeded without causing concern will depend on the chemical involved and other factors, such as the risks and benefits to public health.

Each excursion beyond a guideline value should, however, be a trigger for further action.

Chemicals fall into two categories based on health effects:

- those where the effects are observed only above a certain threshold dose, with no effects observed at doses below this threshold
- those that do not appear to have a threshold.

Sources of data used

Human data

There is little information on the effects of human exposure to organic and inorganic compounds, including pesticides, at the concentrations likely to occur in water. Occasionally, there are useful epidemiological data, and where available, these have been the primary consideration in setting the guideline value.

Animal data

In the absence of human data, experiments on laboratory animals provide toxicological data on the effects of exposure to chemical agents. Ideally, these are long-term studies involving ingestion of the compound dissolved in water or present in food, rather than inhalation or dermal exposure studies. It should be understood that for expediency such studies are conducted at concentrations that are relatively high in comparison to the concentrations likely to be found in drinking water. Furthermore, the most sensitive animal species, and the most sensitive group within that species, are used in order to increase the likelihood of observing a toxicological effect.

Effects of exposure to chemicals in experimental animals are generally classified in the following broad categories:

- organ-specific
- neurological/behavioural
- reproductive/developmental
- carcinogenic/mutagenic.

Effects may be prolonged or short term, reversible or irreversible, immediate or delayed, single or multiple. The nature, number, severity, incidence and prevalence of specific effects generally increase with increasing dose. Adequately designed and conducted experimental studies in animals can usually provide an exposure level below which adverse effects are not seen.

Interpreting these data and extrapolating from them to human populations can be difficult, as health effects vary with dose, route of exposure (e.g. ingestion, inhalation or skin absorption), frequency or duration of exposure, and the species, sex and age of the exposed population. This can require appropriate expertise and prudent judgment (e.g. see IPCS 1978).

Derivation of guideline values for substances for which a threshold exists

Where appropriate human data are available, these have been used in the derivation of the guideline value.

In the absence of human data, the guideline value is generally based on the highest dose that causes no adverse effects in long-term experiments on laboratory animals. It is calculated using the following formula:

$$\text{Guideline value} = \frac{\text{animal dose} \times \text{human weight} \times \text{proportion of intake from water}}{\text{volume of water consumed} \times \text{safety factor}}$$

In using this equation, it is necessary to make assumptions about the amount of water consumed per day, the average body weight and the proportion of total intake that can be attributed to water consumption, and to decide on an appropriate safety factor. Clearly the figures selected will all affect the guideline value, and varying one or more of them could raise or lower the resultant value by a factor of 10 or

more. Any guideline value will thus have a degree of 'fuzziness' surrounding it; however, the assumptions made in calculating these guideline values are generally very conservative, and always err on the side of safety.

Animal dose

The animal dose is usually the 'no observed adverse effect level' (NOAEL); that is, the highest amount of the compound that does not cause observable adverse effects in repeat dose studies on experimental animals. If this is not available, then the dose often used is the 'lowest observed adverse effect level' (LOAEL); that is, the lowest amount of the compound that does cause observable effects in studies on experimental animals. If the latter type of study is used, an additional safety factor is usually applied.

The dose data can come from drinking water studies or feeding or force-feeding studies. Dose is expressed as milligrams of compound per kilogram of animal body weight per day.

Human weight

It has been assumed that the average weight of an Australian adult is 70 kg. This is the figure used in Canada and other developed countries. The World Health Organization (WHO) uses a value of 60 kg, which reflects the lower adult weights in developing countries. The heavier weight assumed here will slightly increase the magnitude of the guideline value.

Where there is a specific need to protect young children, the average weight of a child at 2 years of age is assumed to be 13 kg. The same figure is used in other developed countries, such as Canada. The WHO uses 10 kg.

Proportion of intake from water

The animal dose data are assumed to encompass all sources of exposure. It is thus necessary to estimate the proportion of total human intake of a compound that is derived from water. Intake from air is generally negligible compared with other sources, but intake from food, pharmaceuticals and other products can be significant.

For chemicals that are used commercially or industrially, it is assumed, in the absence of other information, that water contributes 10 per cent of intake. For compounds that are not used commercially or industrially, a higher proportion of intake (usually 20 per cent but sometimes 80 per cent or 100 per cent) is assumed to come from drinking water. These figures are regarded as conservative (assuming a higher proportion deriving from drinking water would result in raising the guideline value), and the approach is consistent with that adopted by the WHO and by other countries.

Although exposure to chemical agents in water is predominantly through drinking the water, skin absorption during bathing or inhalation in a shower can also occur. Such exposures may increase the proportion of the chemical derived from drinking water, but the lower proportion (10 per cent or 20 per cent) is used for calculating the guideline value because it provides a higher margin of safety.

Volume of water consumed

The amount of water consumed by an adult each day is assumed to be 2 L. If the guideline value is based on the weight of a child, 1 L per day is assumed. Consumption can vary with season and climate; however, both figures, which are the same as those used by the WHO, are believed to be appropriate, on average, for Australian conditions. Some colder countries use different values: Canada, for example, uses 1.5 and 0.75 L per day.

Safety factor

Safety factors are used because of the uncertainty inherent in extrapolating from animal studies to human populations, or from a small human group to the general population. Safety factors generally applied are:

- a factor of 10 for variations between animals of the same species (because some animals within a species may be more sensitive to the effects of a chemical than the group tested)
- a factor of 10 for variations between species (because the animal species tested may be less sensitive than humans, and in many cases human sensitivity is unknown)
- a factor of 10 if data from a subchronic study are used in the absence of reliable data from chronic studies (this factor can be less if chronic studies are available and indicate that no other effects occur, or that other effects are mild)
- a factor of up to 10 if adverse effects have been observed at the lowest doses (usually the data used are based on the highest dose at which no adverse effects are seen).

The individual factors for each of the points listed above are multiplied together to give an overall safety factor. A safety factor of 100 to 1000 is common; higher values may be used on occasions.

Occasionally, individual safety factors lower than 10 are used where there is additional information to justify a reduction. This can occur, for instance, where information is available to clarify the mechanism of the effects on humans, where human epidemiological data are available, where the adverse effects observed are regarded as being relatively minor, or where large amounts of animal and human data are available.

Guideline values for carcinogenic compounds that act only above a threshold dose are determined in the same way as for non-carcinogenic compounds, but with an additional safety factor for carcinogenic effects.

Derivation of guideline values for substances where no threshold has been demonstrated

With compounds for which no threshold can be demonstrated, it can be expected that, as the level of exposure decreases, the resultant hazard similarly decreases. The risk associated with exposure to very low concentrations may be extrapolated using a risk assessment model, often over many orders of magnitude, from the dose-response relationship observed at higher doses. A number of uncertainties are involved, but the calculations used tend to overestimate rather than underestimate the risk, and so provide a greater margin of safety: it is possible that the actual risk from exposure to low concentrations may, in fact, be lower than the estimated values by more than an order of magnitude.

This approach can be applied for genotoxic carcinogenic compounds, and has been used by the WHO for this purpose.

Interaction between chemicals

Guideline values are calculated for individual chemicals without specific consideration of the potential for each to interact with others in the water. Normally, the majority of chemicals will not be present in concentrations at or near the guideline value, and the large margin of safety incorporated in the majority of the guideline values is considered to be sufficient to account for potential interactions with other substances.

6.4 Differences between Australian and WHO guideline values

The guideline values in the ADWG take as their point of reference the WHO *Guidelines for Drinking-water Quality,* Volume 1 of which was published in 1993. When the guideline values derived for chemicals in the ADWG differ from those recommended by the WHO, the difference usually arises in one of two ways:

- The ADWG use an average adult weight of 70 kg, consistent with developed countries such as Canada, whereas the WHO figure is 60 kg to cater for lighter body weights in developing countries. The use of a higher average weight can sometimes yield slightly higher guideline values, but the difference is not significant given the large safety factors used.
- For genotoxic carcinogenic compounds, WHO uses a risk assessment calculation, with the guideline value set at the concentration that would give rise to a risk of one additional cancer per 100 000 people. The Australian guideline values for these types of compounds are based on a consideration of:
  - the limit of determination based on the most common analytical method
  - the concentration, calculated by the WHO using a risk assessment model, that could give rise to a risk of one additional cancer per million people, if water containing the compound at that concentration were consumed over a lifetime
  - a value based on a threshold effect calculation, with an additional safety factor for potential carcinogenicity.

Frequently the values determined from these two types of calculations are very similar. The balance between these considerations is assessed as follows:

- If the limit of determination gives an adequate degree of protection (i.e. is within a factor of 10 of values determined from health considerations), it has been used as the guideline value. If the limit of determination is much lower than values determined from health considerations, then the lower of the two calculated values has been used. If, conversely, the calculated value is much lower than the limit of determination, then the calculated value is used, but with a note that it is lower than the practical limit of determination. Improved limits of determination are required for such compounds.
- The approach used for carcinogenic compounds in the ADWG is believed to lead to a more balanced assessment of the health risks, and is similar to that adopted in other countries (e.g. Canada). Whether the assumed risk should be one in 100 000 or one in a million is a value judgment. However, the greater degree of protection afforded by a risk of one in a million is generally consistent with calculations based on a threshold approach, and is in line with the high expectations of Australian consumers.

6.5 References

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IPCS (1978). Principles and methods for evaluating the toxicity of chemicals – Part I. Environmental health criteria, 6, WHO, International Programme on Chemical Safety.

Chapter 7 Radiological quality of drinking water

Chapter 7 Radiological quality of drinking water

7.1 Introduction

This chapter describes the sources of radiation in the environment and in drinking water, the health effects of radiation, how people are exposed to radiation and how radiation exposure is measured. It also explains how the guideline values provided in Chapter 10 are derived.

7.2 Sources of radiation in the environment and in drinking water

Radioactive materials occur naturally in the environment (e.g. uranium, thorium and potassium). Some radioactive compounds arise from human activities (e.g. from medical or industrial uses of radioactivity) and some natural sources of radiation are concentrated by mining and other industrial activities.

By far the largest proportion of human exposure to radiation comes from natural sources – from external sources of radiation, including cosmic radiation, or from ingestion or inhalation of radioactive materials. A very low proportion of the total human exposure comes from drinking water. Radiological contamination of drinking water can result from:

- naturally occurring concentrations of radioactive species (e.g. radionuclides of the thorium and uranium series in drinking water sources)
- technological processes involving naturally radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertiliser production)
- manufactured radionuclides, which might enter drinking water supplies from the medical and industrial use of radioactive materials.

7.3 Health effects of radiation

There is evidence from both human and animal studies that radiation exposure at low to moderate doses may increase the long-term incidence of cancer. There is also evidence from animal studies that the rate of genetic disorders may be increased by radiation exposure.

Acute health effects of radiation, ranging from skin burns to nausea, vomiting, diarrhoea, reduced blood cell counts and death, occur at much higher doses and therefore are not a concern for water supplies except in extreme accident situations.

7.4 Exposure to radiation

Several different forms of radiation can be emitted by radioactive species (alpha particles, beta particles and positrons, gamma rays and x-rays). Each form has different biological effects. Alpha particles have very low penetration of tissue but cause considerable cell damage over a short range. Radionuclides that emit alpha particles are therefore only a hazard if they are taken into the body (internal irradiation). Beta particles are more penetrating than alpha particles but on external exposure do not penetrate to internal organs. Gamma radiation and x-rays, on the other hand, are highly penetrating and radioactive sources of these types of radiation are an external radiation hazard.

Humans are irradiated internally if they ingest radioactive substances in food and water or inhale radioactive components in air. Radionuclides that enter the body in this way can remain in a particular organ or tissue for a long time, resulting in exposure over many months or, in some cases, years. Exposure to radiation from contaminated water comes from internal radiation by ingested radionuclides.

7.5 Units of radioactivity and radiation dose measurement

7.5.1 UNITS OF RADIOACTIVITY AND RADIATION DOSE

The International System of Units (SI) unit of radioactivity is the becquerel, where 1 Bq = 1 disintegration per second.

The radiation dose resulting from ingestion of a radionuclide depends on a number of chemical and biological factors. These include the fraction of the intake that is absorbed from the gut, the organs or tissues to which the radionuclide may be transported and deposited, and the time that the radionuclide might remain in the organ or tissue before excretion. The nature of the radiation emitted on decay and the sensitivity of the irradiated organs or tissues to radiation must also be considered.

The absorbed dose refers to how much energy is deposited in material by the radiation. The SI unit for absorbed dose is the gray (Gy). The equivalent dose is the product of the absorbed dose and a factor related to a particular type of radiation. The equivalent dose of radiation received by a person can be further quantified as the effective dose, which, in simple terms, is the sum of the equivalent doses received by all tissues or organs, weighted to account for the different sensitivities to radiation of different organs and tissues in the human body. The SI unit for effective dose is the sievert (Sv).

To reflect the persistence of radionuclides in the body, once ingested, the 'committed effective dose' is a measure of the total effective dose received over a lifetime (50 years) following intake of a radionuclide (internal exposure).

The term 'dose' is used as a general term to mean either absorbed dose (Gy) or effective dose (Sv), depending on the situation. For monitoring purposes, however, 'doses' are determined from the concentration of the radionuclide, which in the case of water is described in terms of Bq/L. This value is converted to an effective human dose per year using a dose conversion factor and the average annual consumption of water.

7.5.2 DOSE CONVERSION FACTORS

The dose arising from the intake of 1 Bq (by ingestion) of radioisotope in a particular chemical form can be estimated using a dose conversion factor. Data for age-related dose conversion factors for ingestion of radionuclides has been published by the International Commission on Radiological Protection (ICRP 1996). Table 7.1 shows the conversion factors or dose per unit intake (mSv/Bq), for naturally occurring radionuclides or those arising from human activities, that could be found in water supplies.

Table 7.1 *Dose per unit intake by ingestion for adult members of the public (ICRP 1996)*

Category	Radionuclide	Dose per unit intake (mSv/Bq)
Natural uranium series	Uranium-238	4.5×10^{-5}
	Uranium-234	4.9×10^{-5}
	Thorium-230	2.1×10^{-4}
	Radium-226	2.8×10^{-4}
	Lead-210	6.9×10^{-4}
	Polonium-210	1.2×10^{-3}
Natural thorium series	Thorium-232	2.3×10^{-4}
	Radium-228	6.9×10^{-4}
	Thorium-228	7.2×10^{-5}
Fission products	Caesium-134	1.9×10^{-5}
	Caesium-137	1.3×10^{-5}
	Strontium-90	2.8×10^{-5}
	Iodine-131	2.2×10^{-5}
Other radionuclides	Tritium	1.8×10^{-8}
	Carbon-14	5.8×10^{-7}
	Plutonium-239	2.5×10^{-4}
	Americium-241	2.0×10^{-4}
	Potassium-40	6.2×10^{-6}

7.5.3 AVERAGE HUMAN DOSE OF RADIATION

The dose of radiation received varies significantly between individuals and communities, and depends on locality, lifestyle, diet and type of dwelling. The global average for the individual dose of radiation from natural sources has been estimated to be 2.4 mSv per year (UNSCEAR 2000). Of this annual dose, less than 10 per cent comes from ingestion of food and drinking water containing radium and other radionuclides of the natural uranium and thorium series. Australian data suggest that the average annual dose in this country may be slightly lower at approximately 2 mSv per year (Webb *et al* 1999).

7.6 Approach for derivation of guideline values for radionuclides

The *Australian Drinking Water Guidelines* (ADWG) provide:

- a single guideline value for the annual exposure to radioactivity in drinking water
- a method to assess the radiological quality of water
- a simple screening method to assure compliance with the Guideline
- a method for assessing water if screening levels for gross radioactivity are exceeded.

This approach reduces the need for routine costly and time-consuming analyses to identify individual radionuclides present in the water.

7.6.1 PRACTICES AND INTERVENTIONS

The ADWG are based on the recommendations of the ICRP (ICRP 1991, 2000) and the NHMRC (NHMRC 1995). Both organisations distinguish between 'practices' and 'interventions' as follows:

- A 'practice' is a situation where the dose of radiation received is increased by the activities under consideration; for example, the development of a uranium mine or nuclear power station. Radiation dose limits can be imposed on the operation so that compliance with these limits reduces risks from the 'practice' to levels considered 'acceptable'. If the facility cannot be designed or operated to comply with the radiological protection standards, then the facility can be forced to close.
- An 'intervention' may be required when the public are exposed to a radiation source that is already present and incidental to the situation under consideration. Such situations include exposure to natural sources of radiation, or exposure from abandoned radioactive waste from past operations. Frequently, these situations result in prolonged radiation exposures. Action to reduce the radiation dose to the exposed population may therefore be warranted and is called an 'intervention'.

Reducing the radiation exposure from radionuclides in drinking water requires an intervention. For example, the supply may be treated to reduce the levels of radioactive contaminants, an alternative supply may be substituted, or, in the extreme case, the population may be relocated to an area where better quality water is available.

The levels considered acceptable in practice provide a basis for setting levels that require an intervention.

7.6.2 ESTIMATION OF THE DOSE FROM RADIONUCLIDES IN WATER

To estimate the equivalent dose to members of the public from the ingestion of radionuclides in drinking water, the parameters required are the concentration of the radionuclides in water (measured in Bq/L), the daily consumption rate of water (L/day), and the dose conversion factor for the particular radionuclide.

WHO has estimated that adults consume an average of 2 L of water per day, and this figure is believed to be an appropriate average figure for Australia, giving an annual consumption of 730 L for each adult Australian. Therefore, the amount of each radionuclide ingested per year from the water supply is the concentration of that radionuclide in the water (Bq/L) multiplied by 730.

The annual dose from an individual radionuclide consumed in water is calculated using the following equation:

Annual dose =	dose per unit intake	x	annual water consumption	x	radionuclide concentration
(mSv/year)	(mSv/Bq)		(litre/year)		(Bq/L)

Usually, a water supply contains more than one radionuclide; therefore, the doses arising from each individual radionuclide must be summed to give the total dose.

7.6.3 ESTIMATION OF RISK FROM LOW-LEVEL RADIATION

Lifetime

Because of the very low level of exposure resulting from consumption of drinking water containing radionuclides, and the radionuclides involved, it is not possible to distinguish a radiation-induced cancer incidence from the baseline level of cancers in the general population. Therefore, the health risks must be estimated by extrapolation from the effects at higher doses.

The ICRP (1991) estimates the lifetime risk of a fatal cancer resulting from exposure to radiation to be 5×10^{-2} per Sv of radiation dose, that is, five additional fatal cancers for every 100 people exposed per

year. On the basis of this estimate, a dose of 1 mSv per year gives an annual risk of 5 x 10^{-5}, that is, about five additional fatal cancers per 100 000 people exposed per year. (Additional fatal cancers are those that occur in addition to those that result from all other causes.)

Any increase in genetic disorders (including birth defects) is expected to be very much less than any increase in the cancer rate and therefore an acceptable dose level for cancer risk will also be protective for genetic risk.

Acceptable dose from drinking water

Both the ICRP (1991) and the NHMRC (1995) recommend that the need for, and the extent of, intervention to reduce radiation exposure should be determined on the basis of a generalised cost-benefit analysis, where the resulting public health benefit should be balanced against the overall costs of achieving a reduction in radiation exposure. The outcome of this type of analysis will almost always be specific to a particular situation because the costs of reducing exposure vary widely depending on the situation. It is thus not possible to set a completely generic level at which intervention must be undertaken to reduce the radiation dose from radionuclides in water supplies.

Guidance can, however, be gained from the recommendations of Lokan (1998) and the ICRP (2000) on the protection of the public in situations of prolonged exposure. The ICRP noted that, on radiological grounds alone, intervention may not be necessary for doses below 10 mSv per year. However, this applies to the total dose from all sources of exposure. The ICRP also recommended that, for commodities that are essential for normal living and are amenable to intervention, an individual dose of approximately 1 mSv per year is an acceptable intervention exemption level (ICRP 2000). This is consistent with the recommendation of the NHMRC (1995) of a public exposure limit for practices of 1 mSv per year from all sources.

Furthermore, Lokan (1998) concluded that a value of 1 mSv per year might be appropriate as a default action level above which some corrective action will be necessary.

7.6.4 GUIDELINE VALUE FOR DRINKING WATER

Based on the above, it is recommended that a guideline dose of 1 mSv per year should be applied for radioactivity in drinking water. When the existing or potential dose from the radionuclide content exceeds this guideline dose, a decision on the need for and the degree of remedial action (intervention) should be based on advice from the relevant state health authorities, and should include a cost-benefit analysis.

There may be some circumstances where there is no practical alternative but to accept a dose that exceeds the guideline dose of 1 mSv, together with a potential slight increase in the risk to health as a consequence. However, if doses from the use of a particular water supply will exceed 10 mSv per year, immediate action must be taken to reduce the existing or potential exposures.

7.6.5 APPLICATION OF GUIDELINE VALUES

This Guideline deals only with situations where the radionuclide concentrations arise either from natural sources, or, more rarely, as the result of past practices (such as abandoned mining operations). It specifically does not apply to situations where the radionuclides arise from current practices under regulatory control, such as an operating uranium mine.

Therefore, the guideline should not be used to support an increase in the radionuclide concentrations of drinking water as a result of an operation, on the grounds that the overall dose levels remain below 1 mSv per year.

7.7 References

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Chapter 8 Drinking water treatment chemicals

Chapter 8 Drinking water treatment chemicals

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8.1 Introduction

The production of safe reticulated drinking water is vital for society. In recent decades, there have been numerous examples throughout the world of poor water quality impacting adversely on human health. Such episodes are rare in Australia, but the dire consequences of compromised disinfection and blooms of cyanobacteria serve to remind us of the need for drinking water treatment.

Addition of chemicals to make water safe for consumption is widely practiced by the water industry and has generally been accepted by the community. However, safeguards must be sufficient to ensure that any residual amount of these chemicals, byproducts of their reactivity or minor contaminants in their formulations do not pose an unacceptable health risk.

Treatment chemicals are added to drinking water mainly to reduce or eliminate the incidence of waterborne disease, for other public health measures, and to improve the aesthetic quality of the water. Any chemical used in, on, or near drinking water sources, or used during the treatment of drinking water should:

- be effective for the desired outcome
- not present a public health concern
- not result in the chemical, its byproducts or any contaminants exceeding drinking water guideline values.

This chapter provides guidance on chemicals used during the storage, treatment, and distribution of drinking water, quality assurance procedures, and the requirements for gaining approval for these chemicals.

8.2 Scope and limit of application of this chapter

Chemicals used near water for purposes other than direct improvement of water quality are not considered as drinking water treatment chemicals. Such chemicals include fertilisers and other agricultural chemicals used in properties adjacent to water storages, herbicides used to reduce vegetation along waterways, and pesticides used to control mosquitoes and other disease vectors in water storages. Use of these chemicals near raw water sources should be carefully considered, and the risks associated with their use should be minimised to ensure that water quality and public health are not jeopardised. Further information on these chemicals is given in Section 6.3.3 and in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (NWQMS 2000).

This chapter does not cover the specialised chemicals used in water treatment for non-potable uses (e.g. chemicals used in industrial boilers and air conditioning cooling towers), nor does it cover the impact on water quality of materials in direct contact with water. Information on these chemicals and impacts is given in Australian Standards AS3666.1:2002 — *Air handling and water systems of buildings Microbial control – design, installation and commissioning;* AS5667.7:1998 — *Water quality – Guidance on sampling of water and steam in boiler plants;* and AS4020:2002 — *Testing of products for use in contact with drinking water* respectively.

Information on occupational exposure to drinking water treatment chemicals resulting from their manufacture, transportation or use should be obtained from the manufacturer and Material Safety Data Sheets (MSDS), or from the appropriate State or Territory Occupational Health and Safety Authority (see Section 8.9).

8.3 Overview of chemical treatment processes

In the production of drinking water, a number of different chemicals may be added to the water. The types and quantities of chemicals can vary widely and will depend on a range of factors including raw water quality, treatment processes employed and treated water quality objectives. Chemical treatment processes are used to:

- control algae
- remove turbidity and colour
- remove microorganisms
- remove algal metabolites and synthetic pollutants
- reduce organic matter
- reduce the concentration of iron, manganese and other elements
- reduce pesticides and herbicides
- control taste and odour
- soften
- buffer or modify the pH
- disinfect
- control corrosion in distribution systems.

Chemical treatments may also be used for other public health measures, including:

- fluoridation (to prevent dental caries)

The following sections outline common processes employed in water treatment to achieve these objectives.

8.3.1 CONTROL OF ALGAE

Algicides are used to reduce toxic or odorous algal blooms in water reservoirs. The chemical commonly used in the management of algal growth is copper sulfate. Before an algicide is used, the possible effects on aquatic biota, the accumulation of copper in sediments, the potential impacts on downstream treatment processes and final treated water quality should be considered.

The use of copper as an algicide is controlled in some States. Information on the use of these chemicals should be obtained from the appropriate State or Territory authority (see Section 8.9).

8.3.2 COAGULATION AND FLOCCULATION

The primary use of coagulant and flocculant chemicals is in the removal of suspended and colloidal solids such as clays. Coagulation is particularly important in the treatment of surface waters. Removal of the solids is achieved by aggregating fine suspended matter into larger flocs. Coagulant and flocculant chemicals will also remove some natural organic matter, colour and microorganisms (e.g. bacteria, viruses and algae). The size and strength of the floc can be controlled and modified, depending on the treatment process in use, and the floc can be removed by sedimentation and filtration.

8.3.3 ADSORPTION

Adsorption is primarily used to improve water quality through the accumulation of substances at the interface between two phases, such as a liquid and a solid, due to chemical and physicochemical interactions. The solid on which adsorption occurs is called the adsorbent. Activated carbon is an excellent adsorbent.

Adsorption is commonly used to remove organic contaminants such as herbicides, pesticides, algal toxins and metabolites; it is also used to remove compounds which may impact on the taste and odour of water.

8.3.4 SOFTENING

Softening is undertaken as part of water treatment to remove calcium and magnesium salts, particularly carbonates and bicarbonates, which cause water hardness. Hard water can cause scale build-up on water heating elements and can cause problems with the use of soaps and detergents. Softening very hard waters can also lead to high concentrations of sodium in water. While this may possibly give the water a salty taste, it is unlikely to present a health concern. Water that is too soft can be corrosive, which may occur when reverse osmosis is being used for water treatment, in which case it may be necessary to restore some hardness to prevent corrosion.

8.3.5 OXIDATION

Various oxidants may be added to water to oxidise problem compounds. For example, chlorine or potassium permanganate may be added to control iron and manganese. The oxidised forms of iron and manganese are readily removed by coagulation, flocculation and filtration. Oxidants may also be used to oxidise compounds which impact on the taste and odour of water, and organic contaminants such as pesticides.

Ozone, and possibly hydrogen peroxide, may be added to oxidise organic compounds, and thus reduce the amount of coagulant required. Adding these chemicals also helps to reduce the length of long-chain organic molecules, which are then more effectively removed by granular activated carbon.

8.3.6 DISINFECTION

Disinfection of water is generally used either alone or as the final step in water treatment, after clarification or filtration. Disinfection is widely used to prevent the passage of bacteria, viruses and some protozoa into the distribution system. Typical chemicals used for disinfection of drinking water supplies are strong oxidants, such as chlorine (and its derivatives, chlorine dioxide and chloramine), ozone and hydrogen peroxide.

The efficiency of disinfection depends greatly on the quality of the source or treated water, and can also be strongly affected by conditions such as chemical contact time, the pH and turbidity of the water, and organic content of the water.

The aim of treatment processes used before disinfection should be to produce water with the lowest possible turbidity and organic content. Excessive particulate matter in the water can protect microorganisms from the action of disinfection chemicals. Also, excess organic matter and other oxidisable compounds in water can react with disinfection chemicals intended to inactivate microorganisms and can result in an increase in the formation of disinfection byproducts (see Section 6.3.2 for general information on disinfection byproducts, and the fact sheets in Section V for information on specific byproducts). Best practice operation of a conventional water treatment plant should be able to produce treated water with a turbidity of less than 0.1 nephelometric turbidity units (NTU).

8.3.7 ADJUSTMENT OF PH

Adjustment of pH is important in drinking water treatment processes such as coagulation (particularly for the removal of natural organic matter), corrosion control and softening.

Control of pH is also important for effective disinfection and for minimising the formation of disinfection byproducts. The efficiency of certain disinfectants is strongly dependent on pH.

8.3.8 ADDITION OF BUFFERING CAPACITY

Soft waters can be subject to pH change as they travel through the distribution system. The rate of change depends on a number of factors including the water hardness, pipe materials used (e.g. cement lined pipe), the contact time, temperature. Increasing the buffering capacity of the water can help control the rate of change of pH through the distribution system.

8.3.9 CORROSION INHIBITION

The mechanisms of corrosion in a water distribution system are complex, and involve an interrelated combination of physical, chemical and biological processes. These depend greatly on the materials used within the distribution system and the chemical properties of the water, particularly its buffering capacity. Water corrosivity can be minimised by adjustment of pH and increasing calcium carbonate hardness (resulting in a positive Langelier index). Corrosion can also be reduced by maintaining disinfection residual throughout the distribution system.

Corrosion inhibition chemicals (such as sequestering agents) are used to reduce corrosion of pipes and household services. They also control the build-up of scale deposits from the dissolved mineral content of drinking water. This is achieved through the addition of chemicals that form a protective film on the surface of pipes. While corrosion inhibitors reduce corrosion, limit metal solubility or convert one form of corrosion to another (e.g. alleviating tuberculation and replacing it with more uniform corrosion), they do not totally prevent corrosion.

8.4 Public Health Measures

8.4.1. FLUORIDATION

Fluoridation of drinking water is not a water treatment process, but has been and continues to be effective in reducing the incidence of dental caries. It has many advantages over alternative methods for fluoridation, due to its cost effectiveness, consistency of exposure, equal distribution to all socioeconomic groups, and safety. In some areas, fluoride can occur naturally in drinking water.

In areas where the drinking water supply is artificially fluoridated (at the instigation of the relevant State or Territory health authorities), the process is generally undertaken after clarification and chlorination of the water, because fluoride ions may adsorb onto the surface of suspended matter in the water and be subsequently removed through these processes. Fluoridation is generally achieved by adding either a slurry of sodium fluorosilicate, a solution of hydrofluorosilicic acid or (less commonly) a saturated solution of sodium fluoride, added as a metered dose for a given rate of water flow. Correction of pH may need to be carried out after fluoride addition. Use of fluoride is controlled by State and Territory legislation and regulations, and local regulations. Some of these are outlined in Table 8.1 (see also Section 8.9).

Table 8.1 *State and Territory fluoride legislation and regulations*

Australian Capital Territory	• *Electricity and Water (amendment) Act (no 2) 1989*. No 13 of 1989—Section 13
New South Wales	• Fluoridation of Public Water Supplies Regulation 2002. <www.legislation.nsw.gov.au> • *Fluoridation of Public Water Supplies Act 1957*
Northern Territory	• *Dental Act Schedule 3 1999*
Queensland	• Fluoridation of Public Water Supplies Regulation 1998. Reprinted as in force on 4 January 1999 • *Fluoridation of Public Water Supplies Act 1963*. Reprinted as in force on 21 December 1998
South Australia	• There is no fluoride legislation in South Australia
Tasmania	• *Fluoridation Act 1968*
Victoria	• *Health (Fluoridation) Act 1973*
Western Australia	• *Fluoridation of Public Water Supplies Act 1966*

8.5 Assessment of chemicals acceptable for use in drinking water treatment

8.5.1 CHEMICALS PREVIOUSLY ASSESSED

The NHMRC has examined a wide range of chemicals for treating water in Australia. To be acceptable, the chemical must have a practical application (e.g. clarify dirty water, or destroy or inactivate harmful microorganisms). The chemical must achieve its purpose and must not be toxic when ingested at concentrations present in treated water.

A drinking water treatment chemical is considered suitable for use when used in accordance with standard operating procedures.

This does not relieve a water authority from having risk control measures in place to ensure the effectiveness of a particular chemical in a water treatment process. For example controls need to be in place to prevent over- or under-dosing. Water treatment systems also need to be designed to ensure that residuals and contaminants from multiple treatment chemicals added will not exceed recommended guideline values at the consumer's tap.

The potential for a chemical to interact with any other added chemical or other compounds present in the water also needs to be considered.

The chemicals listed in Table 8.2 are considered by the NHMRC to be suitable for use in the treatment of drinking water.

If a chemical not listed in this chapter is to be used in the treatment of drinking water, it is the responsibility of the water authority to seek advice from the appropriate state/territory health regulatory agency, and take into consideration health, environmental, and occupational health and safety issues.

The fact sheets in Section V provide detailed information on chemicals used in the treatment of drinking water.

Table 8.2 *Chemicals recommended for use in the treatment of drinking water*

Treatment chemical	***Formula***	***Original date of approval by NHMRC***	***Uses***
Aluminium chlorohydrates	$AlCl(OH)_5$	2005	Coagulation
Aluminium sulfate (alum)	$Al_2(SO_4)_3$	1983	Coagulation
Ammonia	$NH_{3\ aq}$	1983	Generation of chloramines for disinfection
Ammonium sulfate	$(NH_4)_2SO_4$	1983	Generation of chloramines for disinfection
Calcium hydroxide (hydrated lime)	$Ca(OH)_2$	1983	pH correction Softening Corrosion control
Calcium hypochlorite	$Ca(OCl)_2$	1983	Disinfection/oxidation
Calcium oxide (quick lime)	CaO	1983	Coagulation aid pH correction Softening Corrosion control
Carbon, powdered activated/ granulated activated (PAC/GAC)	C	1983	Adsorption
Chlorine	Cl_2	1983	Disinfection/oxidation
Chlorine dioxide	ClO_2	2005	Disinfection/oxidation
Copper sulfate	$CuSO_4$	1983	Algicide

Table 8.2 *Chemicals recommended for use in the treatment of drinking water (continued)*

Treatment chemical	***Formula***	***Original date of approval by NHMRC***	***Uses***
Ferric chloride	$FeCl_3$	1983	Coagulation
Ferric sulfates	$Fe_2(SO_4)_3$	1983	Coagulation
Hydrochloric acid	HCl	2005	pH correction
Hydrofluorosilicic acid (fluorosilicic acid)	H_2SiF_6	1983	Fluoridation
Hydrogen peroxide	H_2O_2	1983	Disinfection Oxidation
Hydroxylated ferric sulfate		2005	Coagulation
Ozone	O_3	2005	Disinfection/oxidation
Polyacrylamides	$(C_3H_5NO)_n$	1977	Coagulation aid Flocculation aid Filter aid
Polyaluminium chlorides	$Al_n(OH)_mCL_{(3n-m)}$	1979	Coagulation
Poly aluminium silica sulfates	$Na_{12}(AlO_2)(SiO_2)_{12}.xH_2O$	2005	Coagulation
Polydiallyldimethylammonium chlorides (polyDADMACs)		1982	Coagulation and coagulation aid
Potassium permanganate	$KMnO_4$	1983	Disinfection/oxidation
Sodium aluminates	$NaAlO_2$	1983	Coagulation
Sodium bicarbonate	$NaHCO_3$	1983	pH correction Softening Corrosion control
Sodium carbonate (soda ash)	Na_2CO_3	1983	pH correction Softening Corrosion control
Sodium fluoride	NaF	1983	Fluoridation
Sodium fluorosilicate	Na_2SiF_6	1983	Fluoridation
Sodium hexametaphosphate	$(NaPO_3)_x$	1983	Corrosion control
Sodium hydroxide (caustic soda)	NaOH	1983	pH correction Softening Corrosion control
Sodium hypochlorite	NaClO	1983	Disinfection/oxidation
Sodium silicate	Na_2SiO_3	1983	Coagulation aid Flocculation aid pH correction Corrosion control
Sodium tripolyphosphate	$Na_5P_3O_{10}$	2005	Corrosion control Softening
Sulfuric acid	H_2SO_4	1983	pH correction
Zinc orthophosphate	$Zn_3(PO_4)_2$	1987	Corrosion control

8.5.2 ASSESSMENT OF NEW WATER TREATMENT CHEMICALS

The procedure to gain approval by NHMRC for new drinking water treatment chemicals for use in Australia is undertaken on a case-by-case basis. Sponsors of a new water treatment chemical seeking inclusion of the chemical into the NHMRC *Australian Drinking Water Guidelines* should, in the first instance, contact the NHMRC. A comprehensive assessment of toxicological information will be required as part of the approval process.

National procedures established by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS)[1] are followed when assessing existing chemicals, assessing a new use for an existing chemical or assessing new drinking water treatment chemicals for use in Australia. NICNAS reviews of toxicological data, undertaken through a cost-recovery arrangement with the sponsor of the chemical, are required prior to final consideration by the NHMRC.

The Australian Pesticides and Veterinary Medicines Authority (APVMA) are responsible for safety and efficacy assessment and registration of pesticides and veterinary medicines (including algicides).

8.6 Quality assurance for drinking water treatment chemicals

8.6.1 RISKS ASSOCIATED WITH DRINKING WATER CHEMICALS

A cornerstone of the management of drinking water quality (see chapters 2 and 3) is the analysis of hazards and the management of risk.

The intentional addition of chemicals to water intended for drinking purposes carries with it a potential risk. This may result from any of the following:

- the toxicological properties of the chemical itself
- underdosing or overdosing of the chemical
- contaminants in the chemical arising from the manufacturing process or the raw materials used
- contaminants in the chemical arising during transport, storage and use on site
- byproducts formed through the use of the chemical.

Contamination of chemicals can be minimised by the use of good manufacturing practice, which uses quality control and quality assurance programs to maximise product purity. The purity of chemicals used in Australia for the treatment of drinking water supplies will vary depending on the manufacturing process. Contaminants that may occur in specific treatment chemicals are outlined in the fact sheets (see Section V). The information in the fact sheets is based on the best available data at the time of publication. However, research and industry experience may lead to changes in manufacturing processes or better understanding of the properties of the chemicals, which in turn may lead to changes in procedures for how water treatment chemicals should be handled, stored and used.

8.6.2 MANAGING RISKS

A complete water quality management program needs to recognise any potential risks from use of drinking water treatment chemicals and include strategies to manage them appropriately. These risks should be minimised by the implementation of a quality assurance system for the management of production, supply, delivery and use of water treatment chemicals.

The first step in managing the risk associated with the use of drinking water treatment chemicals is to ensure that the chemicals supplied meet a minimum standard, as established by the relevant State or Territory regulatory agency. For example, water authorities may formally specify the strength of active ingredient and acceptable contaminant levels in each drinking water treatment chemical (see Section 8.6.3). However, this in itself will not adequately control the risk. The contractual requirement should be supported by batch-testing data provided by the supplier from an independent NATA (National

[1] http://www.nicnas.gov.au/

Association of Testing Authorities) accredited laboratory, and random testing carried out by the water authority itself. Chemicals should not be accepted for delivery unless a batch analysis certificate has been obtained and checked by the water authority.

Formal accreditation of the manufacturing facility by an independent accreditation agency (e.g. the International Organization for Standardization (ISO) or NSF International) provides a further level of risk management. Such accreditation should include random site visits to the manufacturing facilities by the relevant regulatory agency and, if warranted, the water authority.

Chemical suppliers should be evaluated and selected on their ability to supply products in accordance with required specifications. Documented procedures for the control of chemicals, including purchasing, verification, handling, storage and maintenance should be established to assure the quality of the chemical at the point of application (see Section 3.10.1). Responsibilities for testing and quality assurance of chemicals (supplier, purchaser or both) should be clearly defined in purchase contracts.

An important step in a quality assurance system for chemical addition to drinking water is to ensure that the required chemical is of the specified quality, and specified strength, and is delivered into the correct storage vessel, at the correct site at the correct time. This is necessary to:

- ensure that the correct chemical at the required concentration is used in drinking water treatment
- ensure that cross contamination of storages does not occur
- ensure inappropriate and unsafe mixing of chemicals does not occur
- help to ensure the health and well being of staff and contractors during the delivery and dosing process.

Broadly, the objective of the water treatment chemical quality assurance system is to manage all the factors associated with the specification, contract management, supply, storage, use and handling of water treatment chemicals that could adversely impact upon the health and wellbeing of staff, contractors and consumers. Box 8.1 outlines the components that make up an effective quality assurance system for drinking water treatment chemicals.

Box 8.1 *Desirable components of a quality assurance system*

The desirable components of a quality assurance system for chemicals used in the production of drinking water may include:

- Selection of chemical suppliers based on capability to meet specified requirements for supply and delivery, monitoring and analytical testing of contaminants.
- Selection of suppliers with a quality management system that is certified by an independent accreditation agency.
- An appropriate monitoring program to ensure compliance of chemicals with specifications.
- An audit process for the supplier's manufacturing, storage and delivery processes.
- A formal checklist for the dispatch and delivery process.
- A delivery driver induction system for each site, with each driver inducted onto each site and appropriate record keeping procedures.
- The provision of details of the delivery site (site photographs may be useful).
- An identity check directly linking the delivery driver to the chemical company.
- The clear identification and labelling of chemical storage vessels, filling points and delivery pipe work at all sites (locks on filling points are desirable).
- A requirement that chemicals should only be delivered when an appropriate water authority staff member is present to check documentation including batch analysis certification and ensure unloading to the correct storage vessel.
- A standard operating procedure for the delivery and receipt of chemicals at each delivery site including a documented acceptance criteria system to assist site operations staff in assessing whether to accept or reject the delivery of a chemical.
- A gross visual check of the chemical and, where appropriate, simple physical testing by the water authority representative at the delivery site before unloading.
- A check by both parties that the delivery vessel is being connected to the correct storage vessel.
- A check that appropriate personal protective equipment is being worn, and that relevant health and safety requirements are being addressed.
- Appropriate recording and storage of relevant documentation.
- A system to ensure that any spillage associated with the delivery process is contained and does not escape to the environment.
- An emergency procedure in the event of possible systems failure or human error.

The combination of a chemical quality assurance system and a delivery and storage quality assurance system such as those outlined in Box 8.1 can significantly reduce risks to all stakeholders. The combined system should include formal quality audits (see Section 3.11).

8.6.3 SPECIFICATIONS FOR THE SUPPLY OF DRINKING WATER TREATMENT CHEMICALS

The preparation of specifications for a chemical supply contract can be a time consuming and difficult task. Documents should be prepared in conjunction with a risk assessment and controls recommended in Sections 8.5.1 and 8.5.2.

To simplify the process for water authority staff preparing their own specifications, an example specification for the supply and delivery of liquid aluminium sulfate (Al_2SO_4) to a water authority is provided in Box 8.2.

The specification includes details on the required content of aluminium which is often, but not always, expressed as equivalent aluminium oxide (Al_2O_3), product clarity, solids content and pH as well as specific impurity limits. The specification also details some delivery and acceptance criteria. Product strengths and basic characteristics of the chemicals can be obtained from the Drinking Water Chemical Fact Sheets in Section V. The water authority may customise these specifications to suit their particular situations and risks.

The Specification should also clearly define the arrangements and responsibilities for ensuring the treatment chemical is not contaminated during transport or storage prior to transport.

Box 8.2 *Example specification for the supply and delivery of liquid alum to a water authority*

ALUMINIUM SULFATE (ALUM)– SPECIFICATION REFERENCE

This specification is for the supply and delivery of liquid aluminium sulfate ($Al_2(SO_4)_3.14H_2O$)to [*Name of water authority*] Sites. This specification is based on the NHMRC *Australian Drinking Water Guidelines* (2004), the American Water Works Association Standard for Aluminium sulfate – liquid, ground or lump (ANSI/AWWA B403-93) and the Water Chemicals Codex (NRC, 1982).

Liquid aluminium sulfate is not currently listed as Dangerous Goods.

REQUIREMENTS

Material Safety Data Sheets (MSDS)

The successful Tenderer must supply a current MSDS with a review date not exceeding five (5) years. The MSDS must, as a minimum, comply with the requirements of the National Occupational Health and Safety Council (NOHSC) MSDS Guidelines. Whilst the NOHSC-MSDS format is preferred, alternative formats exceeding the level of information required by NOHSC-MSDS Guidelines are acceptable.

Liquid aluminium sulfate clarity

Liquid aluminium sulfate shall be of such clarity as to permit the reading of flow measuring devices without difficulty.

Content of aluminium

The water soluble aluminium content of liquid aluminium sulfate is expected to be greater than or equal to 4.23% of Al, or to fall within the range of 7.5 to 8.0 % as $Al_2(SO_4)_3$.

Suspended Solids

In liquid aluminium sulfate, it is expected that the level of suspended solids is below 0.2%.

pH

The pH of liquid aluminium sulfate is expected to fall within the range of 2.3 to 2.8 pH units.

Specific Impurity Limits

It is expected that the total water-soluble iron (expressed as Fe_2O_3) content of liquid aluminium sulfate shall be no more than 0.35%.

The level of contamination of the liquid aluminium sulfate shall be such that compliance with the recommended maximum impurity content (RMIC) values from Table 8.4 in the NHMRC *Australian Drinking Water Guidelines* is achieved. The RMICs, in mg/kg, for $Al_2(SO_4)_3$ are:

Box 8.2 *Example specification for the supply and delivery of liquid alum to a water authority (continued)*

Impurity	Dose: 20 mg/L	Dose: 60 mg/L	Dose: 120 mg/L
Arsenic	16.5	5.5	2.7
Cadmium	4.7	1.6	0.8
Chromium	117.5	39.2	19.6
Lead	23.5	7.8	3.9
Mercury	2.4	0.8	0.4
Selenium	23.5	7.8	3.9
Silver	235	78	39

VERIFICATION

Quality Assurance

The supplier is expected to possess a Quality System that facilitates the tracking of product from raw material to delivery. [Name of water authority] may audit this Quality System to verify the correctness of information relating to the purchased product. In addition, [Name of water authority] may sample the purchased product at the point of destination to verify the quality of the supplied product.

Liquid Alum Samples

If [Name of water authority] elects to sample the product at the point of destination, the sampling procedure outlined in the American Water Works Association Standard for Aluminium Sulfate – Liquid, Ground, or Lump (ANSI/AWWA B403-93) will apply.

Nonconforming Product

If [Name of water authority] discovers that the aluminium sulfate delivered does not meet the requirements of this specification, a notice of nonconformance will be issued to the supplier through the [Name of water authority]'s Quality System, within ten working days of the receipt of the goods.

A nonconformance will also be issued if deficiencies are detected during any audit of the supplier's Quality System.

DELIVERY

Liquid

Marking, packaging and shipping of aluminium sulfate shall comply with AS 3780-1994 *The Storage and handling of corrosive substances,* and current federal, State, Territory, and local regulations.

The carrying vessel shall be in a suitable condition for hauling liquid aluminium sulfate and shall not contain any substances that might affect the use or usefulness of the liquid aluminium sulfate in treating potable water or in treating wastewater.

Contamination

Bulk or semi-bulk containers shall be carefully inspected prior to loading of the chemical by the supplier to ensure no contaminating material exists.

The supplier must have a system in place to ensure that liquid aluminium sulfate is not contaminated by any other product. This may involve implementing a specific cleaning regime between loads or the dedication of tankers or containers to only one type of product.

Certificate of Weight

[Name of water authority] may require that weight certificates accompany bulk shipments from a certified weigher or [Name of water authority] may check the weights on delivery.

Affidavit of Compliance

[Name of water authority] requires an affidavit from the manufacturer or supplier that the aluminium sulfate furnished according to *[Name of water authority]*'s order complies with all applicable requirements of this specification. *[Name of water authority]* also requires that the supplier provide a certified analysis of the aluminium sulfate. *[Name of water authority]* may also elect to use in-house analytical equipment to analyse the product to ensure compliance with this specification.

Documentation

A copy of the order, the delivery docket, and the affidavit of compliance and/or the record of certified analysis will accompany the delivery of aluminium sulfate. This documentation shall be left in an appropriate location at the delivery point.

Further, a copy of the delivery docket is to accompany the invoice (with references to the delivery docket number), and forwarded to *[Name of water authority]*'s Accounts Department to facilitate timely payment of accounts.

8.7 Monitoring and analytical requirements

A quality-controlled system for management of drinking water treatment chemicals should be supported by appropriate testing and monitoring.

All chemicals used in water treatment should be tested, to check both the concentration of the active ingredients and the presence of contaminants relative to a specification. This is to ensure that the effectiveness of the treatment process, the quality of the water and the integrity of the assets are not compromised.

Requirements for testing by the manufacturer should be clearly defined in the specification, including testing methods. The amount, type of testing and whether NATA certified results from an external laboratory are required may need to be negotiated to achieve a solution that is both effective and affordable. Clear statements as to the testing methods should be included in the specification. The specification should require test results to be available prior to the chemical delivery being unloaded at the water authority's plant to allow operational staff on site to reject delivery if specified requirements are not met.

Various physical characteristics can also be examined as part of the quality assurance program. Table 8.3 lists simple suggested acceptance criteria for some water treatment chemicals that could be applied by operational staff on site at the treatment plant. These criteria rely on human senses or simple equipment.

Table 8.3 *Acceptance criteria for some water treatment chemicals*

Chemical	***Tests***	***Acceptance criteria***
Aluminium chlorohydrates	*Visual*	Clear, colourless liquid
	Specific gravity	1.32–1.35 at 25°C
	pH	*3.5–4.5*
Aluminium sulfate (alum)	*Visual*	Clear colourless to pale brown (free of solids)
	Specific gravity	1.28–1.34 at 20°C
	pH	*2.3–2.8*
Ammonia	*Visual*	Colourless gas or liquid
	Specific gravity	*0.8 as a liquid*
Ammonium sulfate	*Visual*	Off-white crystal
	Specific gravity	*1.77 at 20°C*
Calcium hydroxide (hydrate lime)	*Visual*	Soft, white crystalline powder
	Solubility	0.165g/100g of saturated solution at 20°C
	Bulk density	*450–560 kg/m^3*
Calcium hypochlorite	*Visual*	White crystalline solid, practically clear in water solution
	Specific gravity	*2.35 in liquid*
Calcium oxide (quick lime)	*Visual*	Grey-white solid (sometimes yellowish to brown)
	Specific gravity	3.2 – 3.4 as calcium hydroxide
	Bulk density	*1030 kg/m^3 (pebble); 1050 kg/m^3 (powder)*
Carbon, powder activated, granular activated	*Visual*	Black solid (PAC 20-50 µm; GAC 0.7 – 1.2 mm)
(PAC/GAC)	*Density*	*250–600 kg/m^3*
Copper sulfate	*Visual*	*Blue crystal, crystalline granule or powder*
Ferric chloride	*Visual*	Brownish-yellow or orange crystalline form
	Specific gravity	42% solution: 1.45 at 20°C
	pH	*42% solution: 1–2*
Ferric sulfates	*Visual*	Yellow crystal or greyish-white powder, or a red-brown liquid solution.
	Specific gravity	*Liquid solution: 1.5–1.6*

Table 8.3 *Acceptance criteria for some water treatment chemicals (continued)*

Hydrochloric acid	*Visual*	Clear colourless to clear yellow (free of solids)
	Specific gravity	28% solution: 1.14 at 20°C
Hydrofluorosilicic acid (fluorosilicic acid)	*Visual*	Colourless to pale yellow liquid
	Specific gravity	*22% solution: 1.18 at 20°C*
Hydrogen peroxid	*Visual*	Colourless syrupy liquid (concentrations from 20% to 60%)
	Specific gravity	1.07–1.24 at 20°C
	pH	*1–4*
Hydroxylated ferric sulfate	*Visual*	Translucent, dark red (free of solids)
	Specific gravity	1.45–1.6 at 25°C
	pH	*< 2*
Polyacrylamides	*Visual*	*White crystalline solid, supplied as a powder or aqueous solution, dispersed in light mineral oil*
Polyaluminium chlorides (10%)	*Visual*	Pale yellow, slightly cloudy liquid
	Specific gravity	1.18–1.22 at 20°C
	pH	*10% solution: 2.2–2.8*
Polyaluminium silica sulfates	*Visual*	Slightly cloudy liquid, clear to yellow (free of solids)
	Specific gravity	1.32–1.36 at 25°C
	pH	*2.8–3.6*
Potassium permanganate	*Visual*	*Odourless, dark purple crystal with blue metallic sheen*
Sodium aluminates	*Visual*	White powder, or clear colourless to pale amber liquid
	Specific gravity	Liquid solution: 1.4–1.6
	pH	*Liquid solution: 14*
Sodium bicarbonate	*Visual*	White powder or crystalline lumps, soluble in water (60 g/L at 20°C)
	Specific gravity	2.159 at 20°C
	Solubility	96 g/L at 20°C
	Bulk density	1000 kg/m3
	pH	*10 g/L solution: 8.4*
Sodium carbonate (soda ash)	*Visual*	Greyish-white powder
	Bulk density	*1000 kg/m^3 (dense); 500 kg/m3 (light)*
Sodium fluoride	*Visual*	White, odourless powder (or crystal), easily soluble in water
	Specific gravity	2.78 at 20°C
	Bulk density	1040 – 1440 kg/m^3
	pH	*1% solution - 6.5* *4% solution - 7.6*
Sodium fluorosilicate	*Visual*	White or yellowish white, odourless, crystalline powder
	Bulk density	*880 – 1150 kg/m^3*
Sodium hexametaphosphate	*Visual*	White granular powder
	Bulk density	*800–1500 kg/m^3*
Sodium hydroxide (caustic soda)	*Visual*	White, deliquescent solid)
	Specific gravity	*30% solution: 1.33* *46% solution: 1.48*
Sodium hypochlorite	*Visual*	*Pale yellow green*
Sodium silicate	*Visual*	*Lumps of greenish glass, white powders of varying degrees of solubility, or cloudy or clear liquids of varying viscosity*
Sodium tripolyphosphate	*Visual*	White powder or granular solid
	pH	*9.8 (aqueous solution) to 10.5 (slurry)*
Sulfuric acid	*Visual*	Dense, oily, colourless to dark brown liquid.
	Specific gravity	1.2–1.85 at 20°C
Zinc orthophosphate	*Visual*	*Clear odourless liquid*

8.8 Contaminants in drinking water treatment chemicals

All chemicals used in the treatment of drinking water should be evaluated for potential contaminants and limits should be included in the specification. The fact sheets for the individual treatment chemicals (see Section V) identify potential contaminants for each chemical. Additional information may also be available from suppliers' specifications or from certification analyses that have been performed for overseas accreditation systems.

The determination of contaminants in drinking water treatment chemicals should be carried out by an independent laboratory accredited to undertake the necessary assays. An appropriate laboratory approved by National Association of Testing Authorities (NATA) should be identified, in consultation with the relevant State or Territory regulatory authority. A list of NATA-approved laboratories is available online[2].

In developing appropriate specification limits for contaminants a more detailed systematic assessment of potential contaminants using a Recommended Maximum Impurity Concentration (RMIC) approach is recommended. The initial approach uses the principle that no contaminant in a particular chemical should add more than 10% of that allowable by the NHMRC *Australian Drinking Water Guidelines* health value. For each contaminant, this involves:

- calculating from the health guideline value the maximum concentration allowable in the treated water as a result of being dosed with the bulk chemical. In some situations a stricter value than the health guideline may be warranted if the contaminant is known to cause aesthetic problems or the water authority wishes to carry a lower risk level.
- Based on the expected maximum dose of chemical and its strength, calculate the RMIC for each contaminant (mg/kg of solution).

A sample calculation for determining the RMIC of lead in Alum is provided in Box 8.3.

Box 8.3 *Sample calculation for determining the lead recommended maximum impurity concentration in Alum*

The following is a sample calculation for the derivation of a Recommended Maximum Impurity Concentration (RMIC) for lead in Alum and is based on the NHMRC guideline value for lead in drinking water of 0.01 mg/L. The maximum amount of lead (in mg/L) that may be added to drinking water through the use of alum is determined through the following three steps:

(1) Derivation of the maximum amount of lead that can be added to drinking water through Alum:

$$\frac{0.01}{10} = 0.001 \; mg/L$$

Where:

- 0.01 mg is the NHMRC guideline value for lead; and
- 10 is the percentage of the guideline value considered an acceptable source of contamination in the drinking water (a safety factor of 10 is considered a reasonable contribution by a given impurity in a water treatment chemical).

(2) Derivation of the amount of Alum that will contain 0.001 mg lead:

In the case of the maximum Alum dose of 80 mg/L(1), with a solution strength of 43 % w/w [$Al_2(SO_4)_3.14H_2O$];

$$\frac{80 \; mg/L}{0.43} = 186 \; mg$$

Where:

- 80 mg/L is the dose of the drinking water treatment chemical (e.g. Alum); and
- 0.43 is the solution strength of the drinking water treatment chemical (e.g. Alum – 43%)

(3) Derivation of the RMIC for Alum at the plant:

$$\frac{1 \times 10exp6}{186 \text{ mg}} \times 0.001 \; mg/L = 5.4 \text{ mg. } lead \; / \; kg \; of \; Alum \; solution$$

Where:

- 1×10^6 is the number of milligrams in a kilogram;
- 186 mg is the amount of Alum solution that will contain 0.001 mg of lead
- 0.001mg/L is the maximum amount of lead per litre that can be added through the Alum dose

Footnote

(1) The dose of 80 mg/L alum is based on the water treatment plant being designed to regularly treat dirty water events under an enhanced coagulation mode. If the plant was designed to treat low turbidity water for particle removal only, the maximum alum dose may be as low as 10 mg/L which would give an RMIC of 43.2 mg/kg for lead at this plant.

[2] http://www.nata.com.au/fs_directory.htm

RMICs calculated by the water authority should be used as the minimum basis for chemical specifications. Water authorities are encouraged to use tighter specification values where these can be easily achieved cost effectively. These calculated RMICs should never be seen as a license to degrade the purity of the drinking water treatment chemical.

To assist water authorities in this process, Table 8.4 contains RMICs for a selected number of contaminants which have NHMRC health guideline values. RMICs have been calculated for some of the more common treatment chemicals, typical maximum dose rates and chemical bulk concentrations. RMICs have not been determined for contaminants which have not been identified in the fact sheet for an individual treatment chemical. Aluminium sulfate has been used to illustrate the principle of applying different maximum doses to determine RMIC.

Some treatment chemicals may also contain known contaminants for which there are only aesthetic NHMRC guideline values. RMICs approach can also be used to calculate these contaminants where appropriate.

Where there is no NHMRC Drinking Water Guideline health value for an identified contaminant, water authorities may be able to determine a RMIC based on a review of overseas drinking water guidelines (eg. WHO, US EPA, EEC, the Chemical CODEX etc). If no RMIC can be calculated from a recognised drinking water guideline value then the principle of due diligence would encourage a water authority to maintain concentrations as low as practicable.

Where suppliers are unable to meet the RMIC, then the water authority should examine what levels of the contaminant are reaching consumers to determine if a higher concentration can be tolerated in the treatment chemical without significantly changing the risk of not meeting the NHMRC Drinking Water Guideline value. This analysis should attempt to identify other significant sources of the contaminant, its variability over time and all expected operational conditions. If a higher contaminant level in the bulk chemical is acceptable (i.e. contributes more than 10% of the guideline value) then water authorities should consider whether there is a need for additional controls specifically for that contaminant in the chemical specification, contractual procurement arrangements, treatment plant operations, and monitoring through to consumers taps.

Table 8.4 *Example – some recommended maximum impurity concentrations for some drinking water treatment chemicals*

IMPURITY			Antimony	Arsenic	Barium	Cadmium	Chromium	Copper	Cyanide	Fluoride	Lead	Mercury	Nickel	Selenium	Silver
		NHMRC Health Guideline Value (mg/L)	0.003	0.007	0.7	0.002	0.05	2	0.08	1.5	0.01	0.001	0.02	0.01	0.1
Treatment Chemical	Chemical	Example doses (mg/L)													
Aluminium chlorohydrate	23	100 (as Al_2O_3)	0.7	1.6	161	0.5	11.5	460		345	2.3	0.2	4.6	2.3	23
Aluminium sulfate (Alum)	47	20 (as $Al_2(SO_4)_3$)	7.1	16.5	1645	4.7	117.5	4700		3525	23.5	2.4	47	23.5	235
Aluminium sulfate (Alum)	47	60 (as $Al_2(SO_4)_3$)	2.4	5.5	548	1.6	39.2	1567		1175	7.8	0.8	15.7	7.8	78
Aluminium sulfate (Alum)	47	120 (as $Al_2(SO_4)_3$)	1.2	2.7	274	0.8	19.6	783		588	3.9	0.4	7.8	3.9	39
Calcium hydroxide	99	30 (as $Ca(OH)_2$)		23.1	2310	6.6	165			4950	33	3.3	66	33	330
Calcium hypochlorite	65	3 (as Cl_2)		151.7	15167	43.3	1083.3			32500	216.7	21.7	433.3	216.7	2167
Calcium oxide	10	500 (as CaO)		0.1	14	0.04	1			30	0.2	0.02	0.4	0.2	2
Chlorine	100	3 (as Cl_2)		233.3							333.3	33.3			
Copper sulfate	25.5	1 (as $CuSO_4.5H_2O$)		178.5							255		510		
Ferric chloride	42	120 (as $FeCl_3$)	1.1	2.5		0.7	17.5	700	28		3.5	0.4	7	3.5	35
Ferric sulfate	20	100 (as $Fe_2(SO4)_3$)	0.6	1.4		0.4	1	400	16		2	0.2	4	2	20
Hydrochloric acid	33	5 (as HCl)	19.8			13.2	330				66		132		
Hydrofluorosilicic acid	16	1.5 (as F)		74.7		21.3					106.7				
Hydroxylated ferric sulfate	12.5	100	0.4	0.9		0.3	6.3	250	10		1.3	0.1	2.5	1.3	13
Polyaluminium chloride	10	100 (as Al_2O_3)	0.3	0.7	70	0.2	5	200		150	1	0.1	2.0	1	10
Potassium permanganate	99	1 (as $KMnO_4$)				198	4950					99			
Sodium fluoride	45	1.5 (as F)	90			60					300				
Sodium Fluorosilicate	60	1.5 (as F)	120			80									
Sodium hydroxide	50	10 (as NaOH)	15			10	250				50	5	100		
Sodium hypochlorite	12	3 (as Cl_2)				8						4	80		
Sulfuric acid	98	5 (as $H2SO_4$)	58.8	137.2	13720	39.2	980	39200		29400	196	19.6		196	

8.9 Useful contacts

AUSTRALIAN GOVERNMENT

National Health and Medical Research Council
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Australian Safety and Compensation Council (ASCC)
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National Industrial Chemicals Notification and Assessment Scheme (NICNAS)
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Office of Chemical Safety
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Workplace Health and Safety
Department of Industrial Relations
GPO Box 69
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PO Box 6 Rundle Mall
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Environment Protection Authority
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Standards Australia Limited
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American Water Works Association (AWWA) 6666 W. Quincy Ave Denver, CO 80235 USA	Internet: http://www.awwa.org/
Codex Alimentarius Commission Viale delle Terme di Caracalla 00100 Rome, Italy	Internet: www.codexalimentarius.net/
International Organization for Standardization (ISO) 1, rue de Varembé, Case postale 56 CH-1211 Geneva 20 Switzerland	Internet: http://www.iso.org/iso/en/ISOOnline.frontpage
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World Health Organization Water, Sanitation and Health Programme Avenue Appia 20 1211 Geneva 27 Switzerland	Tel: (+ 41 22) 791 21 11 Internet: http://www.who.int/water_sanitation_health/en/

8.10 Acknowledgments

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8.11 References

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McEwen JB (ed). American Water Works Association (AWWA) Research Foundation/International Water Supply Association (IWSA), Denver, Colorado, 73–122.

National Registration Authority for Agricultural and Veterinary Chemicals (1996). *The Requirements Manual for Agricultural Chemicals*. National Registration Authority, Canberra.

DEVELOPMENT OF CHAPTER 8 TO THE *AUSTRALIAN DRINKING WATER GUIDELINES*

In 1988, the NHMRC endorsed the "*Guidelines for Clearance of Water Treatment Chemicals and Processes*". These guidelines outlined the data requirements for drinking water treatment chemicals assessment, and provided a standardised approach to the assessment of their safety and efficacy. However, they were not regulatory requirements and relatively few chemicals were evaluated under the guidelines. Since the mid 1990s there has not been a practical mechanism for the national assessment and approval of drinking water treatment chemicals in Australia.

In order to initiate a national approach, in 2000 the NHMRC's Health Advisory Committee established the Drinking Water Treatment Chemicals Working Party. The primary aim of the Working Party was firstly, to protect public health and the aesthetic quality of drinking water by ensuring chemicals used to produce potable water are safe and appropriate for the purpose, and secondly, to provide the water industry with guidance on drinking water treatment chemicals. The Working Party's remit was to develop guidelines for the assessment of chemicals used in drinking water treatment processes, to use these guidelines to assess drinking water treatment chemicals, and make recommendations to the NHMRC concerning acceptability of chemicals for treating drinking water.

MEMBERSHIP OF THE NHMRC DRINKING WATER TREATMENT CHEMICALS WORKING PARTY

Prof Michael Moore (Chair)	National Research Centre for Environmental Toxicology
Dr Peter Di Marco	Health Department of Western Australia
Mary Drikas	South Australian Water Corporation
Dr Jim Fitzgerald	Department of Human Services, South Australia
Dr Peter Mosse	Gippsland Water
Colin Nicholson	Sydney Water Corporation
Phil Callan (Secretary)	National Health and Medical Research Council

TERMS OF REFERENCE OF THE NHMRC DRINKING WATER TREATMENT CHEMICALS WORKING PARTY

The NHMRC Working Party on Drinking Water Treatment Chemicals, reporting to the NHMRC/ARMCANZ Drinking Water Review Coordinating Group will:

1. Develop Australian Guidelines for the Assessment of New and Existing Drinking Water treatment chemicals, taking into consideration the NHMRC "Guidelines for Clearance of Water Treatment Chemicals and Processes" (NHMRC 1988) and other national and international guidelines;
2. Develop and recommend ways to implement procedures for the continued assessment and approval of new and existing drinking water treatment chemicals through the NHMRC, including mechanisms for a fee-for-service schedule for new chemicals;
3. Undertake a systematic rolling-revision of toxicology and public health aspects of water treatment chemicals in the existing NHMRC list of approved chemicals, taking into consideration chemical mixtures, aesthetics and chemical by-products;
4. Undertake extensive public consultation to ensure broad community acceptance of a national assessment and approval process; and
5. Develop a dissemination and implementation strategy for the adoption of the approved list of drinking water treatment chemicals.

In order to develop chapter 8 to the *Australian Drinking Water Guidelines*, the Working Party required an understanding and assessment of existing international policies, regulations and guidelines relevant to drinking water treatment chemicals. The Working Party prepared a comprehensive assessment report of a systematic comparative analysis of existing national and international practices, including toxicological assessment reports on a range of drinking water treatment chemicals. The report summarises the regulatory frameworks under which drinking water treatment chemicals are assessed, and describes and compares the policies and procedures used by various national and international organisations for:

- evaluating the public safety of chemicals used to treat drinking water; and
- approving the use of such chemicals.

A copy of the report, *Overview of National and International Guidelines and Recommendations on the Assessment and Approval of Chemicals Used in the Treatment of Drinking Water* is available at http://www.nhmrc.gov.au/publications/_files/watergde.pdf

This report was used by the Working Party as the basis for the development of Chapter 8.

PUBLIC CONSULTATION ON CHAPTER 8 TO THE AUSTRALIAN DRINKING WATER GUIDELINES

Consultation on Chapter 8 included a call for submissions on the draft guidelines in February 2005. The call for submissions was publicised in the *Commonwealth Notices Gazette*, *The Weekend Australian*, and invitations were forwarded to known interested parties through the enHealth Council, the Australian Water Association and Water Services Association of Australia.

All submissions received during the consultation were taken into consideration in finalising these Guidelines. Comments were considered by the relevant working party and the NHMRC Drinking Water Treatment Chemical Working Party.

Submissions were received from the following individuals/organisations:

Mr Tony Griggs	
Mr N. F. McLeod	
Mr G. S. R. Walker	
Mr Eddy Ostarcevic	
Mr Peter L Rome	
Mr David McRae	Water Quality Australia (Barwon Southwest Chapter)
Dr Roscoe Taylor	Dept Health and Human Services, Hoba
Mrs Patricia Wheeldon	
Mr Ken Scifleet	
Mrs Lyn C James	
Mr G. S. Smith	
Mr Philip Robertson	
Mr J. T. Webber	Safe Water Association of NSW
Glenn Collins	Melbourne Water
Mr Rodney Hearne	
Mr Victor di Paolo	Dept Human Services (Victoria)
Ms Anne Woolley	Dept Natural Resources and Mines (QLD)
Tim Nightingale	Hardman Australia
Mr P Dharmabalan	
Mr Colin Nicholson	Sydney Water
Diana Buckland	MCS-Global

PART III MONITORING

Chapter 9 Overview of Monitoring

Chapter 9 Overview of monitoring

9.1 Introduction

The Framework approach to drinking water quality management outlined in Chapters 2–4 is based on a preventive strategy which focuses attention on total system management. A key aspect of this approach is monitoring programs to verify that the barriers and the system as a whole are working effectively to deliver safe water. Monitoring includes:

- ***Operational monitoring***, which is used to check that the processes and equipment that have been put in place to protect and enhance water quality are working properly. The data are used, if necessary, as a trigger for immediate short-term corrective action to improve water quality, but they are generally not used for assessing conformance with the *Australian Drinking Water Guidelines* (ADWG) or compliance with agreed levels of service. Further information on operational monitoring is provided in Section 3.4.2.
- ***Drinking water quality monitoring***, which is a wide-ranging verification of the quality of water in the distribution system and as supplied to the consumer. The data are used for assessing conformance with the ADWG or compliance with agreed levels of service and/or regulations and, if necessary, as a trigger for corrective action to improve water quality. Background information on drinking water quality monitoring is provided in Section 3.5.1.
- ***Monitoring of consumer satisfaction***, which is an assessment of consumer comments and complaints. It can provide valuable information on potential problems that may not have been identified by performance monitoring of the water supply system. Background information on monitoring of consumer satisfaction is provided in Section 3.5.2.
- ***Investigative and research monitoring***, which includes strategic programs designed to increase understanding of a water supply system, to identify and characterise potential hazards, and to fill gaps in knowledge. It includes baseline and emergency response monitoring. Background information on investigative and research monitoring is provided in Section 3.9.1.

The requirements for each of these types of monitoring differ in terms of water quality characteristics to be measured, sampling location and frequency of sampling. For example, operational monitoring will be frequent and undertaken immediately after water has been treated. Monitoring for investigative and research purposes would be less frequent. Further information on monitoring, including QA/QC and occupational health and safety considerations is also available in the NWQMS *Australian Guidelines for Water Quality Monitoring and Reporting* (2000).

9.2 Developing a monitoring program

Monitoring programs should be developed, detailing the strategies and procedures to follow for monitoring the various aspects of the water supply system. The monitoring plans should be designed by personnel experienced in the assessment of water quality, and should be fully documented. The plans should include the following information:

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

Programs should be designed to cover both random and regular variations in water quality, and to give information representative of the quality of water supplied to consumers. For example, water quality is usually tested by taking samples of water from points in the system and analysing them either in an analytical laboratory or on site. It is important that the results of these tests are representative of all the water throughout the system, including the water that is there between sampling events. Also, sampling must be frequent enough to enable the program to provide meaningful information. Box 3.4 (see Section 3.5.1) details what is needed to ensure that monitoring is representative, reliable and fully validated.

Monitoring programs and the key characteristics to be monitored should be reviewed periodically, and altered where necessary.

9.3 Surrogates and indicators

Some of the more common water quality characteristics can sometimes serve as surrogates or indicators for characteristics that are less common or for which testing is more difficult and expensive. For example, conductivity is a widely used surrogate for total dissolved solids (TDS). Similarly, trihalomethanes (THMs), which are the most common disinfection byproducts and occur in the highest concentrations, serve effectively as a surrogate for a range of related byproducts. Table 9.1 shows a number of indicators, both physical and microbial, that can be incorporated as part of the risk management approach outlined in Chapters 2–4.

Table 9.1 *Examples of water quality indicators*

Hazard or hazardous events	Indicator
Faecal contamination of source water	• Sanitary survey
	• Turbidity
	• *Escherichia coli* (or thermotolerant coliforms)
Treatment failure	• Turbidity/particle size distribution
	• Free chlorine
	• Total coliforms
	• Heterotrophic plate count (HPC)
	• *Escherichia coli* (or thermotolerant coliforms)
Faecal contamination from ingress	• Ammonia
	• Enterococci
	• *Escherichia coli* (or thermotolerant coliforms)
	• Sudden change in dissolved oxygen, free chlorine or pressure
Water stagnation	• Loss of disinfectant residual
	• Dissolved oxygen
	• Heterotrophic plate count (HPC)
	• Total coliforms
Disinfection byproducts	• Trihalomethanes

Baseline and trend assessment monitoring should be used to establish and affirm such associations. Where surrogate monitoring is possible, control of the surrogate to low levels increases the assurance that objectionable characteristics associated with it are either absent or reduced.

9.4 Collection and analysis of samples

If the data collected are to be meaningful, it is vital that samples are collected from appropriate locations (as discussed above), by trained personnel working to a predetermined plan, and that procedures employed in the collection, preservation and transport of samples to the laboratory are chosen with regard to the characteristic being measured.

It is important that the results obtained in analyses are valid. In some cases, different methods of analysis can give different results. For each of the characteristics listed in the ADWG, a suggested method of analysis is given that will ensure consistent results are obtained. Other methods may be used, but they must be fully documented and validated, preferably through comprehensive inter-laboratory comparison programs, and must give results consistent with other standard methods being used.

Specific details regarding preservation of samples are given in the procedures in Part IV (Information Sheet 2.1 *Sampling procedures).*

Field testing

It is possible to acquire, at reasonable cost, robust basic chemical test kits for the common physical and chemical characteristics, including pH, colour, iron, manganese, turbidity, chlorine and fluoride. These test procedures are well within the capabilities of well-trained treatment plant operators. The test results will not have the standing of those produced by National Association of Testing Authorities (NATA) registered laboratories, but they do permit regular and frequent monitoring, and what the tests sometimes lack in precision and reliability is more than compensated for by the increased frequency of monitoring. Furthermore, such kits enable many tests to be performed in the field, thus avoiding the need to preserve and transport samples to a laboratory. Their use is encouraged, but should be regarded as complementary to, not a replacement for, more reliable laboratory tests.

Some tests, including those for dissolved oxygen, pH, temperature, free chlorine and combined chlorine, need to be done in the field. It is essential that those doing field testing are appropriately trained, and that a quality assurance program be in place to monitor testing performance.

Sampling procedures

Procedures for sampling physical and chemical characteristics, heavy metals, organic chemicals, pesticides and microbial characteristics are provided in Information Sheet 2.1 *Sampling information – handling requirements and preservation*.

9.5 Operational monitoring

9.5.1 CHARACTERISTICS TO MONITOR AND LOCATION

The characteristics selected as parameters for operational monitoring should:

- reflect the operational effectiveness of each process or activity
- provide an timely indication of performance
- be able to be readily measured and rapidly responded to.

To comply with these requirements, surrogates are often used as operational parameters, as described in Section 9.3. Examples of some of the parameters commonly used for operational monitoring are given in Table 9.2.

Table 9.2 *Examples of operational parameters*

	Treatment step/process					
Operational parameter	**Raw water**	**Coagulation**	**Sedimentation**	**Filtration**	**Disinfection**	**Distribution system**
pH		✓	✓		✓	✓
Turbidity (or particle count)	✓	✓	✓	✓	✓	✓
Temperature	✓		✓		✓	✓
Dissolved oxygen	✓					
Stream or river flow	✓					
Rainfall	✓					
E. coli (or thermotolerant coliforms)	✓				✓	✓
Total coliforms					✓	✓
Heterotrophic plate count (HPC)					✓	✓
Colour	✓					
Conductivity (total dissolved solids)	✓					
Alkalinity	✓	✓	✓			
Organic carbon	✓		✓			
Algae, algal toxins and metabolites	✓					✓
Chemical dosage		✓			✓	
Flow rate		✓	✓	✓	✓	
Net charge		✓				
Streaming current value		✓				
Headloss				✓		
C.*t*					✓	
Disinfectant residual					✓	✓
Disinfection byproducts					✓	✓
Hydraulic pressure						✓

C.*t* = a measure of disinfection concentration (C) and contact time (*t*)

9.5.2 FREQUENCY OF MONITORING

Operational parameters should be monitored often enough to reveal any failures in a timely fashion. Online and continuous monitoring should be used wherever possible, particularly at critical control points (see Section 3.3.2). For example, where filtration is used, continuous monitoring of turbidity (or particle count) from each individual filter and from the product water outlet of the plant are important to ensure that treatment is effective. For operational parameters that are deemed less critical or that are more stable, 'grab' samples may be sufficient.

9.6 Drinking water quality monitoring

9.6.1 MONITORING OF KEY CHARACTERISTICS

As it is neither physically nor economically feasible to test on an ongoing basis for all substances or organisms that may be present in water, monitoring effort and resources should be directed at significant or 'key' characteristics – that is, those characteristics that require frequent monitoring. Each water supply system will have its own key characteristics, and these need to be identified by evaluating the significance of all water quality characteristics within a water supply system. Key characteristics will also be different for each of the main component parts of the system, that is:

- raw water entering the supply system from a catchment, storage or bore field
- treated water leaving the plant
- distributed water in the reticulation system in major mains, service reservoir storages and reticulation mains
- water supplied to the consumer.

An initial survey to determine key characteristics should include chemicals used or present in the catchment, together with sufficient data to establish likely variations in concentration. Key characteristics should be measured as close to the water or contamination source as possible (as this is simpler to do and hence a more efficient use of resources), provided that the concentration does not change further down the system.

Key characteristics related to health will include:

- microbial indicator organisms
- any chemicals used in treatment processes and any byproducts that may result from their use
- any characteristic that can be reasonably expected to exceed the guideline value, even if only occasionally
- potential contaminants identified in catchment surveys
- pollutants likely to be present but not listed in the ADWG.

Key characteristics that are not related to health include characteristics with significant aesthetic impacts.

9.6.2 MONITORING ZONES

Large, complex reticulation systems should be divided into discrete zones or basins for the purposes of monitoring and reporting. Problem areas should be clearly identified. Although the following is not intended to be prescriptive, zones could be:

- divided in relation to their discreteness within the system (i.e. mainly serviced by a single main, water source or water treatment plant)
- identified as discrete geographical areas that can be recognised by supply operators and the community
- large enough so that the sampling frequency will yield sufficient results to provide reasonable confidence that water is of satisfactory quality (See Chapter 10).

9.6.3 WHAT AND WHERE TO MONITOR

From the water supplier's perspective, some characteristics such as microbial parameters may need to be monitored within the distribution system or at the boundary of the consumer's property. Many physical and chemical characteristics, however, do not change, or change only slowly, within the distribution system, and it is more efficient to analyse for these characteristics closer to the water source. The monitoring sites for each physical and chemical characteristic proposed in the ADWG have therefore been chosen on the basis that it is unlikely that the characteristic will change further into the distribution system.

In reticulated water supplies, physical and chemical water quality characteristics can be divided into different types for monitoring purposes, as shown in Table 9.3.

Table 9.3 *Monitoring required for different types of physical and chemical characteristics*

Characteristic	Examples	Type of monitoring required
Substances for which the concentration depends mainly on the concentration in the water entering the supply and is unlikely to vary in the distribution system	Arsenic, cyanide, fluoride (where fluoridation is not practised), hardness, pesticides, sodium, selenium, sulfate and total dissolved solids	Generally sufficient to sample either the raw water or the water going into the supply [a]
Substances that change in concentration within the distribution system	Aluminium, disinfection residuals and byproducts, iron, manganese, colour, turbidity, taste, odour and pH	Requires sampling the raw water and/or water in the distribution system
Substances for which the distribution system provides the main source	Corrosion products such as cadmium, chromium, lead, zinc and copper	Requires sampling from the distribution system

a – here two or more waters with different concentrations of the characteristics feed the same distribution system, additional sampling may be required within the distribution system.

Tables in Chapter 10 (Tables 10.7) provide a guide on what to measure, and where to measure it, for both operational and system performance purposes. Emphasis should be placed on monitoring those characteristics identified as key characteristics for a water supply system.

Choosing sampling locations

Sampling points must provide data that are representative of the water in that particular component of the system. To establish such points, short-term investigative monitoring programs may be needed. Samples should be included from:

- the raw (source) water
- the treatment plant (for process control, not performance assessment)
- the treated (finished) water
- the headworks of the distribution system
- service reservoirs
- representative fixed and/or random sample points within the distribution system
- points representative of the quality of water supplied to consumers
- consumers' taps for specific investigations (e.g. investigation of corrosion products or to verify distribution sampling points)
- points where previous samples have revealed unsatisfactory water quality.

Routine distribution samples may be taken from either fixed or random sample points. For trend assessment, water from a series of fixed points (to overcome spatial variability) should be tested at regular intervals, and this should be complemented by random samples.

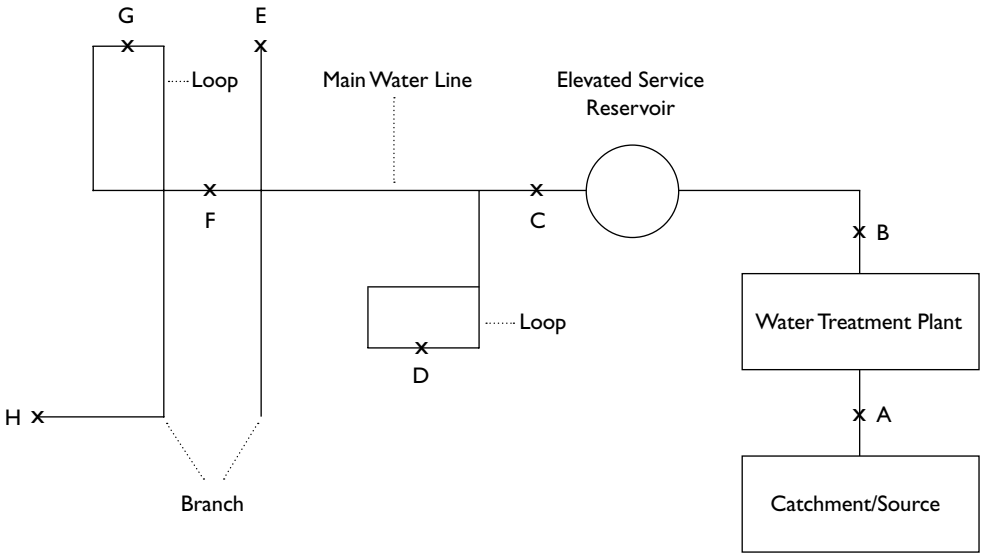
When selecting sample points within the distribution system, the following factors should be considered:

- The distribution of sample points throughout the system, including the extremities, must reflect the numbers of people supplied by the different parts of the system, especially for systems drawing on surface water. For instance, if five per cent of consumers are serviced by distribution loops, then five per cent of samples should be taken from distribution loops.
- Water quality in a given pressure zone can be affected by the specific conditions in that zone; therefore, each pressure zone must be adequately monitored.
- When a system has more than one water source, the location of sample points must be in relative proportion to the number of people served by each source, and sample points must be located at the entry points to the system for the different sources. Similarly, systems with one source and more than one treatment plant must be sampled at the entry point from each plant to the system. Any areas where supply is likely to alternate between different sources should be sampled, as such changes may be noticeable to the consumer and be a source of complaint.
- If a service reservoir has no sampling tap, a sample point should be located sufficiently close to the reservoir to represent the water quality within the reservoir.

The system in Figure 9.1 is representative of a town with a population of approximately 5000 people with one source of water. A similar approach should be used by larger authorities to determine sampling points within supply districts of larger schemes. The selected sample points used in this example would satisfy the requirement to sample as close as practicable to the point of use, and to sample over the whole water supply system.

Figure 9.1 *Example of a water distribution system for 5000 people*

- Point A is representative of the quality of raw water.
- Point B is representative of the quality of water leaving the treatment plant.
- Point C is representative of the water quality within the elevated service reservoir.
- Points D and G are representative of water quality in a distribution loop such as in a sub-development.
- Points E and H are representative of the water quality in a branch line or a branch line dead end.
- Point F is representative of water in the main line.
- Points D to H are representative of the quality of water supplied to consumers.



9.6.4 WHEN AND HOW OFTEN TO SAMPLE

How often a key characteristic should be sampled will depend on its variability, and whether it is of aesthetic or health significance. Sampling and analysis are required most frequently for microbial constituents, and less often for health-related organic and inorganic compounds. A thorough appraisal should be made when a new water source is used and immediately following any major change in treatment processes.

For both the initial baseline survey and the ongoing monitoring program, sufficient samples must be collected over a representative period to enable the data for each characteristic to be statistically evaluated, significant trends or changes identified, and performance against the ADWG assessed. The number of samples required depends on the desired level of precision with a known degree of confidence. Generally the closer the mean value of a characteristic is to the guideline value, and the greater its variability, the greater the number of samples required to assess performance (see Information Sheet 3.3).

For small supplies it may take several years to accumulate sufficient data for statistical evaluation.

Minimum sampling frequencies are given in the monitoring tables included in Chapter 10. The frequencies are suggested minimums only; local knowledge and experience based on the variability of different characteristics and the size of the water supply scheme may dictate different frequencies. Individual water supplies need to work out their own monitoring needs; however, the minimum sampling frequency recommended for most key physical and chemical characteristics is monthly when the population serviced is greater than 5000, and six-monthly for smaller populations.

Consideration should be given to the use of cost-effective surrogate characteristics as indicators of overall water quality, as discussed above (see Section 9.3).

9.7 Monitoring of consumer satisfaction

The performance of a water supply system over time is an important issue for consumers. System performance is often judged by the degree of consumer satisfaction with the quality of the supply, together with the results of analytical tests for a variety of water quality characteristics.

Consumer satisfaction is a significant consideration and will be determined by a number of factors, including:

- the consumer's own assessment of water quality, based on taste, odour and appearance
- information provided by water and health authorities
- confidence in the existing processes for providing information and dealing with water quality issues.

Consumer satisfaction with the quality of water is largely based on people's judgment that the physical quality of water at their tap is 'good' - that it is colourless and free from unpleasant taste and odour. From the consumer's point of view, changes from the norm are particularly noticeable. At present there are no guidelines for consumers' overall impressions or perceptions of physical water quality. It is important to realise that consumer satisfaction may have a regional or even local context, and that it needs to be negotiated at this level.

Experience from major water suppliers indicates that consumer satisfaction has the following characteristics:

- Consumer complaints and concerns about 'healthiness' are driven more by sudden noticeable changes in quality, particularly in taste, odour, colour and turbidity, than by the long-term average.
- Taste and odour associated with disinfectants are tolerated up to a point because they are associated with the protection of public health, although concerns sometimes arise about the health effects of added chemicals.
- It is unrealistic to expect to achieve complete satisfaction. It is unlikely that more than 90 per cent of consumers will give a 'good to excellent' rating on taste and odour.
- The bulk of consumer complaints relate to taste and odour, discolouration and stained washing, many of which stem from household plumbing or are very localised. It is the unusual complaints such as the fishy smell generated by the presence of certain algae in the water, or blue discolouration due to corrosion of the consumer's copper service pipes, which may have much wider implications for the water supply system, and these require immediate attention.

The physical characteristics of water quality are largely surrogate descriptors, in that no single characteristic really measures what the consumer perceives. It may therefore be appropriate to negotiate levels of service or set internally a more direct measure of consumer acceptance, such as complaint rates for taste, odour and appearance based on local circumstances. Some examples of objectives that could be used are:

- to achieve fewer than four water quality complaints per thousand households per year for unfiltered (but disinfected) supplies, and fewer than two water quality complaints for filtered supplies
- to obtain a 'good to excellent' score for water quality at the tap from more than 80 per cent of consumers.

9.8 Investigative and research monitoring

Investigative and research monitoring can be used to increase understanding of a water supply system, identify and characterise potential hazards, and fill gaps in knowledge. By improving understanding of the factors affecting water quality characteristics, such monitoring allows suppliers to anticipate periods of poor water quality and respond to them effectively.

9.8.1 BASELINE MONITORING

Baseline monitoring of all new water supplies and of potential water supplies under consideration is imperative in order to:

- define the key characteristics that should be measured routinely
- identify major water quality problems
- provide an indication of the need for water treatment
- establish a base for assessing long-term trends and variability in water quality
- compare and select source waters for future supply.

In the absence of other data or information, baseline monitoring should be carried out for all health-related characteristics listed in the ADWG. Exceptions may be some chemicals not reasonably expected to be present or for which sampling is not practicable.

Initial baseline monitoring should be carried out for new water supplies as a basis for ongoing monitoring. Baseline monitoring of new water supplies and those not previously sampled should include sampling to characterise the radiological quality of the water supply. The extent of sampling and the timeframe required to make a baseline assessment will depend on land use in the catchment, levels of pollution found and variability or trends in water quality.

An initial land-use survey of the catchment should be undertaken to:

- identify existing and planned developments
- assess potential continuous, intermittent or seasonal pollution patterns
- assess geological features likely to affect water quality
- identify chemicals used in catchments
- locate existing or abandoned waste-disposal or mining sites.

Where catchments and supplies are beyond the water supplier's jurisdiction, exchange of information and collaborative assessment of the quality of source waters is strongly advocated.

Initial investigative monitoring has a number of limitations:

- not all potential water quality problems may be recognised and long-term trends or variability in water quality may be difficult to anticipate
- the comprehensiveness of baseline and follow-up monitoring may be limited by the available human or laboratory resources
- the impacts for harvesting, storage, treatment and distribution of water may not be fully appreciated.

Nevertheless, it is essential that an attempt be made to characterise source waters before they are used for water supply. If sampling is initiated only when the supply is commissioned, major water quality problems that might otherwise have been anticipated could result in long-term operational problems.

An existing sampling database makes a good starting point for establishing a baseline. The baseline, however, will change as land use changes, and new characteristics may need to be monitored. Follow-up sampling regimes are required to assess significant changes in water quality arising from:

- impacts of water abstraction (this is particularly important for water from unconfined aquifer systems)
- changed land-use practices
- longer term natural variability in water quality that may not have been evident from initial baseline monitoring.

9.8.2 EMERGENCY RESPONSE MONITORING

The frequency of monitoring should be increased in response to any emergency or incident. Emergency incident plans need to take into consideration the capability and availability of water and laboratory personnel.

9.9 References

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Chapter 10 Monitoring for specific characteristics in drinking water

Chapter 10 Monitoring for specific characteristics in drinking water

10.1 Introduction

This chapter discusses monitoring for specific characteristics or specific situations. It covers microbial indicators (Section 10.2), physical and chemical characteristics (Section 10.3), radiological characteristics (Section 10.4) and small water supplies (Section 10.5). The chapter also provides a summary of guideline values for monitoring and sampling frequency (Section 10.6), evaluating results (Section 10.7) and a series of summary tables (Section 10.8).

10.2 Microbial monitoring

Routine monitoring for specific pathogens is not recommended. Monitoring of specific bacterial, viral and protozoan pathogens is usually complex, expensive and time consuming, and may fail to detect their presence. It may take days-weeks to determine whether a sample contains a particular pathogen. For these reasons results cannot generally be used to support day-to-day management of water quality. Microbial monitoring under the risk management approach is used for operational purposes and as a final check to verify water quality. Monitoring for microbial indicator organisms, which is relatively simple and inexpensive, is used for this purpose. *E.coli* (or thermotolerant coliforms) is the recommended indicator for faecal contamination while total coliforms and heterotrophic plate counts can be used for operational monitoring. Other parameters can also be used to provide assurance of microbiological quality including C.*t* (for disinfected supplies) and turbidity (for filtered supplies).

Tests for the presence of specific pathogens are appropriate for investigative and research monitoring, or in outbreaks of waterborne disease.

Table 10.1 *Specific pathogens*

Microorganism	Comments
Bacteria	
Aeromonas	Has been isolated in Australian drinking water but the relationship of isolates to disease is not clear.
Burkholderia pseudomallei	Causes Melioidosis, found in soil and muddy water in tropical regions. Limited evidence for the involvement of drinking water in its transmission in Australia.
Campylobacter[a]	Causes gastroenteritis, can be transmitted in water or food. Has been detected in Australian drinking water.
Klebsiella[a]	Widespread environmental organism, spread by handling, especially in hospitals. Has been detected in Australian drinking water but there is no evidence of disease caused through this route.
Legionella	Frequently occurs in natural water but of no health concern unless numbers are amplified at specific sites and conditions (usually thermal enrichment); may then be spread by aerosols and inhaled, causing legionellosis and pontiac fever.
Mycobacterium	Some species associated with opportunistic infections in a minority of susceptible people.
Pseudomonas aeruginos[a]	Common in faeces, soil, water and sewage. Opportunistic pathogen causing wound and respiratory infections often in hospitals, though not usually through drinking water. Has been detected in Australian drinking water.
Salmonella[a]	May enter water through faecal contamination. Has been found in various Australian source waters and occasionally in reticulated waters. Can cause outbreaks of gastroenteritis. Occasionally present in the absence of microbial indicators.

Table 10.1 *Specific pathogens (continued)*

Microorganism	Comments
Bacteria	
Shigella[a]	Causes bacillary dysentery; highly infective. Presence in water indicates recent faecal contamination. Australia has a low incidence of infection with no conclusive evidence of transmission by drinking water.
Vibrio[a]	*V. cholerae* 01 causes cholera and is associated with waterborne epidemics. *Vibrio spp* have been found in source waters in Australia but not in reticulated supplies.
Yersinia[a]	Some strains can cause gastroenteritis if ingested.
Protozoa	
Acanthamoeba	Free-living amoeba common in soil and water; some species can cause encephalitis, particularly in immunocompromised people, or corneal infection amongst contact lens wearers. Significance in drinking water unknown; of most concern in water for use in hospitals, renal dialysis and eyewash stations. Resistant to normal disinfection.
Cryptosporidium[a]	Enteric pathogen; may contaminate water from pasture runoff and human wastes. Causes diarrhoeal illness. Extremely resistant to disinfection. If detected in source waters, appropriate treatment may be warranted to stop entry to distribution system. If in distribution system, seek detailed advice from the relevant health authority.
Giardia[a]	May cause diarrhoeal illness, though symptomless infection is common. Drinking water may play a role in transmission. If detected in source waters, appropriate treatment may be warranted to stop entry to distribution system. If in distribution system, seek detailed advice from the relevant health authority.
Naegleria fowleri	Free-living organism. Bathing or swimming in contaminated water can cause rare but fatal meningoencephalitis. Significance in drinking water not known. Water continually > 25°C or seasonally > 30°C can support growth. Action is indicated if the organism is detected (minimum sample size 500 mL).
Viruses	
Adenovirus[a]	Causes pharyngitis, conjunctivitis, gastroenteritis. Spread by inhalation, ingestion, direct contact. May contaminate water through sewage.
Enterovirus[a]	May enter water via faecal contamination or sewage. Can cause gastroenteritis and other diseases, often symptomless. Can probably be spread by drinking water.
Hepatitis viruses[a]	A and E viruses can be spread in drinking water contaminated with faecal material or sewage effluent.
Norwalk virus[a]	Causes gastroenteritis, can be spread in drinking water, bathing, food (especially shellfish) contaminated with sewage/faecal material.
Rotaviruses, pararotaviruses and reoviruses (Reoviridae)[a]	Widespread in environment; can cause serious gastroenteritis in children, the elderly, and hospital patients. May enter water through faecal material/sewage contamination.
Toxic cyanobacteria	
Cyanobacteria (blue-green algae)	Occur in all natural waters; of no concern in small numbers. Health risks can arise from ingestion of cyanobacterial toxins or from direct contact of the skin and eyes with toxic or non-toxic species For storages with history of algal blooms, inspect twice weekly during danger period. > 500 cells/mL – increase monitoring; >2000 cells/mL – consider need for toxicity testing (seek expert advice) >6500 cells/mL – seek advice from health authority.

a – May be present if microbial indicators are detected. See Section 10.2.1.
Note: if any of these organisms is detected, advice should be sought from the relevant health authority.

10.2.1 MICROBIAL INDICATOR ORGANISMS

An ideal indicator organism for inferring the presence of pathogenic microorganisms in drinking water should:

- always be present when pathogens of like origin are present
- be present in relatively large numbers so that they can be detected after considerable dilution
- not be present in the absence of contamination
- be easy and quick to detect
- survive in water as long as waterborne pathogens
- be of similar sensitivity to disinfection as pathogens.

No single organism has all these inherent qualities.

Escherichia coli (or thermotolerant coliforms) is recommended as the most suitable indicator organism for the possible presence of pathogens arising from faecal contamination. Monitoring drinking water for *E. coli* (or thermotolerant coliforms) as a verification measure is a useful tool within a risk management approach to water quality.

- Total coliforms have, in the past, been used as indicators for pathogens; they are no longer recommended for this purpose. Total coliforms are now recognised as being a poor parameter for measuring the potential for faecal contamination in water because they are present as normal inhabitants of soil and water, and can grow in water distribution systems in the absence of faecal contamination.

However, total coliforms can be used (together with other parameters) as indicator organisms for operational monitoring.

When indicators provide evidence of faecal pollution in a drinking water supply, an increased health risk to consumers is implied. Whether this will manifest in clinical cases of disease will depend (as discussed in Section 5.5) on whether pathogens are actually present, the immunity of the community served, and how the water is being used. Even if there are no clinical cases of disease, the risk to human health may still be significant.

Some enteric pathogens can occur in the absence of bacterial indicators. For example, *Giardia* cysts, oocysts of *Cryptosporidium* and some viruses are relatively resistant to chlorination and may survive disinfection that kills the indicator organisms.

The occasional failure of indicators to predict health risk underlines the importance of maintaining effective barriers to prevent faecal material entering the water supply. Tests of microbial quality are a valuable adjunct to assessing source water protection, treatment, and the integrity of the barriers through to the consumer's tap.

10.2.2 INDICATORS OF FAECAL CONTAMINATION

Escherichia coli *(or thermotolerant coliforms)*

The ADWG recommend testing for *E. coli* (or thermotolerant coliforms) to indicate the presence of faecal contamination. Thermotolerant coliforms have been, inaccurately associated with faecal contamination. Tests for thermotolerant coliforms can be simpler, but *E. coli* is a better indicator because some environmental coliforms (e.g. some *Klebsiella, Citrobacter and Enterobacter*) are thermotolerant. *E. coli* is the most common thermotolerant coliform present in faeces (typically greater than 90 per cent) (Edberg *et al* 2000) and is regarded as the most specific indicator of recent faecal contamination.

E. coli and thermotolerant coliforms come from the family of bacteria known as *Enterobacteriaceae* (meaning 'family of bacteria living in the intestine'). *E. coli* is nearly always present in the gut of humans and other warm-blooded animals. It is usually present in high numbers, and is found in fresh faecal matter at densities of more than 10^9 organisms per gram (Brenner *et al* 1982).

The presence of *E. coli* in drinking water indicates recent faecal contamination because the organism does not generally multiply in drinking water systems. It is not possible to readily determine if *E. coli* in water samples is of human origin, but as animals and birds can harbour human intestinal pathogens, the presence of any *E. coli* indicates that there may be a health risk.

E. coli and thermotolerant coliforms are gram-negative facultative anaerobic bacilli that can ferment lactose at 44.5±0.2°C with the production of acid in 24 hours, in media containing bile salts (naturally found in the gut). *E. coli* are thermotolerant coliforms that produce indole from tryptophan at 44.5±0.2°C.

There are a number of laboratory methods that directly measure the fermentation of lactose using selective media. Alternatively, *E. coli* can be detected by the presence of the enzymes ß-galactosidase and ß-glucuronidase. ß-galactosidase is responsible for the first step fermentation of lactose.

Only a few strains of *E. coli* may themselves be pathogenic; however, this is irrelevant to the use of *E. coli* as an indicator organism. Both pathogenic and nonpathogenic strains are equally significant as indicators of faecal contamination.

See also Fact Sheet on *Escherichia coli* and thermotolerant coliforms in Part V.

Other indicators of faecal contamination

Enterococci are gram-positive cocci found in the faeces of humans and other animals. Despite being approximately an order of magnitude less numerous than *E. coli* and thermotolerant coliforms in human faeces (Feacham *et al* 1983), they can still be detected after significant dilution. Enterococci occur regularly in faeces, but not in such numbers or so invariably as *E. coli* ; also, certain species of *Enterococcus* are not reliably associated with the gut. Enterococci survive longer in water than *E. coli* , and have been suggested as a better indicator of the presence of certain pathogens that are persistent and die off slowly (e.g. viruses) (McFeters *et al* 1974).

Clostridium perfringens is a spore former and is thus highly persistent, but it can frequently be found in environmental material not specifically associated with faeces. As an indicator, it has only limited application.

There are a number of other alternative indicators, including *Bacteriodes fragilis*, Bifidobacteria, bacteriophages and non-microbial indicators such as faecal sterols and turbidity. None of these alternatives is sufficiently widely accepted at present to recommend it as an indicator of faecal contamination.

Further information on indicators is provided in the NHMRC *Review of Coliforms As Microbial Indicators of Drinking Water Quality* (NHMRC 2004).

10.2.3 INDICATORS USED IN OPERATIONAL MONITORING

Microbial indicators that may be useful for verifying the effectiveness of treatment and disinfection, and for assessing system cleanliness, include total coliforms, heterotrophic bacteria.

Coliforms (total coliforms)

Total coliforms include *E. coli, Citrobacter, Enterobacter, Klebsiella* and other related enterobacteria. Coliform bacteria other than *E. coli* are capable of multiplying in water to high numbers, given the right conditions.

Coliform bacteria other than *E. coli* form a small component of the normal intestinal population in humans and animals, and many have an environmental origin and are inhabitants of soil and water.

Coliforms can be present in drinking water as a result of:

- faecal contamination
- the presence of biofilms on pipes and fixtures
- contact with soil as a result of leaks, fractures or repair works.

Due to their widespread occurrence in soil and water environments, total coliforms (in the absence of *E. coli*) are not regarded as a specific indicator of faecal contamination.

The relative abundance of coliforms makes them useful in monitoring the efficiency of water treatment and disinfection processes. They should generally not be detected in water sampled immediately after disinfection.

If used for operational monitoring system specific targets should be established for water within distribution systems. An understanding of system characteristics together with an analysis of historical results should be used in setting such targets.

See also Fact Sheet on *Coliforms* in Part V.

Heterotrophic plate count

HPC can be a useful indicator of operational performance. This test reflects the number of heterotrophic microorganisms in the water supply that are able to grow and produce colonies on the growth medium used for the test under specified conditions (e.g. incubation time, temperature). Not all microorganisms in water will grow under these test conditions.

HPC are usually determined after incubation at 20–22˚C or at 35–37˚C. Plate counts of bacteria able to grow at 20–22˚C or at 35–37˚C in a standard nutrient medium may be relevant to the nutrient status of the water, but not to faecal pollution.

The count at 20–22˚C will favour many environmental organisms; the count at 35–37˚C will include some environmental organisms and possibly some from faecal material. HPC has little sanitary value, but may be useful in assessing the efficacy of water treatment – specifically the processes of coagulation, filtration and disinfection, each of which reduces bacterial numbers. It may be used to assess the cleanliness and integrity of the distribution system and the suitability of water for manufacturing food and drink, where high counts may lead to spoilage. A significant increase in counts may be an early sign of contamination.

10.2.4 SAMPLING FREQUENCY

Samples that are representative of the quality of water supplied to consumers should be collected and analysed for *E. coli* (or thermotolerant coliforms) at the minimum frequency shown in Table 10.2.

Table 10.2 *Guidelines for microbial quality - frequency*

Samples that are representative of the quality of water supplied to consumers should be collected and analysed for *E. coli* (or thermotolerant coliforms) at the following minimum frequency:

Population serviced	Minimum number of samples
> 100 000	Six samples per week, plus one additional sample per month for each 10 000 above 100 000.
5000–100 000	One sample per week plus one additional sample per month for each 5000 above 5000.
1000–5000	One sample per week (52 samples per year).
< 1000	See advice for small communities (Section 10.5).

Sampling frequency should be increased at times of flooding or emergency operations and following repair work or interruptions of supply. With small water supply systems, periodic sanitary surveys are likely to yield more information than infrequent sampling.

Sampling frequency needs to take account of the fact that any sample of water analysed represents only a single point on a probability curve, which could be on a tail that underestimates the numbers of indicator bacteria actually present. The recommended number of samples to be tested for bacterial contamination, shown in Table 10.3, is based on World Health Organization (WHO) recommendations. For populations below 5000, the minimum number of samples has been set at one per week. The statistical basis for this is discussed in the statistics Information sheets (Information Sheet 3.3 *Number of samples required*) but in reality, contamination can occur quite rapidly, and fewer samples than this would mean that there would be substantial periods when the supply was not being monitored, leaving a good chance that the monitoring program would fail to detect the contamination. From a statistical viewpoint, if the water is sampled less than once a week, then even if all samples are free of contamination, there is only a low degree of confidence that the supply is free of contamination.

The frequency of sampling should be increased at times of flooding or emergency operations, or following interruptions of supply or repair work. With systems serving small communities, periodic sanitary surveys are likely to yield more information than infrequent sampling (see Chapter 4).

Investigative surveys should include samples taken throughout the distribution system, including:

- fixed points, such as pumping stations and tanks
- random locations throughout the distribution system
- near the extremities of distribution systems
- taps representing the quality of water supplied to consumers.

10.3 Physical and chemical monitoring

10.3.1 METHODS OF ANALYSIS FOR PHYSICAL AND CHEMICAL CHARACTERISTICS

If analysis of water supplies is to be useful, it must yield consistent results; however, different methods of analysis can in some cases give different results on the same water sample. To ensure consistency, a method of analysis is suggested in the fact sheet for each chemical and physical characteristic.

Where possible, the recommended method is well documented, has undergone extensive evaluation (preferably through comprehensive inter-laboratory comparison programs), is readily available and is widely used by the larger water suppliers.

Other methods can be used; however, it is important that they also meet these criteria, and give results that are consistent with standard methods. Even minor variations to documented methods can lead to inappropriate measurements.

The guideline values must be measurable by existing analytical techniques. The limit of determination for each suggested method has therefore been quoted as a guide.

10.3.2 LIMIT OF DETERMINATION

For some chemicals, the guideline value has been set at the limit of determination. It is recognised, however, that there are many experimental uncertainties in measuring extremely low concentrations. The value has therefore been chosen so that, if the chemical is present in the water sample at the guideline value, there is a high probability that it will be detected, and, conversely, if a positive result is obtained, there is a high probability that this means that the chemical is present in the water sample (i.e. that the result is not due to 'noise' in the measurement process).

From a more rigorous analytical viewpoint, the limit of determination is the point at which measurements become quantitatively meaningful. This should not be confused with the detection limit, which is often taken as three times the standard deviation determined from replicate measurements on blank samples.

The limit of determination is often five times the detection limit, and is usually verified by inter-laboratory tests on prepared samples.

10.3.3 MONITORING OF PHYSICAL AND CHEMICAL CHARACTERISTICS

Chapter 9 gives general information and advice on the design and implementation of a monitoring program. Some more specific advice is offered here in relation to the physical and chemical characteristics of drinking water quality. Further information on monitoring is also available in the NWQMS *Australian Guidelines for Water Quality Monitoring and Reporting* (2000).

The importance of understanding the water supply system cannot be over emphasised. Such understanding entails appreciating the impact that activities in catchments can have on the quality of source waters, and the changes in water quality that can occur in storage reservoirs, service reservoirs, the treatment process and distribution networks. In particular, in relation to organic compounds, it entails understanding the effect of disinfectants such as chlorine on naturally occurring material derived from humus. These factors (which are discussed individually in Chapter 6) must be taken into account in developing a monitoring program.

In any monitoring program for physical and chemical characteristics, the minimum requirement is to routinely collect representative samples from a location towards the end of a supply system. Using a fixed sampling point (or points) allows meaningful comparisons to be made over time. It may be necessary to conduct a more intensive investigation for a short period to establish that water quality at the chosen sampling point is representative of the water quality in the system.

If complaints are received, more frequent sampling should be carried out to determine the cause. Once the problem has been remedied, routine sampling can be resumed.

In addition to the fixed point sampling program, including random samples from locations representing the quality of water supplied to consumers is encouraged.

Sampling locations and frequency are discussed in Section 9.6.

Monitoring for organic compounds

No single method of analysis is suitable for all the organic compounds that may be present in water. Each compound, or perhaps group of compounds, has specific analytical requirements, so monitoring for all of them would be extremely costly, time consuming, and probably unjustified.

Disinfection byproducts

When chlorine is used for disinfection, the byproducts produced in the highest concentrations will normally be trihalomethanes (THMs). A monitoring program based on the analysis of THMs is the minimum requirement. If the concentration of THMs is above the guideline value, then other byproducts may also be present in significant concentrations and should be analysed specifically.

Water samples should be taken at representative sampling points at or near the consumer's tap towards the extremities of a distribution system. This will allow the maximum amount of time for THM formation, and should be representative of the water supplied to consumers. As a minimum, a monthly sample from each distribution system should provide a reliable estimate of variations in the system. More frequent samples should be taken if the chlorine disinfection dose is increased substantially, if THM values exceed the guideline value or if the source of supply is changed.

Other organic compounds

Most of the organic compounds listed in this document are unlikely to be present in Australian drinking water. Source waters in this country are generally relatively free of contamination by organic compounds, particularly those associated with industrial, chemical or manufacturing industries. Most major cities are located on the coast, and they generally lack heavy concentrations of industry. There is little industrial use of rivers and streams upstream of drinking water intakes, accidental spills into major rivers are uncommon and catchment areas are usually fairly well protected. There may be agricultural activities within some catchments, but industrial and chemical industries are generally absent. Thus, regular monitoring for organic compounds may not be justified. However, there may be instances where local knowledge or accidental spillage justifies an increased level of surveillance.

Contaminated groundwater, water from unprotected or partially protected catchments, and water that may be contaminated with industrial discharges or effluent should be monitored more frequently than water from protected catchments. The type of analyses needed will be determined by knowledge of the types of contaminants likely to be present in the water.

For persistent contaminants, monitoring must be based on knowledge of the individual system. A detailed initial monitoring program should be carried out to determine the optimum sampling frequency. The minimum frequency should be one sample per month from each supply; however, conditions, and therefore sampling frequency, can vary with local circumstances. (See Section 9.6 for a discussion of sampling locations and frequency, and Information Sheet 3.3 for a discussion of their statistical basis.)

Monitoring for inorganic and physical characteristics

Water drawn from a large storage reservoir or ground supply

In large storage reservoirs, many water quality characteristics remain relatively stable over long periods. Nevertheless, it is possible for rapid changes to occur, particularly during periods when a large amount of water flows into the system. Factors such as algal growth and temperature stratification can also produce rapid change.

Obviously, any treatment process will change the quality of the water. Once water passes into the distribution system, microbial and slime growths, corrosion and disturbance of pipe sediments due to flow variations can affect the physical characteristics and the concentrations of some inorganic chemicals (see Section 5.6).

Tables 10.3 and 10.4 provide a guide to frequency of monitoring that takes account of these variables, based on wide experience with a number of large distribution systems in different parts of Australia. *This information should not be regarded as a substitute for a detailed assessment of individual systems:* local knowledge and experience may dictate a different monitoring program. (See Section 9.6 for a discussion of sampling locations and frequency, and Information Sheet 3.3 for a discussion of their statistical basis.)

Water drawn from a small storage reservoir or a river

The physical characteristics and the inorganic constituents of water drawn from small storage reservoirs or rivers can vary rapidly.

Monitoring requirements will depend on whether the water passes through a water treatment plant before entering the distribution system. If the water is fully treated, then the monitoring frequency given in Tables 10.3 and 10.4 can be used. If the water passes directly into the distribution system, the frequency of monitoring should be based on the rate at which the quality of the supply can change. This should be determined by an intensive initial monitoring program, and then scaled back once variations have been assessed (see Section 9.8.1 and Section 10.7).

Monitoring for pesticides

Although guideline values have been provided for a large number of pesticides, most are unlikely to be present in Australian drinking water supplies. Monitoring should be undertaken for those pesticides that have been detected in the source water, or where local usage suggests that they might be detected. Inlets to storage reservoirs or other water sources should be sampled monthly for relevant pesticide residues.

To help in establishing monitoring programs, the Table 10.11 identifies pesticides that have been detected from time to time in Australian drinking water sources or whose likely use would indicate that they might occasionally be detected.

Table 10.3 *A guide to the monitoring frequency for inorganic compounds in a distribution system when water is drawn from a large storage reservoir or ground supply*

Frequency	Characteristic	Comments
Weekly	Aluminium, chlorine, chloramines, chlorine dioxide, fluoride, bromate	Concentrations can change relatively quickly within a distribution system, and may have important public health or aesthetic significance. Particular disinfectants (and byproducts) will only require monitoring if they are used. Fluoride and aluminium may not require frequent monitoring if fluoridation is not carried out, or if alum-based coagulants are not used for clarification.
Fortnightly	Iron, manganese	Iron and manganese can cause taste and staining problems. Concentrations in a distribution system can change as a result of microbial growths in pipes and chemical changes in distribution systems. Changes in the water quality of deep storages can also occur due to temperature stratification.
Monthly	Ammonia, copper, hydrogen sulfide, nitrate/nitrate, lead, zinc	Concentrations can change within distribution systems, but only relatively slowly. The quality of consumers' plumbing can affect concentrations of some constituents markedly. Use of copper-based algicides can cause short-term variations in copper concentrations in a distribution system.
Quarterly	Antimony, arsenic, barium, boron, cadmium, chloride, chromium, mercury, molybdenum, nickel, selenium, sodium, sulfate	While some change is possible within a distribution system, this is likely to be very slow. Concentrations are generally stable and are determined by conditions in the water storage or catchment (for example, elevated concentrations of boron may result from irrigation return water).
Annually (if at all)	Asbestos, tin, beryllium, cyanide, iodine, silver	It would be unusual to detect these constituents in most Australian drinking water supplies. If rarely or never detected, monitoring is probably unnecessary. Local information may indicate that more frequent monitoring is required.

Table 10.4 *A guide to the monitoring frequency for physical characteristics in a distribution system when water is drawn from a large storage reservoir or ground supply*

Frequency	Characteristic	Comments
Weekly	Temperature	Varies slowly with season; however, rapid changes can occur occasionally, and may cause consumer complaints. Normally measured in conjunction with microbial sampling.
Fortnightly	pH	pH can change quite rapidly within a distribution system and cause problems for consumers.
Monthly	Turbidity, colour, dissolved oxygen	May be affected by changes in flow, which disturb sediments in pipes. Usually, however, change is relatively slow in response to conditions in the storage, or to water treatment. More rapid change can follow sudden storms, and sampling should be more frequent after such events.
Quarterly	Total dissolved solids	Generally change is determined by conditions in the water storage or catchment and is very slow.
	Hardness	Generally change is determined by conditions in the catchment and is very slow.
Annually	Taste and odour	Large consumer surveys need to be well planned and organised. More frequent surveys may be logistically difficult and expensive. Consumer complaints may necessitate more frequent monitoring or investigation.

10.4 Radiological monitoring and assessment of compliance

10.4.1 SCREENING OF WATER SUPPLIES

The process of identifying individual radioactive species and determining their concentration requires sophisticated and expensive analysis, which is normally not justified because concentrations in most circumstances are very low. A more practical approach is to use a screening procedure, where the total radioactivity present in the form of alpha and beta radiation is determined without regard to the identity of specific radionuclides.

The 'screening' levels that are recommended for both gross alpha and gross beta activity are 0.5 becquerels per litre (Bq/L). The gross beta measurement includes a contribution from potassium-40, a natural beta emitter, which occurs naturally in a fixed ratio to stable potassium. Potassium is an essential element for humans, and is absorbed mainly from ingested food. Potassium-40 does not accumulate in the body but is maintained at a constant level independent of intake. The contribution of potassium-40 to beta activity is therefore subtracted following a separate determination of total potassium. The specific activity of potassium-40 is 30.7 becquerels per gram of potassium. However, not all the radiation from potassium-40 appears as beta activity. The beta activity of potassium-40 is 27.6 becquerels per gram of stable potassium, which is the factor that should be used to calculate the beta activity due to potassium-40. Although potassium-40 can make a significant contribution to the gross beta activity of drinking water (in Bq/L), this translates into a trivial dose in mSv. For example, assuming potassium-40 activity was at the 0.5 Bq/L screening level for total beta activity, the dose would only be 0.003 mSv per year, based on the calculation given in Section 7.6.3 and using the ICRP (1996) 'dose per unit intake' value for potassium-40 of 6.2×10^{-6} mSv/Bq.

If the 'screening' levels are not exceeded there is no need for further assessment. The recommended screening levels provide a good margin of safety against the dose-based guideline values. The likely worst case leading to the highest exposure is where these gross activities are due entirely to radium-226 (an alpha emitter) and radium-228 (a beta emitter). The total dose corresponding to total alpha and total beta activities just within the respective screening level of 0.5 Bq/L, will be approximately 0.35 millisieverts (mSv) per year with 0.1 mSv from radium-226 and 0.25 mSv from radium-228. Water that meets the screening guideline will result, at worst, in an annual dose of approximately one-third of the minimum dose at which intervention should be considered (see Table 10.5).

If either or both screening levels are exceeded, further investigation is necessary to identify the nature of the radioactivity. It should be emphasised that the screening level is intended only as a practical means to ascertain if further consideration of the radiological quality of the water supply is needed. It should never be regarded as a guideline value, or even as an indicative water quality target.

10.4.2 DOSE ASSESSMENT

If the screening level for gross alpha or gross beta activity is exceeded, specific radionuclides should be identified and their activity concentrations determined. This may involve taking a resample if the volume of the original sample is inadequate to allow specific radionuclide analysis. Activity concentrations for the most common sources of emissions, radium-226 and radium-228, should be evaluated at this stage. If radium does not account for all the gross alpha and beta emissions, then additional radionuclides will need to be identified. In accounting for all gross alpha and beta activity, the analytical service provider needs to provide information on counting and other errors associated with the determinations.

The annual dose rate from each radionuclide can be calculated using the method described in Section 7.6.2.

If the sum of the annual doses from all radionuclides is less than 0.5 mSv, no further action is required and routine monitoring can continue. If the sum of the annual doses from all radionuclides exceeds 0.5 mSv, it is not appropriate to rely on a single analysis to determine annual exposure. In this case, radionuclides should be sampled quarterly to obtain a profile of radiological water quality, as some water supplies show seasonal variations.

The quarterly results should be reviewed as they become available to ensure that there are no immediate problems. Otherwise, a final assessment of annual dose can be made when at least four results are available and the average concentration of each radionuclide can be used to calculate the annual doses.

10.4.3 OPERATIONAL RESPONSE

The operational response will depend on the estimated annual dose determined by the sum of the contribution from each radionuclide present in the water.

If the total annual dose is less than 0.5 mSv, the guideline level for intervention has not been exceeded and routine monitoring can be maintained.

If the total annual dose lies between 0.5 and 1.0 mSv, the guideline value for intervention has not been exceeded. In this instance, however, discussions should be held with the relevant health authority to determine the frequency of ongoing sampling.

If the total annual dose exceeds 1.0 mSv, the guideline exposure for considering intervention has been exceeded. The water service provider and the relevant health authority should assess the results and examine options to reduce the levels of exposure. Water supply providers should consider operational changes that can be implemented at minimal cost to reduce annual exposures. For example, water could be preferentially taken from bores with the lowest radionuclide concentrations wherever possible.

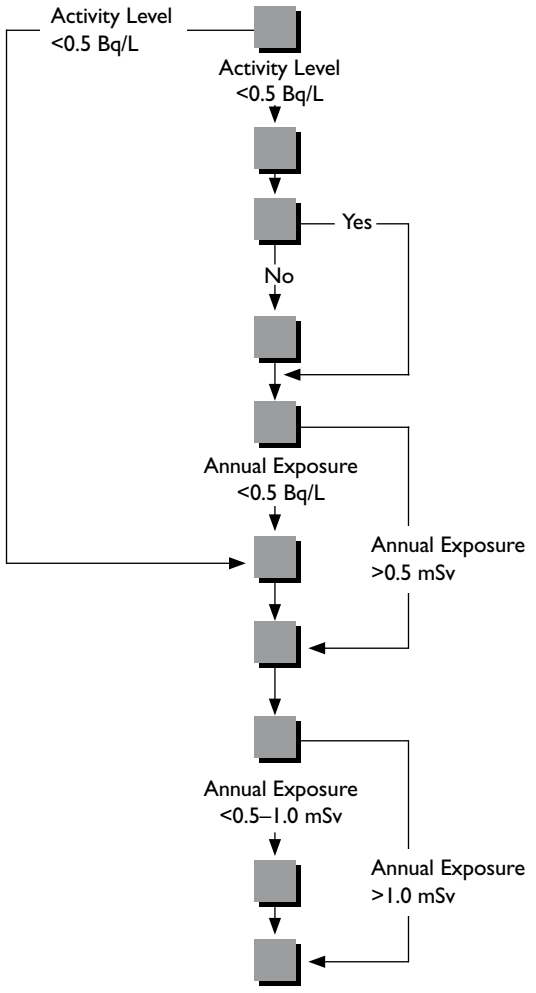
A total annual dose that exceeds 10 mSv is unacceptable for drinking water and immediate action should be taken to reduce the dose below guideline levels.

Recommendations on the response process are presented in Table 10.5. The monitoring and assessment process is further illustrated in Figure 10.1.

Table 10.5 *Summary of operational responses*

Dose level (mSv per year)	Response
< 0.5	1. Continue routine monitoring.
0.5-1	1. Consult with relevant health authority.
	2. Review frequency of ongoing sampling.
	3. Evaluate operational options to reduce exposure.
>1-10	1. Consult with relevant health authorities.
	2. Assess in detail possible remedial actions, taking into account potential health impacts and cost effectiveness of actions.
	3. Implement appropriate remedial action on the basis of the cost-benefit evaluation.
> 10	1. Water not suitable for consumption on the basis of radioactivity levels.
	2. Consult with relevant health authorities.
	3. Immediate intervention is expected and remedial action must be taken to reduce doses to below the guideline value of 1.0 mSv.

Figure 10.1 *Flowchart showing how to determine whether the radiological quality of drinking water complies with the Guidelines*

Step	Activity	Process flow	Guidance note
1	Determine gross alpha and [gross beta excluding – K40].		Monitoring includes steps 2 to 4.
2	Retest for gross alpha and [gross beta excluding – K40] and determine Ra-226 and Ra-228 activity levels.		
3	Are all gross alpha and gross beta accounted for?		
4	Determine the activity levels of additional radionuclides.		
5	Calculate annual exposure.		
6	Complies with Guidelines. Continue routine monitoring.		
7	Commence quarterly monitoring.		
8	Calculate annual exposure based on quarterly monitoring.		
9	Complies with ADWG. Continue monitoring at frequency agreed with health department.		
10	Exceeds guideline. Consider intervention.		

10.4.4 METHODS OF ANALYSIS

Gross alpha and beta activity concentration

For analysis of drinking water for gross alpha and beta activity, the most common approach is to evaporate a known volume of the sample to dryness and measure the activity of the residue. As alpha radiation is easily absorbed within a thin layer of solid material, the reliability and sensitivity of the method for alpha determination may be degraded in samples with a high content of total dissolved solids (TDS).

Where possible, standard methods should be used to determine concentrations of gross alpha and beta activities. Table 10.6 lists the three procedures that are recommended.

Table 10.6 *Recommended methods for the analysis of gross alpha and beta activities in potable water*

Method reference	Technique	Detection limit	Application
ISO 9695 and ISO 9696 (1991)	Evaporation	0.02-0.1 Bq/L	Groundwater with TDS greater than 0.1 g/L
AS 2531 (1982)	Evaporation	0.02 Bq/L	Surface water and groundwater with TDS 0.1 g/L
APHA, AWWA, WEF(1998)	Coprecipitation	0.02 Bq/L	Surface and groundwater (low Fe) (TDS not a factor)

AS = Australian Standard (of Standards Australia); AWWA = American Water Works Association;
APHA = American Public Health Association; Bq = becquerel; ISO = International Organization for Standardization;
TDS = total dissolved solids; WEF = Water Environment Federation.

The determination of gross beta activity using either of the evaporation methods in Table 10.6 includes the contribution from potassium-40. An additional analysis of total potassium is therefore required.

The coprecipitation technique shown in Table 10.6 excludes the contribution due to potassium-40, so determination of total potassium is not necessary. This method is not suitable for assessment of water samples containing fission products such as caesium-137. However, under normal circumstances, concentrations of fission products in Australian drinking water supplies are so low that they cannot be detected.

Analytical methods for specific radionuclides

Generally, Australian standard or international standard methods are not available for key natural radionuclides such as radium-226 and radium-228; however, suitable methods have been published in the literature. Suggested methods for specific radionuclides are included the relevant Fact Sheets.

Sample handling and pretreatment

Water samples should be pretreated to prevent significant losses of radionuclides from solution following collection and in transit to a laboratory.

Details of appropriate procedures for the handling of water samples, including suitable containers and pretreatment methods are described in the relevant Australian/New Zealand Standards (AS/NZS 1998a and 1998b).

Analytical methods for potassium-40

It is impractical to use a radioactive measurement technique to determine the concentration of potassium-40 in a water sample. This is because gamma ray analysis is not very sensitive and it is difficult to chemically isolate the radionuclide from solution. Because the ratio of potassium-40 to stable potassium is fixed, chemical analysis for potassium is recommended. A measurement sensitivity of 1 mg/L

for potassium-40 is adequate for monitoring purposes; this can readily be achieved by atomic absorption spectrophotometry or specific ion analysis. The activity due to potassium-40 can then be calculated using a factor of 0.0276 Bq of beta activity per milligram of potassium.

Sampling frequency

New water supplies and those not previously sampled should be sampled often enough to characterise the radiological quality of the water supply and to assess any seasonal variation in radionuclide concentrations. This should include analysis for radon. Quarterly sampling should provide sufficient data.

Once the radiological quality of a supply has been established, sampling can be less frequent – every two years for groundwater supplies, every five years for surface water supplies.

Reporting of results

The analytical results for each sample should contain the following information:

- sample identifying code or information
- reference date and time for the reported results (e.g. sample collection date)
- identification of the standard analytical method used or a brief description of any non-standard method used
- identification of any radionuclides or type of total radioactivity determined
- calculated concentration or activity value using the appropriate blank for each radionuclide
- estimates of the counting uncertainty and total propagated uncertainty
- decision level (in units consistent with the counting uncertainty) and nominal minimum detectable concentration for each radionuclide or parameter analysed.

The estimate of total propagated uncertainty of the reported result should include the contributions from all the parameters within the analytical method (i.e. counting and other random and systematic uncertainties).

10.5 Small water supplies monitoring

Monitoring of small water supplies should be based on the principle that it is much more effective to test for a narrow range of key characteristics as frequently as possible, supplementing this with sanitary inspection, than to conduct comprehensive but lengthy (and possibly largely irrelevant) analyses less often. In addition to health-related characteristics, small communities need to include other analyses relevant to the operation and maintenance of water treatment and distribution systems.

As a minimum, small community supplies should be monitored for the four characteristics that best establish the hygienic state of the water and the potential for other problems to occur:

- indicator microorganisms
- disinfectant residual
- pH
- turbidity.

Except for the indicator microorganisms (see Section 10.2.1), these characteristics can be determined on site using relatively unsophisticated testing equipment. It is essential to determine disinfectant residual at the site at the time of sampling. It is also important to do this for the other characteristics where laboratory support is lacking or where transportation problems would render conventional sampling and analysis difficult or impossible. There are test kits for rapid microbial examination of water; the results obtained, however, may be variable and require careful interpretation. Some jurisdictions have given in-principle approval for test kits, and field trials are proceeding. Further pursuit of this approach is desirable.

Health authorities and water authorities should also be aware of other specific regional or local sources of contamination, such as chemical or radiological contamination, and monitoring should be undertaken for the relevant characteristics.

10.6 Guide to monitoring and sampling frequency

Table 10.7 provides guidance for operational and drinking water quality monitoring by location. Operational monitoring is used to check that the processes and equipment that have been put in place to protect and enhance water quality are working properly, whereas drinking water quality monitoring is a wide-ranging assessment of the quality of water in the distribution system and as supplied to the consumer.

The table is based on experience from a number of water authorities throughout Australia and is intended to provide a guide to monitoring frequency. The table does not preclude the need to carry out a comprehensive survey to determine the monitoring requirements of an individual system, but can be used as a starting point for this process.

Individual water authorities should work out their own cost-effective monitoring programs in consultation with personnel experienced in water quality assessment. The emphasis should be on identified key characteristics, local knowledge and experience based on the identified key characteristics and their variability. The size of the water supply scheme may dictate a different sampling program from that suggested here.

Table 10.7 should be used in conjunction with the more detailed information on monitoring provided in relevant sections of the ADWG.

Table 10.7 *Drinking Water Guidelines and operational monitoring by location*

Location	Drinking water quality monitoring	
	Characteristic	**Sampling frequency**
Raw water (storage, stream or bore)	Pesticides	Monthly for specific pesticides and/or event-related – (One sample per month should be analysed for those pesticides previously detected in the source water, or where their likely use would indicate that they might be detected.)
	Organics other than disinfection byproducts (benzene, chlorobenzene, dichlorobenzenes, dichloroethanes, dichloroethenes, ethylbenzene, ethylenediamine tetraacetic acid, hexachlorobutadiene, nitrilotriacetic acid, organotins, styrene, tetrachloroethene, trichlorobenzene (total), 1,1,1-trichlorothane, trichloroethylene, vinyl chloride	Monthly if persistent, otherwise event-related
	Arsenic, selenium, mercury, molybdenum, boron, barium	Quarterly or event-related
	Tin, silver, beryllium, iodide,	Annually (if at all)
	Radionuclides	Every 5 years for surface water, every 2 years for groundwater, more often if guideline value exceeded. (Radiological quality should be assessed when a new supply is brought into service, and then every two years for groundwater supplies, and every five years for surface water supplies.)
	Operational monitoring	
	Characteristic	**Sampling frequency**
	Water treatment-related colour, turbidity, pH, alkalinity, iron, manganese, hardness, fluoride	Weekly/monthly (depends on variability in water quality)
	E.coli, total coliforms and HPC	Weekly/monthly
	Disinfection byproduct precursors (e.g. total organic halogen)	Monthly/quarterly
	Dissolved oxygen	Monthly/quarterly
	Taste/odour and toxin-producing organisms and characteristics affecting their growth	Weekly/monthly

Table 10.7 *Drinking Water Guidelines and operational monitoring by location (continued)*

Location	Drinking water quality monitoring	
	Characteristic	**Sampling frequency**
Treated water (water entering distribution system after clarification or disinfection)	Fluoride	If fluoridation carried out, continuous to weekly; otherwise quarterly
	Hardness	Monthly if water is treated for hardness, otherwise quarterly
	Total dissolved solids, sodium, chloride, sulfate	Quarterly (more often if significantly affected by water treatment)
	Organic contaminants from water treatment chemicals (acrylamide, carbon tetrachloride)	Quarterly
	Operational monitoring	
	Characteristic	**Sampling frequency**
	Epichlorohydrin	Annually (if at all)
	Disinfectant residuals	Daily/weekly
	Treatment-related characteristics: colour, turbidity, pH, aluminium, iron, manganese	Daily/weekly
	E.coli, total coliforms and HPC	Weekly for surface water; fortnightly for groundwater

Table 10.7 *Drinking Water Guidelines and operational monitoring by location (continued)*

Location	Drinking water quality monitoring	
	Characteristic	**Sampling frequency**
Distribution system (at points well into the system)	Aluminium	Weekly if aluminium salts used in flocculation
	Chlorine residual	Continuous to weekly. Frequency depending on size of system
	pH, manganese	Fortnightly
	Organic byproducts of disinfection	Monthly if disinfection practised (As a minimum, monitoring should be carried out for trihalomethanes (THMs). If concentrations exceed the guideline value, other byproducts should be analysed specifically. Monthly samples should be taken from each distribution system, with more samples if: • the chlorine disinfection dose is increased substantially • THM concentrations exceed the guideline value • the source of supply is changed.
	Dissolved oxygen, hydrogen sulfide, nitrite, nitrate, ammonia	Monthly
	Colour, turbidity	Monthly
	Chromium	Quarterly or event related
	Asbestos, cyanide	Annually (if at all)
	Organic materials used in water systems (pipe/fitting/adhesive toluene, xylene)	Annually (if at all)
	Operational monitoring	
	Characteristic	**Sampling frequency**
	Disinfectant residuals	Weekly
	Total coliforms and HPC	Weekly/monthly

Table 10.7 *Drinking Water Guidelines and operational monitoring by location (continued)*

Location	Drinking water quality monitoring	
	Characteristic	**Sampling frequency**
Supply to consumer (samples should be taken from points representing the quality of water supplied to consumers)	Disinfectant residuals (bromate, chlorine, chlorine dioxide, iodine, monochloramine)	Weekly
	E. coli (thermotolerant coliforms) temperature	At least weekly (depending on population)
	Corrosion products:	
	Iron	Fortnightly (or weekly if used as coagulant)
	Copper, lead, zinc	Monthly/special investigations
	Cadmium, nickel, antimony	Quarterly
	Taste/odour	Annually/complaints
	Benzo(a)pyrene, plasticisers	Annually (if bitumen-based products in contact with water)

Notes:

(1) The frequencies and locations shown are intended only as a guide to assist in establishing monitoring programs. They are based on the experience of water authorities throughout Australia, but are not a substitute for a detailed assessment of individual systems.

(2) Water supplied to consumers should occasionally be monitored for all characteristics. Monitoring by the water authority would normally be undertaken outside the consumer's property from a service pipeline directly off a main selected to represent the quality of water supplied to a consumer. Some specific investigations (e.g. leaching of metals by corrosive water), will require sampling from consumers' taps.

(3) In large storages or groundwater, many water quality characteristics remain relatively stable over long periods. Rapid changes may occur during periods of large water inflow, and in the case of storages, through other factors such as thermal stratification/destratification, algal growth. In streams and small storages the concentration of water quality characteristics can vary rapidly. Sampling frequencies shown are based on the rate of change in the supply, and are provided as a guide only. More frequent monitoring may be required depending on local conditions and circumstances.

(4) Unless otherwise stated:

- 'raw water' is water in a storage reservoir, river, stream or underground source
- 'treated water' is water entering a distribution system after disinfection or clarification
- 'distribution system' refers to water in the distribution system, but at points well into the distribution system where off-take to consumers has occurred
- 'supply to consumer' means water representative of that supplied to consumers and is normally monitored by the water authority outside the consumer's property from a service pipeline directly off the main selected to represent the quality of water supplied to the consumer. Some specific investigations (e.g. leaching of metals by corrosive water) will require sampling from consumer's taps
- 'consumer's tap' refers to the point of use within the consumer's property (e.g. the kitchen tap).

10.7 Guide to evaluating results

Results from both operational monitoring and drinking water quality monitoring should be evaluated in the short and long term. Results should be documented appropriately and a system of regular reporting of results to relevant staff, departments and external stakeholders such as regulators should be implemented. Results should be reviewed frequently to assess performance against target criteria and critical limits, as well as against guidelines or agreed levels of service. Where results show that critical limits have been exceeded or deviated from, control of the process has been lost, and corrective actions should be undertaken immediately. However, the purpose of this section is not to consider such incidents in isolation or offer advice on the immediate action to take if a guideline value is exceeded. Its aim is provide water suppliers with a means of using the results of a planned monitoring program to assess the performance of the water supply system over a given period (typically the preceding 12 months).

The performance of a water supply system over time is an important issue both for consumers, and for the managers and operators of water systems. Such an assessment may be of use, for example, in an annual report. From a capital works viewpoint, comparisons of performance can be used to evaluate the need to upgrade supplies and to set priorities to achieve these improvements in a rational and systematic way.

10.7.1 ASSESSING LONG-TERM PERFORMANCE: PHYSICAL, CHEMICAL AND RADIOLOGICAL CHARACTERISTICS

The information provided here applies to the physical, inorganic, organic and radiological characteristics of water quality.

Data for key characteristics should be displayed in a 'control chart' format (see Information Sheet 3.4).

For all health-related characteristics, a reasonable objective is to be confident that the 95th percentile of results over the preceding 12 months is less than the guideline value. This means that the upper bound of the 95% confidence interval for the percentile should be less than the guideline value.

Water quality characteristics that are not health related should be the subject of community service agreements. Where these agreements involve meeting certain aesthetic guideline values, a reasonable objective is to be confident that the mean value (or average) of results over the preceding 12 months is less than the guideline value. This means that the upper bound of the 95% confidence interval for the mean should be less than the guideline value.

The minimum sampling frequency should be determined from a statistical assessment of the data.

10.7.2 ASSESSING LONG-TERM PERFORMANCE: MICROBIOLOGICAL CHARACTERISTICS

The assessment of long-term performance for microbial quality requires a different approach, and this is summarised in Table 10.8.

Table 10.8 *Guidelines for microbial quality – assessing system performance*

For samples representative of the quality of water supplied to consumers, performance can be regarded as satisfactory if over the preceding 12 months:
• at least the minimum number of routine samples has been tested for *E. coli* (or thermotolerant) (see Table 10.2)
AND
• at least 98% of scheduled samples (as distinct from repeat or special purpose samples) contain no *E. coli* (or thermotolerant coliforms)

NOTE: It is the number of samples with positive results that should be used to assess performance; the number of organisms found for each positive result is irrelevant for this purpose. Each positive result requires action as detailed in the monitoring section above.

It is unrealistic, both from a statistical viewpoint and practically, to expect a water supply system to have zero indicator bacteria at all times. There may be instances where *E.coli* (or thermotolerant coliforms) are detected and when this occurs it is important that action is taken to rectify the problem. It is not possible to be certain that disinfection is 100% effective under all circumstances, or even that contamination of the sample container never occurs. It would be unreasonable to equate these occurrences with unsatisfactory or poor performance. Allowance has therefore been made in the assessment of performance for an occasional failure.

What then, can be regarded as acceptable performance, or more specifically, what should be regarded as an 'acceptable' failure?. There is no unequivocal answer. The guideline for *E.coli* (or thermotolerant coliforms) allows one failure in 50 samples (or 98% of samples having zero isolations), for the following reasons:

- no reasonable sampling program can achieve zero *E.coli* (or thermotolerant) bacteria all of the time
- one isolation of *E.coli* (or thermotolerant) bacteria per year is the next best alternative, and still provides a high degree of protection for public health
- one failure in 50 samples (i.e. one failure per year at the minimum recommended sampling frequency) means that 98% of samples are free from contamination
- this requirement can be met with a high degree of confidence by a well-operated system and a realistic and practical monitoring program.

It is essential that data used to assess long-term system performance are from independent samples, and so the criteria for evaluating performance deliberately exclude repeat and special purpose samples. Repeat samples are taken when contamination has been detected, and hence can not be regarded as independent of the first sample. Special purpose samples are also unlikely to be independent samples; they might, for example, be part of an investigative survey to assess problem areas in a supply. If such samples were included in performance assessment requirements, this could discourage water suppliers from conducting investigative and research monitoring, which are, on the contrary, to be encouraged as a means of identifying sources of contamination.

10.8 Summary of guideline values

Table 10.9 *Guidelines for microbial quality - monitoring of E. coli (or thermotolerant coliforms)*

Guideline	No sample of drinking water should contain any *E. coli* (or thermotolerant coliforms) (minimum sample 100 mL).
Action	If *E. coli* (or thermotolerant coliforms) are detected, then irrespective of the number of organisms, both the following steps should be taken immediately: 1) Another sample (a repeat sample) should be taken from the same site and from the immediate upstream treated sources of supply and tested for the presence of *E. coli* (or thermotolerant coliforms). – If the additional samples are negative for *E. coli* (or thermotolerant coliforms), then routine sampling can resume, but only after step 2 (below) has been completed. – If any additional sample is positive for *E. coli* (or thermotolerant coliforms), then increased disinfection and a full sanitary survey should be implemented immediately. The sanitary survey should include a review of the integrity of the system. AND 2) Disinfection should be increased and/or an investigation undertaken to determine possible sources of contamination. These might include a breakdown in disinfection, a mains break, interruption to the supply, surges in supply, or deliberate or accidental contamination of the system. The investigation may include a visual inspection of the system and associated service reservoirs by trained personnel. When found, the source of contamination should be eliminated.

Table 10.10 *Guideline values for physical and chemical characteristics*

Characteristic	Guideline values*		Comments
	Health	Aesthetic[a]	
Acrylamide	0.0002		Minor impurity of polyacrylamide, used sometimes as a flocculant aid.
Aluminium (acid-soluble)	[c]	0.2	Guideline value based on post-flocculation problems; < 0.1 mg/L desirable. Lower levels needed for renal dialysis. No health-based guideline value can be established currently.
Ammonia (as NH_3)	[c]	0.5	Presence may indicate sewage contamination and/or microbial activity. High levels may corrode copper pipes and fittings.
Antimony	0.003		Exposure may rise with increasing use of antimony-tin solder.
Arsenic	0.007		From natural sources and mining/industrial/agricultural wastes.
Asbestos	[c]		From dissolution of minerals/industrial waste, deterioration of asbestos-cement pipes in distribution systems. No evidence of cancer when ingested (unlike inhaled asbestos).
Barium	0.7		Primarily from natural sources.
Benzene	0.001		Could occur in drinking water from atmospheric deposition (motor vehicle emissions) and chemical plant effluent. Human carcinogen.
Beryllium	[c]		From weathering of rocks, atmospheric deposition (burning of fossil fuels) discharges.
Boron	4		From natural leaching of minerals and contamination. < 1 mg/L in uncontaminated sources; higher levels may be associated with seawater intrusion.
Bromate	0.02		Possible byproduct of disinfection using ozone, otherwise unlikely to be found in drinking water.
Cadmium	0.002		Indicates industrial or agricultural contamination; from impurities in galvanised (zinc) fittings, solders and brasses.
Carbon tetrachloride	0.003		Sometimes occurs as impurity in chlorine used for disinfection (it is not a disinfection byproduct).

Table 10.10 *Guideline values for physical and chemical characteristics (Continued)*

Characteristic	Guideline values*		Comments
	Health	Aesthetic[a]	
Chloramine – see monochloramine			
Chlorate	[c]		Byproduct of chlorine dioxide disinfection.
Chloride	[e]	250	From natural mineral salts, effluent contamination. High concentrations more common in groundwater and certain catchments.
Chlorinated furanones (MX)	[c]		Byproduct of Chlorination.
Chlorine	5	0.6	Widely used to disinfect water, and this can produce (free) chlorinated organic byproducts. Odour threshold generally 0.6 mg/L, but 0.2 mg/L for a few people. In some supplies it may be necessary to exceed the aesthetic guideline in order to maintain an effective disinfectant residual throughout the system.
Chlorine dioxide	1	0.4	Oxidising agent and disinfectant in water treatment.
Chlorite	0.3		Byproduct of chlorine dioxide disinfection.
Chloroacetic acids			Byproduct of chlorination.
chloroacetic acid	0.15		
dichloroacetic acid	0.1		
trichloroacetic acid	0.1		
Chlorobenzene	0.3	0.01	Could occur in drinking water from spills or discharges. Taste/odour threshold (0.01 mg/L) is well below health level.
Chloroketones			Byproduct of chlorination.
1,1-dichloropropanone	[c]		
1,3-dichloropropanone	[c]		
1,1,1-trichloropropanone	[c]		
1,1,3-trichloropropanone	[c]		
Chlorophenols			Byproduct of chlorination of water containing phenol or related chemicals.
2-chlorophenol	0.3	0.0001	
2,4-dichlorophenol	0.2	0.0003	
2,4,6-trichlorophenol	0.02	0.002	
Chloropicrin	[c]		Byproduct of chlorination.
Chromium (as Cr(VI))	0.05		From industrial/agricultural contamination of raw water or corrosion of materials in distribution system/plumbing. If guideline value exceeded, analyse for hexavalent chromium.
Copper	2	1	From corrosion of pipes/fittings by salt, low pH water. Tast threshold 3mg/L. High concentrations colour water blue/green. >1mg/L may stain fittings. >2mg/l can cause ill effects in some poeple.
Cyanide	0.08		From industrial waste and some plants and bacteria.
Cyanogen chloride (as cyanide)	0.08		Byproduct of chloramination.
Dichlorobenzenes			
1,2-dichlorobenzene	1.5	0.001	Could occur in drinking water from spills, discharges, atmospheric deposition, leaching from contaminated soils. Health levels are well above offensive taste/odour thresholds.
1,3-dichlorobenzene	[c]	0.02	
1,4-dichlorobenzene	0.04	0.003	
Dichloroethanes			
1,1-dichloroethane	[c]		Could occur in drinking water from industrial effluents, spills, discharges.
1,2-dichloroethane	0.003		

Table 10.10 *Guideline values for physical and chemical characteristics (Continued)*

Characteristic	Guideline values*		Comments
	Health	**Aesthetic**	
Dichloroethenes			Rarely found in drinking water; found occasionally in groundwater from wells heavily contaminated by solvents.
1,1-dichloroethene	0.03		
1,2-dichloroethene	0.06		
Dichloromethane (methylene chloride)	0.004		Widely used solvent, commonly found in ground and surface waters overseas. Volatilises from surface waters and biodegrades in the atmosphere.
Dissolved oxygen	Not necessary	> 85%	Low concentrations allow growth of nuisance microorganisms (iron/manganese/sulfate/nitrate-reducing bacteria) causing taste and odour problems, staining, corrosion. Low oxygen concentrations are normal in groundwater supplies and the guideline value may not be achievable.
Epichlorohydrin	0.0005[d]		Used in manufacture of some resins used in water treatment.
Ethylbenzene	0.3	0.003	Natural component of petrol and petroleum products.
Ethylenediamine tetraacetic acid (EDTA)	0.25		Metal-complexing agent widely used in industry and agriculture, and as a drug in chelation therapy.
Fluoride	1.5		Occurs naturally in some water from fluoride-containing rocks. Often added at up to 1 mg/L to protect against dental caries. > 1.5 mg/L can cause dental fluorosis. > 4 mg/L can cause skeletal fluorosis.
Formaldehyde	0.5		Byproduct of ozonation.
Haloacetonitriles			Byproduct of chlorination.
dichloroacetonitrile	[c]		
trichloroacetonitrile	[c]		
dibromoacetonitrile	[c]		
bromochloroacetonitrile	[c]		
Hardness (as $CaCO_3$)	Not necessary	200	Caused by calcium and magnesium salts. Hard water is difficult to lather. < 60 mg/L $CaCO_3$ soft but possibly corrosive. 60-200 mg/L $CaCO_3$ good quality. 200-500 mg/L $CaCO_3$ increasing scaling problems. > 500 mg/L $CaCO_3$ severe scaling.
Hexachlorobutadiene	0.0007		Industrial solvent.
Hydrogen sulfide	[c]	0.05	Formed in water by sulfate-reducing microorganisms or hydrolysis of soluble sulfide under anoxic conditions. Obnoxious 'rotten egg' odour, threshold 0.05 mg/L.
Iodine	[c]		Can be used as an emergency water disinfectant. Taste threshold 0.15 mg/L.
Iodide	0.1		From mineral and salt deposits.
Iron	[c]	0.3	Occurs naturally in water, usually at < 1 mg/L, but up to 100 mg/L in oxygen-depleted groundwater. Taste threshold 0.3 mg/L. High concentrations stain laundry and fittings. Iron bacteria cause blockages, taste/odour, corrosion.
Lead	0.01		Occurs in water via dissolution from natural sources or household plumbing containing lead (e.g. pipes, solder).
Manganese	0.5	0.1	Occurs naturally in water; low in surface water, higher in oxygen-depleted water (e.g. groundwater at bottom of deep storages). > 0.1 mg/L causes taste, staining. < 0.05 mg/L desirable.
Mercury	0.001		From industrial emissions/spills. Very low concentrations occur naturally. Organic forms most toxic, but these are associated with biota, not water.

Table 10.10 *Guideline values for physical and chemical characteristics (Continued)*

Characteristic	Guideline values*		Comments
	Health	**Aesthetic**[a]	
Molybdenum	0.05		Concentrations usually < 0.01 mg/L; higher concentrations from mining, agriculture, or fly-ash deposits from coal-fuelled power stations.
Monochloramine	3	0.5	Used as water disinfectant. Odour threshold 0.5 mg/L.
Nickel	0.02		Concentrations usually very low; but up to 0.5 mg/L reported after prolonged contact of water with nickel-plated fittings.
Nitrate (as nitrate)	50		Occurs naturally. Increasing in some waters (particularly groundwater) from intensive farming and sewage effluent. Guideline value will protect bottle-fed infants under 3 months from methaemoglobinaemia. Adults and children over 3 months can safely drink water with up to 100 mg/L nitrate.
Nitrite (as nitrite)	3		Rapidly oxidised to nitrate (see above).
Nitrilotriacetic acid	0.2		Chelating agent in laundry detergents (replacing phosphate). May enter water through sewage contamination.
Organotins			
dialkyltins	[c]		
tributyltin oxide	0.001		Stabilisers in plastics, may leach from new poly vinyl chloride (PVC) pipes for a short time. Tributyltins are biocides used as antifouling agents on boats and in boiler waters.
Ozone			As ozone used for disinfection leaves no residual, no guideline value has been established.
pH	[c]	pH 6.5-8.5	While extreme pH values (< 4 and > 11) may adversely affect health, there are insufficient data to set a health guideline value. < 6.5 may be corrosive. > 8 progressively decreases efficiency of chlorination. > 8.5 may cause scale and taste problems. New concrete tanks and cement-mortar lined pipes can significantly increase pH and a value up to 9.2 may be tolerated provided monitoring indicates no deterioration in microbial quality.
Plasticisers			
di(2-ethylhexyl) phthalate	0.01		Used in all flexible PVC products, and may leach from these over a long time. Could also occur in drinking water from spills.
di(2-ethylhexyl) adipate	[c]		
Polycyclic aromatic hydrocarbons (PAHs)			
Benzo-(a)-pyrene	0.00001 (10 ng/L)		Widespread. Contamination can occur through atmospheric deposition, or leaching from bituminous linings in distribution systems.
Selenium	0.01		Generally very low concentrations in natural water.
Silver	0.1		Concentrations generally very low. Silver and silver salts occasionally used for disinfection.
Sodium	[e]	180	Natural component of water. Guideline value is taste threshold.
Styrene (vinylbenzene)	0.03	0.004	Could occur in drinking water from industrial contamination.
Sulfate	500	250	Natural component of water, and may be added via treatment chemicals. Guideline value is taste threshold. > 500 mg/L can have purgative effects.
Taste and odour	Not necessary	Acceptable to most people	May indicate undesirable contaminants, but usually indicate problems such as algal or biofilm growths.
Temperature	Not necessary	No value set	Generally impractical to control; rapid changes can bring complaints.

Table 10.10 *Guideline values for physical and chemical characteristics (Continued)*

Characteristic	Guideline values*		Comments
	Health	Aesthetic	
Tetrachloroethene	0.05		Dry-cleaning solvent and metal degreaser. Could occur in drinking water from contamination or spills.
Tin	[e]		Concentrations in water very low; one of the least toxic metals.
Toluene	0.8	0.025	Occurs naturally in petrol and natural gas, forest-fire emissions. Could occur in drinking water from atmospheric deposition, industrial contamination, leaching from protective coatings in storage tanks.
Total dissolved solids	Not necessary	500	< 500 mg/L is regarded as good quality drinking water based on taste. 500-1000 mg/L is acceptable based on taste. > 1000 mg/L may be associated with excessive scaling, corrosion, and unsatisfactory taste.
Trichloroacetaldehyde (chloral hydrate)	0.02		Byproduct of chlorination.
Trichlorobenzenes (total)	0.03	0.005	Industrial chemical.
1,1,1-Trichloroethane	[c]		Could occur in drinking water from contamination/spills.
Trichloroethylene	[c]		Industrial solvent, cleaning fluid, metal degreaser. Could occur in drinking water from direct contamination or via atmospheric contamination of rainwater.
Trihalomethanes (THMs) (Total)	0.25		Byproduct of chlorination and chloramination
True Colour	Not necessary	15 HU	15 HU just noticeable in a glass. Up to 25 HU is acceptable if turbidity is low. If colour is high at time of disinfection, then the water should be checked for disinfection byproducts such as THMs.
Turbidity	[c]	5 NTU	5 NTU just noticeable in a glass. >1 NTU may shield some microorganisms from disinfection. <1 NTU desirable for effective disinfection.
Uranium	0.02		Occurs naturally, or from release from mine tailings, combustion of coal and phosphate fertilizers.
Vinyl chloride	0.0003		From chemical spills. Used in making PVC pipes. Human carcinogen.
Xylene	0.6	0.02	Could occur in drinking water as a pollutant, or from solvent used for bonding plastic fittings.
Zinc	[c]	3	Usually from corrosion of galvanised pipes/fittings and brasses. Natural concentrations generally < 0.01 mg/L. Taste problems > 3 mg/L.

* All values mg/L unless otherwise stated

HU = Hazen units; NTU = nephelometric turbidity units; THMs = trihalomethanes.

a – Aesthetic values are not listed if the compound does not cause aesthetic problems, or if the value determined from health considerations is the same or lower.

b – If present at all in Australian drinking waters, concentrations of all organic compounds other than disinfection byproducts are likely to be very low relative to the guideline value.

c – Insufficient data to set a guideline value based on health considerations.

d – The guideline value is below the limit of determination. Improved analytical procedures are required for this compound.

e – No health-based guideline value is considered necessary.

Note: All values are as 'total' unless otherwise stated.

Note: Routine monitoring for these compounds is not required unless there is potential for contamination of water supplies (e.g. accidental spillage).

Note: The concentration of all chlorination byproducts can be minimised by removing naturally occurring organic matter from the source water, reducing the amount of chlorine added, or using an alternative disinfectant (which may produce other byproducts). Action to reduce trihalomethanes and other byproducts is encouraged, but must not compromise disinfection.

Table 10.11 *Guideline values for pesticides*

Pesticide	Guideline value[a] (mg/L)	Health value[b] (mg/L)
Acephate		0.01
Aldicarb	0.001	0.001
Aldrin[c] (and dieldrin)	0.00001	0.0003
Ametryn	0.005	0.05
Amitrole[c]	0.001	0.01
Asulam		0.05
Atrazine[c]	0.0001	0.04
Azinphos-methyl	0.002	0.003
Benomyl		0.1
Bentazone		0.03
Bioresmethrin		0.1
Bromacil	0.01	0.3
Bromophos-ethyl		0.01
Bromoxynil		0.03
Carbaryl	0.005	0.03
Carbendazim		0.1
Carbofuran	0.005	0.01
Carbophenothion		0.0005
Carboxin	0.002	0.3
Chlordane[c]	0.00001	0.001
Chlorfenvinphos		0.005
Chlorothalonil	0.0001	0.03
Chloroxuron		0.01
Chlorpyrifos[c]		0.01
Chlorsulfuron		0.1
Clopyralid[c]	1	1
2,4-D[c]	0.0001	0.03
DDT[c]	0.00006	0.02
Diazinon	0.001	0.003
Dicamba		0.1
Dichlobenil		0.01
Dichlorvos	0.001	0.001
Diclofop-methyl		0.005
Dicofol		0.003
Dieldrin[c] (see aldrin)	0.00001	0.0003
Difenzoquat		0.1
Dimethoate		0.05
Diphenamid	0.002	0.3
Diquat[c]	0.0005	0.005
Disulfoton	0.001	0.003
Diuron[c]		0.03
DPA (2,2-DPA)		0.5
EDB	0.001	0.001
Endosulfan[c]	0.00005	0.03
Endothal	0.01	0.1
EPTC	0.001	0.03
Ethion		0.003
Ethoprophos	0.001	0.001
Etridiazole	0.0001	0.1
Fenamiphos		0.0003
Fenarimol	0.001	0.03
Fenchlorphos		0.03
Fenitrothion		0.01
Fenoprop		0.01
Fensulfothion	0.01	0.01
Fenvalerate		0.05
Flamprop-methyl		0.003
Fluometuron		0.05
Formothion		0.05
Fosamine[c]		0.03
Glyphosate	0.01	1
Heptachlor[c] (including its epoxide)	0.00005	0.0003
Hexaflurate		0.03
Hexazinone[c]	0.002	0.3
Lindane[c]	0.00005	0.02
Maldison		0.05
Methidathion		0.03
Methiocarb	0.005	0.005
Methomyl	0.005	0.03
Methoxychlor	0.0002	0.3
Metolachlor	0.002	0.3
Metribuzin	0.001	0.05
Metsulfuron-methyl		0.03
Mevinphos	0.005	0.005
Molinate[c]	0.0005	0.005
Monocrotophos		0.001
Napropamide	0.001	1
Nitralin		0.5
Norflurazon	0.002	0.05

Table 10.11 *Guideline values for pesticides*

Pesticide	Guideline value[a] (mg/L)	Health value[b] (mg/L)
Oryzalin		0.3
Oxamyl	0.005	0.1
Paraquat[c]	0.001	0.03
Parathion		0.01
Parathion methyl	0.0003	0.1
Pebulate	0.0005	0.03
Pendimethalin		0.3
Pentachlorophenol	0.00001	0.01
Permethrin	0.001	0.1
Picloram[c]		0.3
Piperonyl butoxide		0.1
Pirimicarb		0.005
Pirimiphos-ethyl		0.0005
Pirimiphos-methyl		0.05
Profenofos		0.0003
Promecarb		0.03
Propachlor	0.001	0.05
Propanil	0.0001	0.5
Propargite		0.05
Propazine	0.0005	0.05
Propiconazole[c]	0.0001	0.1
Propyzamide	0.002	0.3
Pyrazophos		0.03
Quintozene		0.03
Simazine	0.0005	0.02
Sulprofos		0.01
Silvex (see Fenoprop)		
2,4,5-T	0.00005	0.1
Temephos[c]	0.3	0.3
Terbacil	0.01	0.03
Terbufos	0.0005	0.0005
Terbutryn	0.001	0.3
Tetrachlorvinphos	0.002	0.1
Thiobencarb		0.03
Thiometon		0.003
Thiophanate		0.005
Thiram		0.003
Triadimefon	0.1	0.002
Trichlorfon		0.005
Triclopyr[c]		0.01
Trifluralin	0.0001	0.05
Vernolate	0.0005	0.03

a – These are generally based on the analytical limit of determination (the level at which the pesticide can be reliably detected using practicable, readily available and validated analytical methods). If a pesticide is detected at or above this value the source should be identified and action taken to prevent further contamination.

b – Based on 10% of acceptable daily intake (ADI).

c – These pesticides have either been detected on occasions in Australian drinking water or their likely use would indicate that they may occasionally be detected.

Note: Routine monitoring for pesticides is not required unless potential exists for contamination of water supplies. See also Section 6.3.3

Table 10.12 *Guideline values for radiological quality of drinking water*

Guideline value
The total estimated dose per year from all radionuclides in drinking water, excluding the dose from potassium-40, should not exceed 1.0 mSv. If this guideline value is exceeded, the water provider, in conjunction with the relevant health authority, should evaluate possible remedial actions on a cost-benefit basis to assess what action can be justified to reduce the annual exposure.
Screening of water supplies
Compliance with the guideline for radiological quality of drinking water should be assessed, initially, by screening for gross alpha and gross beta activity concentrations. The recommended screening level for gross alpha activity is 0.5 Bq/L. The recommended screening level for gross beta activity is 0.5 Bq/L after subtraction of the contribution from potassium-40. If either of these activity concentrations is exceeded, specific radionuclides should be identified and their activity concentrations determined. The concentration of both radium-226 and radium-228 should always be determined, as these are the most significant naturally occurring radionuclides in Australian water supplies. Other radionuclides should be identified if necessary to ensure all gross alpha and beta activity is accounted for, after taking into account the counting and other analytical uncertainties involved in the determination.

10.9 References

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PART IV INFORMATION SHEETS

Disinfection of drinking water

INFORMATION SHEET 1

Disinfection is the single process that has the greatest impact on drinking water safety, resulting in substantial decreases in waterborne disease. Disinfection is generally accomplished either alone or as the final step following clarification of water in a water treatment plant.

Agents and processes used to disinfect water include chlorine, chloramines, chlorine dioxide, ozone, ultraviolet (UV) and ionising radiation, bromine, bromine chloride, iodine, silver and silver compounds, filtration and changes to physical and chemical properties. Information Sheets 1.2–1.7 describe the commonly used processes used for disinfection.

The information given here should be read in conjunction with Section 6.3.2 on the chemical byproducts of disinfection.

PROPERTIES OF AN IDEAL DISINFECTANT

An ideal disinfectant should:

- effectively remove pathogens over a range of physical and chemical conditions
- produce a disinfectant residual that is stable and easily measured
- produce no unacceptable byproducts
- be easily generated, safe to handle and suitable for widespread use
- be cost effective.

No disinfectant currently in use meets all of these criteria. The choice of disinfectant will depend on the quality of the source water, the origin of the contaminating microorganisms, the length and complexity of the system and the size of the population served.

PRETREATMENT OF WATER

The physical quality (particularly turbidity and pH) of the water should be improved before disinfection to decrease the likelihood that disease-causing organisms or pollutants will be harboured in suspended matter, and to increase the efficiency of disinfection. Generally, turbidity of less than one nephelometric turbidity unit is required for effective disinfection.

EFFECTIVE DISINFECTION

The effectiveness of disinfection depends on:

- the nature and concentration of the disinfecting agent
- the type of microorganisms present
- contact time (the length of time the disinfectant is available for inactivation)
- satisfactory mixing of disinfectant and target microorganisms
- the degree to which the microorganisms are protected by
  – adsorption to, or inclusion in, solid particles
  – attachment to surfaces of pipes or fittings
- the level of competing inorganic and organic reactants
- turbidity, temperature and pH.

Turbidity, the concentration of the disinfectant, contact time and pH can all be monitored continuously, and can provide a useful indication of microbial quality control.

MAINTAINING EFFECTIVE DISINFECTION

Disinfection is of paramount importance in controlling microbial quality. Particular attention should be paid to the following points:

- Operational factors affecting microbial quality (e.g. pH, disinfectant residual and turbidity) should be monitored frequently (daily or preferably continuously).
- No animal or plant material should be directly visible.
- A minimum total chlorine residual should be present (0.5 mg/L after 30 minutes) if chlorination is used.
- Turbidity should be low (preferably < 1 nephelometric turbidity unit).
- The pH should be optimised to suit the disinfectant used (subject to the need to minimise corrosion).
- If the water temperature is more than 30˚C, the water should be monitored for amoebae.
- The reticulation system should be adequately maintained.
- The levels of disinfectant residual in the distribution system should be monitored frequently.

DETERMINING THE EFFECTIVENESS OF A DISINFECTANT

The C.*t* concept describes the relative effectiveness of a specific disinfectant against different microorganisms under specified conditions. It is determined by multiplying the concentration of residual disinfectant (in mg/L) by the contact time (in minutes). The C.*t* concept is expressed mathematically as:

$$k = C^n.t$$

where: C = concentration of residual disinfectant

n = constant (also called the coefficient of dilution)

t = contact time required for a fixed per cent of inactivation

k = constant for a specific microorganism exposed under set conditions.

Several disinfection experiments are required to determine the time to achieve a 99% kill of a test microorganism using different concentrations of the disinfectant under specific conditions. Log-log plots of the results generally result in a straight line with slope n. If the specific conditions such as the pH or temperature during chlorination are varied, then several lines result, which still follow the general C.*t* equation. Reported values for n range from 0.5 to 1.8 for most aqueous disinfectants. Generally, however, n approximates 1, and the equation is simplified to k = C.*t*.

C.*t* values for specific organisms exposed to particular disinfectants can be calculated from the graphs. A low C.*t* value indicates a strong primary disinfectant. Comparative disinfection efficiencies, based on the C.*t* concept, of four major disinfectants for *Escherichia coli,* two viruses, bacteriophage f_2 and protozoan cysts are summarised in table IS1.1.

Microorganisms are generally very susceptible to ozone, chlorine dioxide and chlorine, but less so to monochloramine. The relative speed of action of disinfectants, from most to least effective, is ozone, chlorine dioxide, hypochlorous acid, hypochlorite ion, dichloramine and monochloramine. Increased speed of action means a shorter contact time is required, increasing the flexibility of the system.

Caution should be used in applying C.*t* values to disinfection practice in the field because:

- disinfection data do not always follow exponential rates
- different isolates of the same species may have different disinfection rates, and rates also vary between different species and types of organisms
- no consideration is given to the state of growth, protection and adsorption of microorganisms, mixing, variation in disinfectant concentration, and inactivation rates
- laboratory data obtained under ideal conditions do not always relate to field conditions.

Table IS1.1 *Summary of C.t value ranges for 99% inactivation of various microorganisms by disinfectants at 5˚C*

Microorganisms	**Free chlorine pH 6–7**	**Preformed chloramine pH 8–9**	**Chlorine dioxide pH 6–7**	**Ozone pH 6–7**
Escherichia coli	0.034–0.05	95–180	0.4–0.75	0.02
Polio 1	1.1–2.5	768–3740	0.2–6.7	0.1–0.2
Rotavirus	0.01–0.05	3806–6470	0.2–2.2	0.006–0.6
Phage f_2	0.08–0.18	–	–	–
Giardia intestinalis cysts	47– >150	–	–	0.5–0.6
Giardia muris cysts	30–630	–	7.2–18.5	1.8–2.0

Source: Hoff JC (1986) Inactivation of Microbial Agents by Chemical Disinfectants, Report EPA/600/2–86, Water Engineering Research Laboratory, United States Environmental Protection Agency, Cincinnati, Ohio, United States.

Choice of disinfectant

INFORMATION SHEET 1.1

Each of the various ways of disinfecting drinking water has advantages and disadvantages. The most appropriate disinfectant will depend on local conditions and the choice will generally involve a compromise. The most commonly used disinfectants are chlorine, chloramine and ozone, followed by chlorine dioxide and UV irradiation (see Information Sheets 1.2–1.7). The applicability of these commonly used disinfectants is summarised in the table below.

Table IS1.2 *Applicability of disinfection techniques to different situations*

Consideration	Chlorine	Chloramination	Ozone	Chlorine dioxide	Ultraviolet
Size of plant	All sizes	All sizes	Medium to large	Small to medium	Small to medium
Equipment reliability	Good	Good	Fair to good	Good	Fair to good
Relative complexity of technology	Simple to moderate	Simple to moderate	Complex	Moderate	Simple to moderate
Safety concerns	Yes	Yes	Moderate	Yes	Minimal
Bactericidal	Good	Good	Good	Good	Good
Virucidal	Moderate	Poor	Good	Good	Good
Byproducts of possible health concern	Yes	Fewer	Significance unresolved	Yes	No
Persistent residual	Moderate	Long	None	Moderate	None
Contact time	Moderate	Moderate	Short	Moderate	Short
pH dependent	Yes	Yes	Slight	Slight	No
Process control	Well developed	Well developed	Developing	Developing	Developing

Chlorine

INFORMATION SHEET 1.2

GENERAL DESCRIPTION

Chlorine was introduced as a water disinfectant early in the 20th century and still remains the major chemical in use for this purpose around the world. It is a strong disinfectant with excellent bactericidal properties, and is effective at short contact times. It is also a strong oxidising agent that can bleach colour compounds in water, oxidise iron and manganese, and remove the tastes and odours produced by some algae.

In water, chlorine reacts to form hypochlorous acid (HOCl), a very effective disinfectant. The hypochlorous acid dissociates to form hypochlorite ion (OCl^-) which is estimated to be 150 to 300 times less effective as a disinfectant than hypochlorous acid. (See also Section V – Fact Sheet – *Chlorine*).

APPLICABILITY

Chlorine is suitable for all sizes of plant and is easy to apply either as a gas or as the hypochlorite (calcium hypochlorite powder or sodium hypochlorite liquid).

EFFECTIVENESS AGAINST MICROORGANISMS

Chlorine is highly effective against bacteria, moderately so against most viruses and is effective against the protozoan parasite *Giardia*. The concentrations of chlorine that can safely be used in disinfecting drinking water are ineffective against *Cryptosporidium*.

GENERAL CONSIDERATIONS FOR USE

Reliable equipment is available for chlorination, the technology involved is simple to moderate and controls for the process are well developed. Natural water contains inorganic and organic compounds that react with chlorine. Sufficient disinfectant must be used to satisfy this demand and still provide the required dose for disinfection.

TURBIDITY AND PH

Turbidity should be less than one nephelometric turbidity unit. Chlorination requires a pH of less than 8 because the relative proportions of HOCl and OCl^- in solution depend on pH and, to a lesser extent, on temperature. Lower pH and temperature result in higher proportions of HOCl:

- at 0ºC and pH 7, 83% exists as HOCl
- at 0ºC and pH 8.5, 14% exists as HOCl.

Decreasing the pH at the point of disinfection increases the efficiency of chlorine disinfection (by increasing the proportion of HOCL relative to OCl^-), but also increases the corrosion potential of the water.

CONTACT TIME AND PERSISTENT RESIDUAL

In clean water, a combined available residual chlorine level of 0.5 mg/L after a contact time of 30 minutes should be sufficient to ensure microbial control, given a clean distribution system and no significant recontamination.

Maintaining a persistent chlorine residual throughout the distribution system can be difficult, particularly in long distribution systems. However, in a number of treated water supply systems in Europe where treatment (including disinfection) produces a biologically stable water that will not support microbial growth, chlorine residuals can be maintained within the distribution system. In such systems, the loss of a chlorine residual can highlight an area of contamination and the need for remedial action. The extensive water treatment practised and the minimal chlorine doses used also minimise levels of disinfection byproducts.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

Reactions with naturally occurring organic matter produce chlorinated byproducts, particularly the trihalomethanes. Chlorine may also react with compounds such as phenols to impart a taste and odour to water.

Chloramines

INFORMATION SHEET 1.3

GENERAL DESCRIPTION

Chloramines (principally monochloramine) are formed when chlorine and ammonia are added to water:

$NH_3 + HOCl \longrightarrow NH_2Cl + H_2O$

monochloramine

$NH_2Cl + HOCl \longrightarrow NHCl_2 + H_2O$

dichloramine

$NHCl_2 + HOCl \longrightarrow NCl_3 + H_2O$

nitrogen trichloride (trichloramine)

Dichloramine is a stronger disinfectant than monochloramine, but is less stable and has a distinct disagreeable odour. Nitrogen trichloride has an extremely offensive odour, but is readily destroyed by sunlight.

Chloramines are weaker oxidising agents than chlorine; therefore, they are less likely to cause undesirable tastes and odours by oxidation of natural organics, but are also less likely to reduce tastes and odours produced by algae.

APPLICABILITY

Chloramination is suitable for all sizes of plant. Field results from most Australian systems that use chloramine indicate satisfactory primary disinfection capability and continued protection in reticulation systems. Chloraminated water is unsuitable for use in renal dialysis; the chloramine must first be removed by activated carbon filters.

EFFECTIVENESS AGAINST MICROORGANISMS

The biocidal activity of chloramines is slower than that of free chlorine. Chloramine is effective against bacteria but its activity against viruses is poor.

GENERAL CONSIDERATIONS FOR USE

Reliable equipment is available for chloramination, the technology involved is simple to moderate and controls for the process are well developed. To ensure that monochloramine is the major species formed at normal pH levels (7.5–8.0), the ratio of chlorine to ammonia is controlled at levels of 3:1 to 5:1.

Problems have occurred with open online storages where nitrification and the loss of chloramine residuals result in high levels of nitrite nitrogen at the ends of systems. Nitrification also accelerates the loss of chloramine, and often requires chlorination of infected storages to eliminate nitrifying bacteria and re-establish the chloramine residual.

TURBIDITY AND pH

Turbidity should be less than one nephelometric turbidity unit. Chloramination requires a pH of 8–9 because low pH (together with a high ratio of chlorine to ammonia) favours the formation of the less stable chloramines.

CONTACT TIME AND PERSISTENT RESIDUAL

Monochloramine is a weak disinfectant; it requires a contact time of many hours and a residual of 1.5 mg/L to be effective. However, chloramine persists in distribution systems and continues to disinfect in the extremities of long systems. The high stability of chloramines can be a disadvantage in some instances. Low levels of chloramines are acutely toxic to a variety of aquatic organisms and this must be considered when introducing chloramines to storages and aquariums.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

Provided that chloramines are formed by pre-ammoniation, chloramination produces considerably lower concentrations of trihalomethanes and other chlorinated byproducts than chlorination. Chloramination produces higher concentrations of cyanogen chloride than does chlorination, but the concentrations detected are still considerably lower than the guideline value for this compound (See also Section V – Fact Sheet – *Cyanogen chlorine*). No additional byproducts have been identified as a result of chloramination.

Chlorine dioxide

INFORMATION SHEET 1.4

GENERAL DESCRIPTION

Chlorine dioxide is a reactive gas that cannot be easily stored or transported, and must be generated on site. In Europe this is usually done by acid treatment of sodium chlorite, which generates the gas with little or no chlorine contamination and so avoids the formation of chlorinated byproducts during disinfection.

Chlorine dioxide is a more effective disinfectant than chlorine, although the overall kinetics of bacterial destruction appear to be similar. It has excellent oxidising ability, which reduces taste, minimises colour and oxidises iron and manganese complexes.

APPLICABILITY

Chlorine dioxide is a suitable disinfectant for a small to medium sized water treatment plant. It has been used mainly as a preoxidant (rather than as a primary disinfectant) to control taste and odour, remove iron and manganese, and more recently, remove trihalomethane and total organic halogen (TOX) precursors. In some supplies chlorine dioxide has been used in combination with chloramination.

EFFECTIVENESS AGAINST MICROORGANISMS

Chlorine dioxide has excellent biocidal activity; it is effective against bacteria and viruses.

GENERAL CONSIDERATIONS FOR USE

Reliable equipment is available for disinfection with chlorine dioxide, the technology involved is moderately complex and controls for the process are developing. In raw water, chlorine dioxide is rapidly consumed and volatilised, and this is a major disadvantage.

TURBIDITY AND pH

Turbidity should be less than one nephelometric turbidity unit. Disinfection with chlorine dioxide requires a pH of less than 8. Its effectiveness increases about three-fold between pH 6 and 9.

CONTACT TIME AND PERSISTENT RESIDUAL

The dose of chlorine dioxide required is 1–2.5 mg/L or slightly higher, with residuals of 0.3 mg/L or less, for a contact time of 30 minutes. Chlorine dioxide provides a moderately persistent residual.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

End products from the use of chlorine dioxide include chloride ions, chlorite ions, chlorate ions and residual chlorine dioxide. The oxidative end products have been found to be a health hazard. (See also Section V – Fact Sheet – *Chlorine dioxide*)

Ozone

INFORMATION SHEET 1.5

GENERAL DESCRIPTION

Ozone is generated on site by passing an electric discharge through clean dry air or oxygen. The resultant ozone is a very strong biocide and oxidising agent and is effective in reducing colour, iron, manganese, taste and odour.

APPLICABILITY

Ozone can be used in medium to large treatment plants although it has not been used in Australia to date for the disinfection of sizeable potable water supplies. It reacts with natural organics to produce lower molecular weight compounds, which are more biodegradable and promote the growth of bacteria in distribution systems. This can be used to advantage in biological filtration processes. Ozonation can break up high molecular weight organics before filtration through a bed of granular activated carbon, and the resulting low molecular weight compounds can be used by bacteria that grow on the carbon, thereby reducing organic concentrations in the water. In Europe, ozone has a long history of use for disinfection and for the control of taste, odour and colour. Ozone is more expensive than chlorine and has low solubility in water.

EFFECTIVENESS AGAINST MICROORGANISMS

Ozone is effective against bacteria and viruses.

GENERAL CONSIDERATIONS FOR USE

The equipment used for ozonisation is fairly reliable but the technology involved is complex and process controls are developing. Ozone is highly sensitive to turbidity.

TURBIDITY AND PH

Turbidity should be less than one nephelometric turbidity unit. The pH should be less than 8 for effective disinfection because ozone is unstable above pH 8 (at pH 8, half of the ozone is lost in less than 30 minutes).

PERSISTENT RESIDUAL

Due to its low solubility in water and instability above pH 8, an ozone residual cannot be maintained in a distribution system, particularly as temperature increases.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

Ozone is a powerful oxidant and can convert naturally occurring bromide to bromine, and this can lead to the formation of brominated trihalomethanes (THMs). However, the brominated THMs produced in ozonation usually occur in lower concentrations, and constitute less of a problem, than chlorinated THMs produced by chlorination. Interest in ozonation has increased significantly in the United States in recent years since the adoption of stringent limits for trihalomethanes and because of the need for a strong oxidant and primary disinfectant to replace chlorine for pretreatment.

Low molecular weight aldehydes such as formaldehyde and acetaldehyde have also been detected as byproducts of ozonation.

Ultraviolet light

INFORMATION SHEET 1.6

GENERAL DESCRIPTION

Ultraviolet light (UV) is generated by low-pressure mercury lamps. UV irradiation disrupts the chemical bond of many organic molecules and hence is a potent disinfectant.

UV irradiation has a minimal effect on the chemical composition or taste of the water. Overdosing presents no danger and is sometimes contrived as a safety factor.

APPLICABILITY

UV irradiation is applicable to small or medium sized treatment plants. Internationally, UV irradiation has found numerous applications in situations where lack of a disinfection residual is not important, such as point-of-use disinfection in hospitals.

EFFECTIVENESS AGAINST MICROORGANISMS

UV irradiation is effective against bacteria and viruses. It causes specific deleterious changes in the nucleic acid of cells, resulting in death or mutation such that the cell is no longer capable of division. Microorganisms may, however, become viable again in the presence of visible light (photoreactivation) if UV disinfection is inadequate. Varying intensities of UV irradiation are required for removal of different microorganisms, with the recommended dose being of the order of 16–46 mW–sec/cm^2; the higher dose is roughly equivalent to chlorine in instantaneous disinfection efficiency.

GENERAL CONSIDERATIONS FOR USE

The equipment required for UV irradiation is fairly reliable, the technology required is relatively simple and controls for the process are being developed. High colour and turbidity and the presence of metals and organic matter reduce the amount of UV radiation reaching microorganisms and necessitate higher doses of applied radiation for effective disinfection. Units require regular cleaning and maintenance to remain effective.

TURBIDITY AND PH

Turbidity should be less than one nephelometric turbidity unit. UV irradiation is not pH dependent.

CONTACT TIME AND PERSISTENT RESIDUAL

UV requires only a short contact time, but has a disadvantage in that it leaves no residual disinfectant.

BYPRODUCTS OF POSSIBLE HEALTH CONCERN

Few data are available on the byproducts of UV disinfection; however, the potential to produce organic byproducts is minor because the intensities required for UV disinfection are less than those needed to cause photochemical effects.

Other disinfectants

INFORMATION SHEET 1.7

BROMINE

Bromine has been widely used to disinfect swimming pools through the addition of solid bromine-releasing agents such as N-bromo-N-chloro-5,5-dimethylhydantoin or dibromocyanuric acid. Bromine chloride (BrCl) is under investigation for large-scale use, such as control of biofouling in cooling towers or wastewater disinfection, as it is much less corrosive than liquid bromine and has sufficient vapour pressure to enable it to be metered in equipment similar to that used for chlorine.

IODINE

Iodine has been used as a disinfectant for small drinking water supplies; however, like bromine, it is costly to use on a municipal scale. It is not recommended for regular use as a disinfectant due to possible health effects associated with long-term consumption. It can, however, be used for emergency water disinfection. (See also Section V – Fact Sheet – *Iodine*).

POTASSIUM PERMANGANATE AND HYDROGEN PEROXIDE

Potassium permanganate and hydrogen peroxide are effective disinfectants that are not used in large-scale plants, but may be used in small-scale or emergency applications. Recently, hydrogen peroxide has been used in conjunction with ozone (peroxone) to provide a more effective oxidising agent, particularly to remove taste and odour metabolites. Peroxone and ozone are equally effective for disinfection.

HEAT

Heat is the traditional emergency disinfectant, and boiling water under normal conditions will kill most pathogens.

SILVER

Silver is a weak biocide that has been used occasionally for disinfection, particularly with point-of-use devices. (See also Section V – Fact Sheet – *Silver)*.

ULTRASONICS AND ULTRAFILTRATION

Ultrasonics can disintegrate microorganisms and ultrafiltration of waters can remove microorganisms: these methods are used for special applications.

EXTREMES OF PH

Altering the pH to greater than 12 or less than 2 will kill microorganisms; however, this is not recommended for permanent water supplies as it causes adverse health effects, and also affects distribution system pipework. As with many of the alternative disinfectants listed here, such an option is relatively expensive and is only considered for small-scale, emergency, or specialist applications. (See also Section V – Fact Sheet – *pH*).

Sampling Information – handling requirements and preservation

INFORMATION SHEET 2.1

This sheet gives information of general handling requirements for heavy metals, filterable metals, organic compounds and pesticides and microbial characteristics, and a summary of the special handling requirements for sampling for physical, chemical and radiological characteristics.

SAMPLING FOR HEAVY METALS

Treatment of the sample with acid at the time of collection places the metals in solution and prevents adsorption or deposition on the container walls. 1.5 mL of concentrated nitric acid per litre of sample is usually sufficient for short-term preservation. The sample should be stored at approximately 4ºC. It will be stable for up to 28 days.

Some laboratories will supply acid-washed bottles with the acid preservative. When such bottles are not available, samples should be collected in acid-washed bottles, and preserved immediately by acidifying with concentrated nitric acid to pH < 2. The advice of the analyst should be sought prior to taking a sample.

Mercury and chromium have special requirements. An analyst should be consulted before collection of samples.

Procedure for acid washing:

1. Wash bottle and cap with a metal-free, nonionic detergent and tap water.
2. Rinse thoroughly with tap water.
3. Rinse with one part distilled water, one part concentrated nitric acid.
4. Drain and fill with one part concentrated nitric acid, fourteen parts water.
5. Cap and store until required, but for at least a week.
6. Empty before use, rinse with metal-free water such as distilled water.

Metals can be divided into various fractions as determined by the analytical Information:

- Filterable metals (soluble or dissolved metals) – those constituents of an unacidified sample that pass a 0.45 µm membrane filter.
- Suspended metals – those constituents of an unacidified sample that are retained on a 0.45 µm membrane filter.
- Total metals – the concentration of metals determined on an unfiltered sample after vigorous digestion, or the sum of the concentrations of metals in both the filterable and suspended fractions. Total metals include all metals inorganically and organically bound, both filterable and particulate.
- Acid-extractable metals – the concentration of metals in solution after treatment of an unfiltered sample with hot mineral acid.
- Readily acid-soluble aluminium (see Section V – Fact Sheet – *Aluminium*).

The fraction(s) to be analysed will determine the requirements for sample handling and preservation. It is generally advisable to collect two samples, one for total metals and one for dissolved metals.

PRELIMINARY FILTRATION FOR FILTERABLE METALS

The membrane filter and filter device should be preconditioned by rinsing with deionised or distilled water, or soaking the membrane filter and filter device in approximately one part distilled water, one part nitric acid, and rinsing with deionised or distilled water before use.

- Before use, a blank consisting of deionised or distilled water should be filtered to ensure freedom from contamination.
- The sample should be filtered as soon as possible after collection, discarding the first 50 mL of filtrate, and the filtrate should be acidified with nitric acid to below pH 2.
- If suspended metals are to be determined, the filter should be retained for digestion.

Care must be taken to avoid introducing contaminating metals from containers, lids, distilled or deionised water, acid preservative, or membrane filters; or from airborne contaminants in the form of smoke, dust, soot or aerosols.

SAMPLING FOR ORGANIC COMPOUNDS AND PESTICIDES

Because organic compounds and pesticides, if present at all, are likely to occur only in very low concentrations, considerable care is needed in choosing and preparing sample containers. Bottles supplied by the analyst should be used, and the analyst's instructions for sample handling and preservation followed. These instructions will vary with the compound being analysed and the methods of analysis used by the laboratory.

SAMPLING FOR MICROBIAL CHARACTERISTICS

- Sufficient sodium thiosulfate should be added to the sample bottle to neutralise all residual chlorine.[1]
- A chelating agent should be used in bottles receiving water containing copper, zinc or other heavy metals.
- Drinking water samples should be taken directly from a service pipe, not from an intermediate tank or cistern.
- The bottle should not be filled to the top (leave an air space of at least 2.5 cm).
- An ice-filled cooler should be used to transport samples to the laboratory.

The sample should, ideally, be analysed within 6 hours. Under exceptional circumstances the elapsed time may exceed 6 hours, but should not exceed 24 hours. If 6 hours is exceeded, the time interval should be reported with the results.[2]

1 – APHA Method 9060, (1992), Microbiological Examination: Samples, Standard Methods for the Examination of Water and Wastewater. 18th Edition, American Public Health Assoc., Wahington, United States

2 – AS 2031.2, (1987), Selection of containers and preservation of water samples for chemical and microbiological analysis. Part 2: Microbiological, Standards Association of Australia

Table IS2.1 *Special handling requirements for sampling for chemical, physical and radiological characteristics*[3]

Characteristic	Container	Minimum sample size (mL)	Preservation procedure	Maximum holding period	Comments
Aluminium	P(A), G(A)	100	Add HNO_3 to pH < 2	28 days	
Arsenic	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Boron	P	500	None required	28 days	
Cadmium	P(A), P(G)	500	Add HNO_3 to pH < 2	28 days	
Chloride	P, G	100	None required	6 months	
Chlorine residual	P, G	200	Analyse immediately	5 minutes	Keep sample out of direct sunlight
Chromium (total)	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Chromium (VI)	P(A), G(A)	1000	Refrigerate	24 hours	Avoid adding reagents
Colour	P, G	100	Refrigerate	24 hours	
Copper	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Cyanide (total)	P, G	500	Add NaOH to pH > 12, refrigerate in the dark	24 hours	Remove sulfide
Fluoride	P	500	None required	28 days	
Hardness	P, G	200		7 days	
Iron	P(A), G(A)	100	Add HNO_3 to pH < 2	28 days	
Lead	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Manganese	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	
Mercury	G(B), (A)	500	Add HNO_3 to unfiltered sample to pH < 1. Add $K_2Cr_2O_3$		Consult analyst for further instruction
Metals (general)	P(A), G(A)		Add HNO_3 to pH < 2	28 days	
Metals (filterable)	P(A), G(A)		Filter immediately, add HNO_3 to pH < 2	28 days	0.45 µm filter
Nitrate	P, G	500	1. Refrigerate or 2. Freeze immediately or 3. Add H_2SO_4 to pH < 2 and refrigerate	6 hours 7 days 7 days	Consult analyst – depends on analytical method
Odour	G	500	Analyse as soon as possible; refrigerate	6 hours	
Oxygen, dissolved	G(A)	300	1. Electrode: analyse immediately on site 2. Winkler: titration may be delayed after acidification	*In situ* 24 hours	Consult with analyst. Store in dark
Pesticides					
1. Organo-phosphates	G(S)	2000	No reference available	No reference available	Consult with analyst
2. Others	G(S)	4000	Solvent-extract on-site with appropriate solvent; refrigerate	24 hours	If residual chlorine present , add 1000 mg/L ascorbic acid. Consult with analyst

3 – Data complied from AS 2031.1–1986, Selection of Containers and Preservation of Water Samples for Chemical and Microbiological Analysis, Part 1–Chemical, APHA Method 1060 (1992).

Table IS2.1 *Special handling requirements for sampling for chemical, physical and radiological characteristics[3] (Continued)*

Characteristic	Container	Minimum sample size (mL)	Preservation procedure	Maximum holding period	Comments
pH	P, G(B)	100	Analyse immediately; determine on site or *in situ*	6 hours	
Polycyclic aromatic hydrocarbons (PAH)	G(S)	2000	1. Add 1000 mL of methanol to container before adding an equal volume of sample; or	7 days	
			2. Add extracting solvent on site	24 hours	
Radioactivity gross *alpha* and *beta* activity	P(A), G(A)	1000	Add HNO_3 to pH < 2	28 days	Consult with analyst
Selenium	P(A), G(A)	1000	Add HNO_3 to pH < 2	28 days	
Sodium	P	100	None required	28 days	
Sulfate	P(A)	200	Refrigerate	7 days	
Taste	G	500	Analyse as soon as possible, refrigerate	24 hours	
Temperature	–	–	Analyse immediately allowed	No storage allowed	Determine in situ
Total dissolved solids	P, G	500	Refrigerate	28 days	
Trihalomethanes	G(S)	100	Add 2 mL of 5% ascorbic acid solution. Fill bottle to brim.	21 days	
Turbidity	P, G	100	Analyse same day, store in dark, refrigerate	24 hours	Preferably determine on–site or *in situ*
Zinc	P(A), G(A)	500	Add HNO_3 to pH < 2	28 days	

Container	P	= Plastic (polyethylene or equivalent)
	G	= Glass
	G(B)	= Glass, borosilicate
	P(A), G(A)	= Rinsed with 50% HNO_3
	G(S)	= Glass, rinsed with organic solvent
Preservation	Refrigerate	= Store between 1 and 4°C in the dark, do not freeze
	HNO_3	= Nitric acid (hydrochloric acid may be used in this context but nitric acid is preferred)
	NaOH	= Sodium hydroxide solution (40% w/v)
	H_2SO_4	= Sulfuric acid
	$K_2Cr_2O_3$	= Potassium dichromate

3 – Data complied from AS 2031.1–1986, Selection of Containers and Preservation of Water Samples for Chemical and Microbiological Analysis, Part 1–Chemical, APHA Method 1060 (1992).

Statistics – assessing performance

INFORMATION SHEET 3.1

PRELIMINARY CONSIDERATIONS

In deciding how the performance of a water supply system should be assessed, it is necessary to consider:

- the statistical implications of the assessment mechanism
- possible health implications of using different statistical measures
- community perceptions of what constitutes good quality water.

Three commonly used procedures measure performance against a maximum value, a mean or a percentile.[4]

ASSESSING PERFORMANCE AGAINST A MAXIMUM VALUE

Using this approach, performance is measured by quoting the percentage of scheduled samples tested that are below the guideline value. Although the approach is used often and is superficially easy to comprehend, it has a number of serious deficiencies:

- While measurements will show how a system is performing at the time of sampling, there is no way of determining what the water quality is like between sampling events. Statistical procedures cannot be used to indicate whether or not the measurements are representative of the quality at other times. (Other methods of assessing performance, however, can provide this information.)
- There is no way of reliably estimating what the true maximum value is, as this may well occur between samples. Any sampling program can only provide a biased estimate of the true maximum value, which it will invariably underestimate. There is always the possibility that the next sample analysed may have a higher value.
- The approach can create a real disincentive to rational planning of monitoring programs, as it may persuade water authorities to take a minimum number of samples in order to reduce the possibility of poor performance.

ASSESSING PERFORMANCE AGAINST A MEAN

Performance is assessed by comparing the mean value of measurements with the guideline value over a period (usually 12 months). Such an approach has a number of attractions:

- For characteristics not related to health, the guideline values are generally midpoints in a range of acceptability rather than maximum values, and thus it can be argued that it is the mean or average value that is significant. In many cases it is sudden large increases in a value that can bring an increased number of consumer complaints.
- Simple and well-proven statistical procedures can be used to provide statistically unbiased estimates of the mean with a known degree of confidence. The degree of confidence (or the confidence interval) will determine how well the mean represents the quality between sampling events.
- Use of a mean value encourages rational planning of monitoring programs. Water that fails to meet the guideline will encourage more sampling, and good quality water less sampling. These are positive incentives to the water manager to 'get it right'.

The disadvantage of this approach is that a few high values can be offset by a number of low values. This is less of a problem if confidence intervals are applied to the estimate of the mean.

4 – Data complied from AS 2031.1–1986, Selection of Containers and Preservation of Water Samples for Chemical and Microbiological Analysis, Part 1–Chemical, APHA Method 1060 (1992).

ASSESSING PERFORMANCE AGAINST A PERCENTILE

Using this approach, performance is satisfactory if a large percentage of results (although not necessarily all) are less than the guideline value. Like the use of a mean, this approach has a number of attractions:

- For health-related characteristics, performance could not be regarded as satisfactory if the guideline values were exceeded on more than the rare occasion. This is consistent with using a high percentile such as a 95th percentile (higher values could be used if required).
- Although this approach is slightly less satisfactory than requiring all the results to be less than the guideline value, it avoids the difficulties associated with a 'maximum value' approach. Most importantly, it is possible, using statistical procedures, to estimate with a known degree of confidence how well the results of sampling represent the quality of water at other times.
- Using a percentile to assess performance against the guideline is consistent with the requirement that the upper control limit of the control chart be equal to or less than the guideline value. Say, for example, that the 95th percentile is used. If the control limits are placed at 1.64 times the standard deviation on either side of the mean then, as discussed above, they will encompass about 90% of the data, and of the remaining 10%, about 5% will be above the upper control limit and 5% below the lower (provided the data are not skewed). This means that if the upper control limit is the same as or less than the guideline value, then 95% or more of the data should be below the guideline value.
- Poor quality water will encourage more sampling, while good quality water will encourage less sampling.
- More samples need to be analysed to assess performance against a percentile than are needed for a mean. This is reasonable for health-related characteristics, as exceeding the guideline may have significant health effects in some cases. More sampling provides a greater degree of protection.

The main disadvantage of this approach is that estimates of percentiles are inherently more uncertain than estimates of means.

Statistics – statistical principles

INFORMATION SHEET 3.2

Statistical advice should be sought in devising a sampling program; however, this sheet sets out some general principles and considerations.

When a mean or the 95th percentile is calculated or estimated from a given number of samples, the question arises, how accurately does the figure represent the true mean or 95th percentile? In order to answer this question, some basic statistical principles must be understood.

MEASUREMENT ERROR

A set of results is no more than a series of snapshots of some process over the period of sampling. A statistic calculated from these results, such as a percentile, a mean, or a standard deviation, can never exactly coincide with the true statistic, except by chance. The true statistic could only be determined by continuous error-free measurement of every drop of water – an impossibility in water quality analysis.

Values determined experimentally from a set of measurements are, thus, often referred to as estimates of the true statistic. These estimates may be too high or too low – there is no way of knowing. This uncertainty is known as the measurement error (although the term 'error' is unfortunate as it really means 'small departures from the true result', not mistakes made in analysis), and quantification of this error is the central purpose of statistical methods.

NORMAL AND SKEWED DISTRIBUTIONS

When analysing chemical or physical data, particularly large data sets, it is common to find that measurements are fairly evenly distributed about the mean, with most measurements very close to the mean (slightly below, slightly above, or at the mean), and progressively fewer measurements as one moves away from the mean. This type of distribution is called a normal distribution and, when plotted as a frequency distribution, forms a characteristic bell-shaped curve. The normal distribution has special significance in statistics, with a number of useful properties. It is symmetric about the mean, and is defined by only two parameters – the mean and the standard deviation. As a result, a number of simple statistical procedures have been developed to deal with data that follow a normal distribution.

If the data set is skewed, a higher proportion of the data will be on one side of the mean than the other, giving rise to an asymmetric distribution. From a statistical point of view, it is more difficult to deal with a skewed distribution. Fortunately, if the data set is large enough, it will usually approximate a normal distribution.

There are statistical tests that can be used to determine whether a set of data is approximately normal[5] and if in doubt, these tests should be applied. A simple check, however, is to compare the mean and the median (the median is the midpoint in the data, such that half the data are greater in magnitude than the median, and half are less). If the two are close, then the data are likely to be evenly distributed about the mean and probably follow a normal distribution. Transforming highly skewed data (e.g. by taking logarithms) can often be used to generate a pseudonormal data set that can then be analysed as if it were normal. If data are transformed prior to analysis then the reverse transformation must be applied to the calculated statistics.

5 – Sokal RR and Rohlf FJ (1969). ***Biometry.*** WH Freeman and Company, San Francisco.

CONFIDENCE INTERVALS

The uncertainty in the estimated percentile or mean can be measured by the confidence interval. The confidence interval specifies upper and lower limits, so that within a known probability, the interval covers the true percentile or true mean.

The confidence interval for a normal distribution can be calculated from the number of samples, the mean, and the standard deviation. A confidence interval for the mean, or the 95th percentile, is {z-D, z+D}, where z is the mean or the 95th percentile, and the term D is derived from the standard deviation and the number of results (D is known as the precision, and is equal to half the width of the confidence interval).

The formula used to calculate D is:

$$D = \frac{t(a) \times s \times h}{\sqrt{n}}$$

where: h = an uncertainty factor in estimating percentiles: for the 95th percentile it is equal to 1.64; for the mean it is equal to 1

t(a) = Student's t statistic with (n–1) degrees of freedom corresponding to a single tail probability of *a* (or a confidence of 100 ((1–2a)%)

n = number of independent random samples

t(*a*), known as the Student's t statistic, is a mathematical function that is commonly used in statistics. If more than 20 results are available, it is common to use t(*a*) = 2 at the 95% confidence level. More precise values for the Student's t-statistic for different values of n, and for different degrees of confidence, are given in statistical tables.

For example, suppose that:

mean = 10

standard deviation = 5

number of results = 25

then:

$$D = \frac{2 \times 5}{\sqrt{n}} = 0.7$$

Hence, in this example, the 95% confidence interval for the mean is {10–2, 10+2} or {8, 12}. Another way of expressing this is to say that there is a 95% chance that the interval {8, 12} contains the true mean.

The 95th percentile can be estimated using the mean and the standard deviation (s):

95th percentile = mean + 1.64 x s

The confidence interval for the 95th percentile is calculated in the same way as given above.

It is important to note that, for a given probability (or degree of confidence), the confidence interval becomes narrower as the number of results increases (i.e. the more sample results available, the greater the confidence in the estimate of the mean or percentile). This is a function of the Student's t statistic (or the t(*a*) value), which becomes smaller as the number of results increases, and of the √n term in the denominator in the above equation.

Box IS3.1 *– Assessment of turbidity data*

Turbidity is a non-health related characteristic and consequently performance can be assessed using the mean value of results for the last 12 months. For the monthly data given below (turbidity in nephelometric turbidity units, or NTU):

1.8, 3.2, 1.4, 2.8, 2.6, 1.2, 1.5, 5.2, 3.2, 3.4, 3.4, 2.8

Mean = 2.7

Standard deviation = 1.1

t(a) = 2.2 for 12 results (which equals 11 degrees of freedom, i.e. n – 1)

Hence:

$$D = \frac{2.2 \times 1.1}{3.46} = 0.7$$

Therefore for the above data, performance can be quoted as follows:

Guideline value = 5 NTU

Mean = 2.7 ± 0.7 (with 95% confidence)

It could therefore be concluded that performance is satisfactory as the upper bound of the confidence interval (2.7 + 0.7 = 3.6) is below the guideline value.

Box IS3.2 *– Assessment of trihalomethane data*

Trihalomethanes (THMs) are health-related, and consequently performance can be assessed using the 95th percentile of results for the last 12 months. For the monthly data given below (THMs in mg/L):

0.295, 0.250, 0.209, 0.222, 0.214, 0.211, 0.138, 0.143, 0.087, 0.093, 0.090, 0.200

Mean = 0.180

Standard deviation = 0.068

95th percentile = mean + 1.64 x s

= 0.180 + 1.64 (0.068 = 0.290

t(a) = 2.2 for 12 results (which equals 11 degrees of freedom, i.e. n – 1)

Hence:

$$D = \frac{2.2 \times 0.068 \times 1.64}{3.46} = 0.07$$

Therefore for the THM data, performance can be quoted as follows:

Guideline value = 0.25 mg/L

95th percentile = 0.29 ± 0.07 (with 95% confidence)

It could therefore be concluded that performance is unsatisfactory as the upper bound of the confidence interval (0.29 + 0.07 = 0.36) is above the guideline value.

OUTLIERS AND 'LESS THAN' VALUES

Two persistent problems cause difficulties in the use of the mean in assessing water quality data. These are:

- Outliers; that is, numbers that appear to be extreme when compared with other data in the data set. These are not numbers generated by some malfunction of measuring equipment or transcription errors, which clearly ought to be discarded. They are numbers that seem anomalous, although there is no obvious explanation and they cannot be discarded on technical grounds.
- Values that are recorded as less than the limit of detection.

As an example, consider the following set of data:

< 0.5, < 0.5, 1.2, 1.4, 1.45, 2.1, 21.3

The first problem is what to do about the less-than values. Should they be ignored, replaced by 0.25, replaced by 0 or should the < symbol be ignored? There is no clear answer except that it can be shown that using L/2, where L is the limit of detection, is effectively a worst-case method and not the even-handed approach it appears to be at first sight.[6] If the values below the limit of detection are critical in determining how a supply performs against the guidelines, then steps should be taken to reduce the limit of detection. Statistical treatment of values below the detection limit is possible but is complex and not entirely satisfactory.

The second problem is the very high 21.3 value. Is it genuine, or an analytical error? If it is genuine, is it valid to include it in the calculation of the mean (and hence the 95th percentile) when it will clearly have a marked effect on the result? The answer is that it must be included in the calculation as it may have an impact on the health of people receiving the water. To remove it would have the same effect as censoring the data set. Only those data points that have been clearly shown to be in error should be removed.

6 – Ellis JC (1989). Handbook on the Design and Interpretation of Monitoring Programmes, Water Research Centre, Medmenham, United Kingdom, Technical Report NS29

Number of samples required

INFORMATION SHEET 3.3

NON-MICROBIAL

It is intuitively obvious that poor quality water supplies should be more frequently monitored than good quality water supplies; this is supported by statistical arguments as shown below.

Provided the data are distributed normally, the minimum number of samples required to achieve a desired level of precision with a known degree of confidence can be determined using the following formula:

$$n = \frac{\{t(a) \times h \times s\}^2}{D}$$

Where:

- t(a) = Student's t statistic with infinite degrees of freedom corresponding to a single tail probability of a: at the 95% confidence level this value is 1.96
- h = an uncertainty factor in estimating percentiles: for the 95th percentile the value is 1.64 (at the 95% confidence level): for means the value is 1.0
- s = standard deviation
- D = precision in measurement
- n = number of samples required.

If the data are skewed then it is still possible to calculate the number of samples required but the calculation is more complex.[7]

***Box IS3.3** – Samples required to meet a guideline based on a 95th percentile*

Suppose that in the past a characteristic has been running with a mean of 20 mg/L with a standard deviation of 20 mg/L, and that for this characteristic the guideline value is 100 mg/L. The 95th percentile can be estimated as follows:

95th percentile = mean + 1.64 x s = 20 + 1.64 x 20 = 52

This is well below the guideline value. It would be possible to take fewer samples and still be confident that the guideline has been met.

To estimate the minimum number of samples necessary, the first step is to calculate the necessary precision (calculated as D in Information Sheet 3.2) by halving the difference between the 95th percentile and the guideline value:

$$\frac{(100-52)}{2} = 24 \text{ mg/L}$$

The lower limit of the confidence interval is the estimated 95th percentile, and the upper limit is the guideline value. The number of samples required to achieve this can then be calculated as follows:

$$n = \frac{\{1.96 \times 1.64 \times 20\}^2}{2} = 8 \text{ with rounding up}$$

Thus, a precision of 24 mg/L can be achieved (with 95% confidence) by taking 8 samples over the year. Alternatively, 8 samples per year will be sufficient to be sure (with 95% confidence), that the 95th percentile is less than the guideline value.

7 – Ellis JC (1989). Handbook on the Design and Interpretation of Monitoring Programmes, Water Research Centre, Medmenham, United Kingdom, Technical Report NS29

Box IS3.4 *– Samples required to meet guidelines based on 95th percentile, with a different mean*

Suppose that after taking these 8 samples it is found that the mean has drifted up to 40 mg/L but the standard deviation remains the same at 20 mg/L. The 95th percentile is now:

95th percentile = mean + 1.64 x s = 40 + 1.64 x 20 = 72

The precision now required is 14 mg/L (as 100–72/2=14 mg/L). This is a smaller value and hence the number of samples required to achieve it with the same degree of confidence will increase. In fact:

$$n = \frac{\{1.96 \times 1.64 \times 20\}}{14} = 22$$

Thus, the sampling frequency would have to be increased to 22 per year, or about 1 per fortnight, to meet this change in precision.

Box IS3.5 – Number of samples based on meeting a mean

Using the same data given in Example 2 above, the precision required can be calculated by halving the difference between the mean and the guideline value, i.e. (100–40)/2 = 30 mg/L. (The lower limit of the confidence interval in this example is the mean, and the upper limit is the guideline value). The number of samples required is then:

$$n = \frac{\{1.96 \times 20\}^2}{30} = 2 \text{ with rounding up}$$

Thus, 2 samples per year would be sufficient to be sure (with 95% confidence) that the mean is less than the guideline value. Using a mean instead of a 95th percentile can make a substantial difference to the number of samples required.

MICROBIAL

One of the aims in any sampling program, particularly microbiological sampling, is to have a high degree of confidence that the water quality as measured in the laboratory is representative of that actually used by the consumer, not just at the time of sampling, but all the time. Unless all water is sampled, it is not possible to be 100% confident that this condition is met. A properly designed sampling program, testing only a very small percentage of the total amount of water in a system, can give a high degree of confidence about the overall water quality. The degree of confidence is related to the number of samples analysed. (This assumes, of course, that the sampling locations selected are representative of the water supplied to the consumer.)

Even if all samples tested are free of bacterial indicators, no sampling program can guarantee that *all* the water in a system is free of indicator organisms. In fact it can be shown that for any reasonable sampling program, the degree of confidence in achieving a situation where 100% of the water in a system is free of bacterial contamination is close to zero (Ellis 1989).

It is far better to have a high degree of confidence that a large proportion of the water is free of contamination, than to have no confidence that all the water is uncontaminated. Realistic monitoring programs can give a high degree of confidence that 98% of all the water in a system is free of bacterial contamination.

This does *not* mean that the other 2% of water is contaminated. All it indicates is that the sampling program is statistically unable to show a high degree of confidence that more than 98% of all the water in the system is free of contamination.

Even if all samples tested are uncontaminated it does not follow that there is necessarily a high degree of confidence that the water is free from contamination. The number of samples required to meet the 98% compliance requirement, and the degree of confidence that this confers when all samples are free of contamination is shown in Figure 1 (Ellis 1989).

For example, if 50 samples are tested per year and all are free of contamination, then there is only 65% confidence that 98% of the water in the system is free of contamination. It would be necessary to take 150 samples, each free of contamination, before the degree of confidence reached 95%. Fewer than 50 samples per year, even if each sample was free of contamination, give a low degree of confidence that the water system as a whole is 98% free of contamination.

If one or more samples taken over a year are positive, then the degree of confidence that 98% of water in the system is free of contamination is reduced. This is shown in Figure 2 (Ellis 1989). Suppose, for example, that 150 samples were collected in a year but some of those samples showed faecal contamination. The degree of confidence that 98% of the water in the system is free of contamination drops from 95% with a positive result to 80% with one positive result, and 60% with two positive results.

The plateau shown in Figure 2 at the 50% confidence level is an artefact of the difficult computation procedure used to derive these graphs. The graphs should only be regarded as an approximate guide, but they nevertheless provide a highly informative summary.

REFERENCE

Ellis JC (1989) Handbook on the design and interpretation of monitoring programmes. Water Research Centre, Medmenham, UK, Report NS No 29.

Figure 1

The curve shows the level of confidence that 98% of water in a supply is free of faecal contamination for different numbers of samples when all samples tested are free of faecal contamination (from Ellis 1989, reprinted with permission of the Water Research Centre, Medmenham).

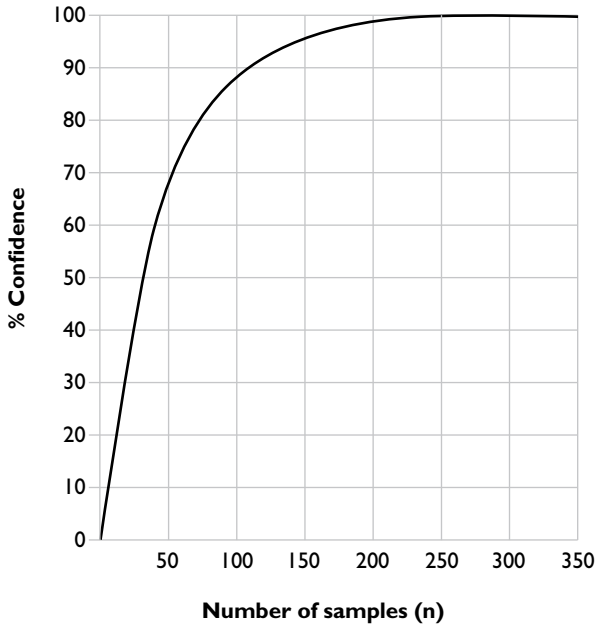
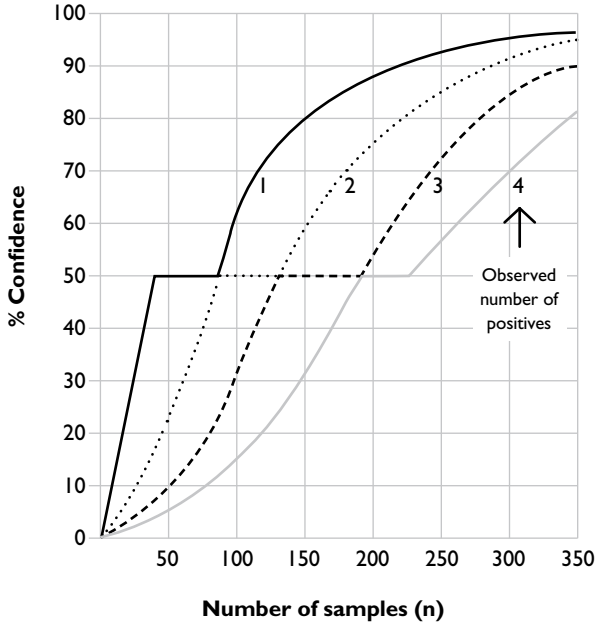


Figure 2

The curves shows the level of confidence that 98% of the water in a supply is free of faecal contamination for different numbers of samples when 1, 2, 3 or 4 samples give positive results (from Ellis; 1989, reprinted with permission of the Water Research Centre, Medmenham).



Statistics – control charts

INFORMATION SHEET 3.4

PURPOSE AND CONTENTS OF A CONTROL CHART

A control chart displays monitoring data for a given characteristic against either time or sample sequence number.[8] It has the following important features clearly marked:

- the guideline value
- each measured data point
- the mean value of the measurements
- control limits.

PURPOSE OF CONTROL LIMITS

Control limits are based on long-term monitoring data (including data from the reporting period). They are horizontal lines parallel to the mean but shifted from it by a number of standard deviations (at least 1.64), and they are calculated from the long-term standard deviation. They thus define the area within which most of the long-term data fall. Provided that the system is 'in control', most of the data for the reporting period will also lie between these limits.

Control charts can also be used to assess performance on an ongoing basis (rather than for a given reporting period), in which case the control limits and mean should be calculated from all the available data over previous years, and recalculated periodically (see figure 3).

ADVANTAGES OF USING CONTROL CHARTS TO ASSESS PERFORMANCE

There are a number of advantages in using control charts to assess performance:

- It is easy to see if data exceed the guideline value, and by what amount. A number of small excursions above the guideline value spaced well apart in time may be of less concern than one very high value or a number of closely spaced excursions.
- The difference between the mean and the guideline value can be easily seen. For some characteristics, what is critical is the total amount accumulated over a lifetime. Where the mean value for such characteristics is well below the guideline value, there may be no cause for concern, even if some individual measurements are well above the guideline. Such a pattern is clearly visible on a control chart.
- The variability in the data can be quickly determined. Characteristics with a low variability may be of less concern than those that vary markedly. Trends in the data may also be significant.
- The difference between the upper control limit, the guideline value and the mean provide a useful guide as to the likelihood that the guideline value will be exceeded at some time. If the upper control limit is well below the guideline value and close to the mean, it is unlikely that the guideline value will be exceeded. If, on the other hand, the upper control limit is close to the guideline value and distant from the mean, the guideline value is more likely to be exceeded. This can be a useful way of determining the key characteristics for monitoring.

8 – APHA Method 1010B (1992). General Introduction: Statistics, Standard Methods for the Examination of Water and Wastewater, 18th Edition. American Public Health Association, Washington, United states

SETTING CONTROL LIMITS

A decision must be made on where to place the control limits; that is, on the percentage of the long-term measured data that they will contain (see table below). The greater this percentage, and the further the upper control limit is below the guideline value, the greater the confidence that the guideline value will not be exceeded in the periods between measurements, and that the quality of the water will be regarded as good. It is suggested that the control limits should be not less than 1.64 times the long-term standard deviation: this will encompass approximately 90% of the long-term data and, provided the system remains in control, approximately 90% of the data for the reporting period. The distances for other percentages of the data are shown below. These figures are constants for any normal distribution curve, and can be determined from cumulative normal probability tables given in most statistical textbooks.

Table IS3.1 *Relationship between control limits and multiples of the standard deviation*[9]

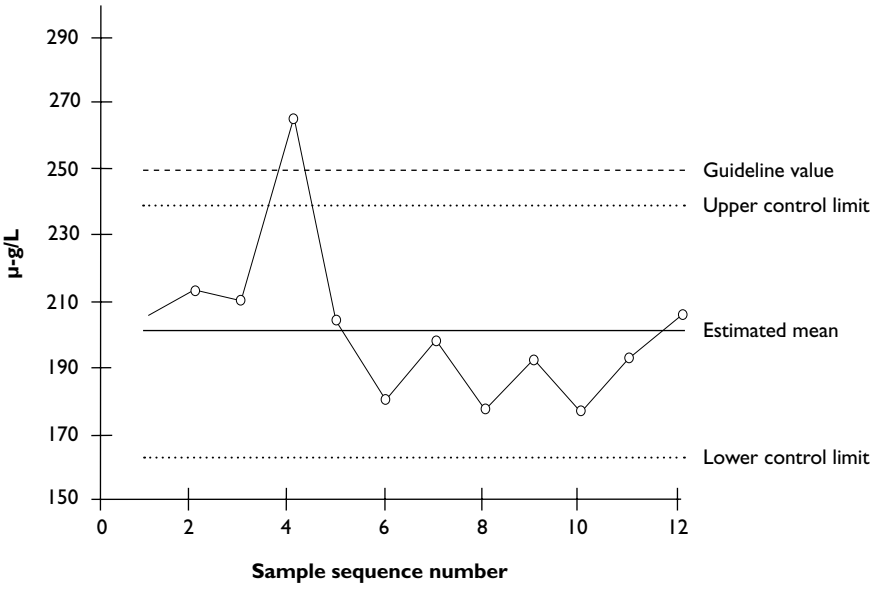
Standard deviations(s)	% of data expected to fall within the bounds
1.64 x s	90.00
1.96 x s	95.00
3.00 x s	99.85

DETERMINING THE STANDARD DEVIATION

In order to establish control limits, it is necessary to determine a reliable mean and long-term standard deviation. To obtain initial estimates of these statistics, no less than 7 and preferably 15 or more measurements are required from independent representative samples. It is clearly unsatisfactory to bias the results by selecting sampling times or locations that are favourable (or unfavourable).

Figure 3

An example of a control chart for trihalomethane data using 12 monthly measurements. The control limits have been placed at two standard deviations away from the mean.



9 – Taylor JK (1987). ***Quality assurance of chemical measurements***, Lewis Publishers, Chelsea, Michigan

PART V FACT SHEETS

Microorganisms · Bacteria

Aeromonas

GUIDELINE

***No guideline value has been set for* Aeromonas *in drinking water. The absence of* Escherichia coli *(or alternatively thermotolerant coliforms) does not indicate the absence of* Aeromonas.**

GENERAL DESCRIPTION

Aeromonas spp are gram-negative, rod-shaped, nonsporing bacteria which are presently classified in the family Vibrionaceae, although they also bear many similarities to the Enterobacteriaceae. They are isolated from certain patients with diarrhoea and may cause septicaemia.

The genus *Aeromonas* is divided into two groups. The group of psychrophilic nonmotile aeromonads consists of one species *A. salmonicida*, an obligate fish pathogen that will not be considered further here. The group of mesophilic motile aeromonads consists of three biochemically distinguishable groups: *A. hydrophila, A. sobria* and *A. caviae.* Each of these three species consists of at least three different DNA-hybridisation groups.

Aeromonas is a normal inhabitant of fresh water, and occurs in water, soil and food, particularly meat, fish and milk.

AUSTRALIAN SIGNIFICANCE

Aeromonas spp have been isolated from several drinking waters in Australia but the relationship between the isolates and clinical disease is not clear.

TREATMENT OF DRINKING WATER

Free available chlorine residuals of 0.2–0.5 mg/L are generally sufficient to control Aeromonas in distribution systems.

METHOD OF IDENTIFICATION AND DETECTION

The numbers of *Aeromonas* in drinking water can be quantified using membrane filtration and anaerobic incubation (Cunliffe and Adcock 1989).

HEALTH CONSIDERATIONS

Mesophilic aeromonads have long been known to be pathogenic for cold-blooded animals such as fish and amphibians. In humans, three types of infections are described: systemic infections, usually in people who are seriously immunocompromised; wound infections (mainly surface contact); and diarrhoea (Jana *et al* 1988). They have given rise to serious cases of septicaemia, often in people with underlying disease; and they have been linked with gastroenteritis in children (Gracey *et al* 1982), although no causative role has been established, and their significance as an enteropathogenic organism is not clear. In animal test models, such as the suckling mouse test and the rabbit ileal loop test, pure cultures of *Aeromonas* have been found to cause marked fluid accumulation. This can partially be ascribed to the production of extracellular cytotoxins; however, despite the strong toxin production by *Aeromonas* strains *in vitro*, it has not been possible to induce diarrhoea in test animals or human volunteers.

It is assumed that *Aeromonas* strains are only poorly able to colonise the gastrointestinal tract. Little information is available on adhesion factors of *Aeromonas* or their interaction with receptors in the gastrointestinal tract.

NOTE: Important general information is contained in PART II, Chapter 5

Epidemiological investigations on the significance of *Aeromonas* as an enteropathogenic organism have been contradictory. In some studies the occurrence of *Aeromonas* in faeces of patients with diarrhoea was higher than in control groups, whereas other studies showed no difference. Sometimes the bacterium was even found more often in control groups. Aeromonads have sometimes been associated with acute self-limiting gastroenteritis.

DERIVATION OF GUIDELINE

No specific guideline value can be established for *Aeromonas* because of difficulties in determining the pathogenicity of an isolate and its relevance to human health. Further work in the area is currently under way in Australia. Water must be tested directly for *Aeromonas* if their presence is suspected.

REFERENCES

Cunliffe DA and Adcock P (1989). Isolation of *Aeromonas* spp. from water by using anaerobic incubation. *Applied and Environmental Microbiology*, 55, 2138–2140.

Gracey M, Burke V and Robinson J (1982). Aeromonas-associated gastroenteritis. *Lancet*, ii, 1304–1306.

Jana JM and Duffy PS (1988). Mesophilic aeromonads in human disease: current taxonomy, laboratory identification, and infectious disease spectrum. *Reviews of Infectious Diseases*, 10, 980.

Campylobacter

GUIDELINE

***Escherichia coli* (or alternatively thermotolerant coliforms) can be used to indicate the possible presence of pathogenic Campylobacter. If explicitly sought, Campylobacter *spp* should not be detected. If detected, advice should be sought from the relevant health authority.**

GENERAL DESCRIPTION

Thermophilic *Campylobacter* spp are transmitted by the oral route, and cause gastrointestinal illness. Wild birds and poultry are the most important reservoirs of *Campylobacter*. Other domestic animals, such as pigs, cattle, dogs and cats, are also reservoirs of thermophilic *Campylobacter* organisms, and so meat, and particularly poultry products and unpasteurised milk, are important sources of *Campylobacter* infection. Milk may be contaminated with faeces or by secretion of organisms into the milk of cows with mastitis. Recent studies have shown that raw sewage frequently contains from 10 to 10^5 thermophilic *Campylobacter* organisms per 100 mL; high counts can be reduced by wastewater treatment processes. Thermophilic *campylobacters* have been found in crude sewage sludge, but were not detectable in digested conditioned sludge or filter effluent. Their occurrence in surface waters is dependent on rainfall, water temperature and the presence of water fowl.

Several waterborne outbreaks caused by *Campylobacter* spp have been reported in the past decade worldwide. The number of people involved ranged from a few to several thousand. Water was implicated in the only two of these outbreaks where *Campylobacter* was isolated from patients the main sources were found to be unchlorinated surface water and faecal contamination of water storage reservoirs by wild birds. Communities are at risk of outbreaks of campylobacteriosis from the consumption of unchlorinated or inadequately chlorinated surface waters. Contamination of drinking water reservoirs by excrement of water fowl should be controlled, particularly if *Campylobacter* contamination is suspected. Hygienic precautions should be improved in case the water is distributed without disinfection, or disinfection is interrupted.

Campylobacter spp, like other bacterial pathogens, survive well at low temperatures, and can survive for several weeks in cold groundwater or unchlorinated tap water.

The presence of thermophilic *Campylobacter* organisms in piped water supplies, whether treated or untreated, suggests a serious fault in the design or management of the system.

Two closely related genera, *Helicobacter* and *Archobactor,* include species previously identified in the *Campylobacter* genus. *Helicobacter pylori* may be differentiated from *Campylobacter* spp by a strong urease activity. It is a cause of gastritis in humans.

AUSTRALIAN SIGNIFICANCE

Campylobacter have been identified in some Australian water supplies, but there have been no reports of infections from drinking water in Australia. No information is available on *Helicobacter* spp in Australian water supplies.

NOTE: Important general information is contained in PART II, Chapter 5

TREATMENT OF DRINKING WATER

Provided the water has low turbidity, standard disinfection procedures are sufficient to prevent the spread of *Campylobacter* in distribution systems.

METHOD OF IDENTIFICATION AND DETECTION

Campylobacter are gram-negative, slender, comma-shaped rods which show a characteristic corkscrew-like motion which can be easily seen by phase contrast microscopy. They also appear S-shaped and gull-winged when in pairs. They are microaerophilic, requiring a low oxygen tension (3–6%) for growth.

There is no endorsed Australian standard method for the detection of *Campylobacter* in waters. However an Australian method for the isolation of these organisms from food may be applicable to waters (AS1766.2.13 1991). Other methods of detection are available (APHA Method 9260G 1992).

HEALTH CONSIDERATIONS

Some of the 14 described species are pathogens for humans and animals (for example *C. jejuni, C. coli, C. fetus)*, while others are considered to be nonpathogenic (for example *C. sputorum, C. concisus)* (Penner 1988). Most the members of the thermophilic group (growing at 42°C) of campylobacters cause enteritis in humans. In Australia, *Campylobacter* are very important bacterial causes of acute gastroenteritis.

Several major outbreaks of *Campylobacter* enteritis have been linked to the ingestion of contaminated food, milk or water.

DERIVATION OF GUIDELINE

Campylobacter in drinking water can cause acute gastroenteritis. As it is not possible, at this stage, to determine an infectious dose, *Campylobacter* should be absent from drinking water supplies.

REFERENCES

APHA Method 9260G, (1992). Detection of pathogenic bacteria: *Campylobacter jejuni*. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington DC.

AS 1766.2.13, (1991). Food microbiology: examination for specific organisms – *Campylobacter*. Australian Standard, Standards Association of Australia, Sydney, NSW.

Penner JL (1988). The genus *Campylobacter*: A decade of progress. *Clinical Reviews in Microbiology,* 1, 157–172.

Coliforms

(Revised 2002)

GUIDELINE

Due to the lack of direct health significance, no guideline value is proposed for coliforms (excluding* Escherichia coli*).

GENERAL DESCRIPTION

Coliforms are a diverse group of bacteria including *Escherichia coli* and other thermotolerant coliforms (see also Fact Sheet on *Escherichia coli* and *thermotolerant coliforms*). Faecal material contains large numbers of coliform bacteria but there are many species that occur naturally in the environment. Coliforms are gram-negative nonsporing rod-shaped bacteria, capable of aerobic and facultative anaerobic growth in the presence of bile salts or other surface-active agents with similar growth-inhibiting properties. They are able to ferment lactose with the production of acid within 48 hours at 35–37°C. Fermentation by these organisms begins with the cleavage of lactose into galactose and glucose by the enzyme ß-galactosidase. Coliforms are oxidase-negative.

It should be noted that the above characteristics are not taxonomic criteria, but practical working definitions used for water examination purposes.

Some test methods may identify aeromonads, which can also produce acid from lactose, as presumptive coliform organisms unless excluded by subsequent confirmatory tests. Aeromonads are oxidase positive.

TREATMENT OF DRINKING WATER

Treatment by chlorination or other acceptable forms of disinfection inactivates these microorganisms in water, provided the turbidity is low.

METHOD OF IDENTIFICATION AND DETECTION

Total coliforms can be quantified in water by using membrane filtration (MF) for concentration of the organisms from water, followed by growth in enrichment/selective media or multiple tube dilution (most probable number – MPN) procedures (AS 4276.4 and 4276.5 1995). Specific secondary tests are used with both MF and MPN procedures to confirm the identification of coliform organisms.

Alternatively, the presence of coliform bacteria can be detected by testing for the production of the enzyme ß-galactosidase (APHA method 9223 1998). Enzyme substrate tests incorporate chromogenic substrates such as ortho-nitrophenyl-ß-D-galactopyranoside (ONPG) or chlorophenol red-ß-D-galactopyranoside (CPRG). When the substrates are hydrolysed, a colour change is produced. Test methods may also include a substrate such as 4-methylumbelliferyl-ß-D-glucuronide (MUG), which is hydrolysed by the enzyme ß-glucuronidase, produced by most *E. coli*, to form the fluorogenic metabolite 4-methylumbelliferyl. It has been reported that more coliform bacteria may be detected using enzyme substrate based methodology in comparison to MF based methodology (Adcock and Saint 1997).

HEALTH CONSIDERATIONS

Total coliforms (excluding *E. coli)* are not considered useful as indicators of the presence of faecal contamination and enteric pathogens. There are many environmental coliforms that are not of faecal origin. The presence of these coliforms may represent release from pipe or sediment biofilms or ingress of soils as a result of faults or repairs, or disinfection failure.

NOTE: Important general information is contained in PART II, Chapter 5

DERIVATION OF GUIDELINE

Coliforms can be used in operational monitoring to indicate inadequate treatment, breakdowns in system integrity or the presence of biofilms. No guideline value is established, if used, numbers should be established on a system specific basis, taking into consideration relevant historical data and an understanding of the characteristics of the system.

REFERENCES

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APHA Method 9223 (1998). Standard Methods for the Examination of Water and Wastewater, 20th Edition. American Public Health Association, Washington.

AS 4276.4 (1995). Coliforms – Estimation of most probable number (MPN). Australian Standards, Standards Association of Australia, Sydney, NSW.

AS 4276.5 (1995). Coliforms – Membrane filtration method. Australian Standards, Standards Association of Australia, Sydney, NSW.

Escherichia coli and thermotolerant coliforms

(revised 2002)

GUIDELINE

Escherichia coli ***(or thermotolerant coliforms) should not be detected in a minimum 100 mL sample of drinking water. If detected, immediate action should be taken (see summary table of microbiological guidelines).***

GENERAL DESCRIPTION

Coliforms are gram-negative, nonsporing rod-shaped bacteria capable of aerobic and facultative anaerobic growth in the presence of bile salts or other surface active agents with similar growth-inhibiting properties. They are found in large numbers in the faeces of humans and other warm-blooded animals.

Thermotolerant coliforms are more specific indicators of faecal contamination than total coliforms. Either thermotolerant coliforms as a group, or *Escherichia coli,* can be used to indicate the presence of contamination. Tests for thermotolerant coliforms can be simpler but *E. coli* is a better indicator because some environmental coliforms are thermotolerant (*Klebsiella, Citrobacter* and *Enterobacter*). *E. coli* is the most common thermotolerant coliform present in faeces and is regarded as the most specific indicator of recent faecal contamination.

Thermotolerant coliforms, including *E. coli,* can ferment lactose (or mannitol) at 44.5± 0.2˚C with the production of acid within 24 hours. Thermotolerant coliforms that produce indole from tryptophan at 44.5± 0.2˚C are regarded as being *E. coli*. *E. coli* also give a positive result in the methyl-red test and a negative Voges-Proskauer test and cannot use citrate as the sole source of carbon. Also, most *E. coli* produce the enzyme ß-glucuronidase.

AUSTRALIAN SIGNIFICANCE

E. coli (or thermotolerant coliforms) are used as specific indicators of faecal contamination and hence the safety of water for drinking. However, some waters can support survival or regrowth of environmental thermotolerant coliforms. Where this is suspected, *E. coli,* should be used.

TREATMENT OF DRINKING WATER

Treatment by chlorination or other acceptable forms of disinfection inactivates *E. coli,* (or thermotolerant coliforms) in water, provided the turbidity is low.

METHOD OF IDENTIFICATION AND DETECTION

E. coli, (or thermotolerant coliforms) numbers can be determined using membrane filtration (MF) for concentration of the organisms from water, followed by growth in enrichment/selective media or multiple tube dilution (most probable number – MPN) procedures (AS 4276.6 and 4276.7 1995). Specific secondary tests are used with both MF and MPN procedures to confirm the identification of thermotolerant coliforms.

Alternatively, the presence of *E. coli,* can be detected by testing for the production of the enzyme ß-glucuronidase (APHA method 9223 1998). Test methods include the enzyme substrates such as 4-methylumbelliferyl-ß-D-glucuronide (MUG) which is hydrolysed by ß-glucuronidase to produce the fluorogenic metabolite 4-methylumbelliferyl. Both enumeration and presence/absence tests are available.

As the detection of any *E. coli,* in 100 mL of drinking water requires further action, either form of test is acceptable.

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Thermotolerant coliforms are normal inhabitants of the intestine, are always present in high numbers in human and animal faeces, and are generally regarded as specific indicators of faecal contamination. However, environmental thermotolerant coliforms, which can occur in some waters, are of lesser significance. *E. coli,* is the most specific indicator for faecal contamination. While most thermotolerant coliforms are nonpathogenic there are some pathogenic subtypes of *E. coli,* that can cause enteric illness including enteropathogenic, enteroinvasive, enterotoxigenic and enterohaemorrhagic strains (Bopp 1999).

Enteropathogenic *E. coli,* have been associated with outbreaks of infantile gastroenteritis but experiments in adult volunteers have shown that they also cause disease in adults. The pathogenic mechanisms employed by these organisms are not fully understood.

Enteroinvasive *E. coli,* (EIEC) produce dysentery by a mechanism similar to *Shigella* spp. These organisms invade the colonic mucosa and cause bloody diarrhoea. This property seems to be restricted to a few O sero-groups.

Epidemiological evidence suggests that enterotoxigenic *E. coli* (ETEC) are responsible for most episodes of *E. coli* diarrhoea, particularly in developing countries. ETEC strains can cause a cholera-like syndrome in infants, children and adults, producing a heat-labile enterotoxin (LT) related to cholera enterotoxin and/or a heat-stable enterotoxin (ST). The action of LT is the same as the cholera toxin. The ability of ETEC to cause disease depends not only on the production of enterotoxin but also upon the ability of these organisms to colonise the small intestine. Various colonising factors or adhesins have been described.

Enterohaemorrhagic *E. coli* (EHEC), including serogroups such as O111 and O157 are relatively rare strains that produce large quantities of shiga-like (or vero) toxins that can cause illness ranging from mild diarrhoea to haemorrhagic colitis. The latter is characterised by blood-stained diarrhoea accompanied by abdominal pain. In addition, EHEC strains can cause haemolytic uraemic syndrome (HUS), which is characterised by acute renal failure and haemolytic anaemia. The infectious dose may be very low.

Standard *E. coli* identification methods cannot be used to detect EHEC strains. *E. coli* 0157:H7 does not grow above 41ºC on selective media and it does not produce ß-glucuronidase. However, specific testing is not recommended unless presence is suspected.

DERIVATION OF GUIDELINE

E. coli (or thermotolerant coliforms) should not be present in a minimum 100 mL sample of drinking water. The presence of these organisms is indicative of faecal contamination and suggests a potentially serious fault in the integrity of the water supply system.

The effect on the community of noncompliance with the guideline will depend on the *E. coli* strain involved, whether faecal pathogens are also present, the number of organisms and the presence of susceptible individuals.

REFERENCES

APHA Method 9223 (1998). Standard methods for the examination of water and wastewater, 20th edition. American Public Health Association, Washington.

AS 4276.6 (1995). Thermotolerant coliforms and *Escherichia coli* – Estimation of most probable number (MPN). Australian Standards, Standards Association of Australia, Sydney, NSW.

AS 4276.7 (1995). Thermotolerant coliforms and *Escherichia coli* – Membrane filtration method. Australian Standards, Standards Association of Australia, Sydney, NSW.

Bopp CA, Brenner FW, Wells JG and Strockbine NA (1999). Escherichia, Shigella and Salmonella. In: Murray PR, Baron EJ, Pfaller MA, Tenover FC and Volken RH (eds), *Manual of Clinical Microbiology*, 7th edition. ASM Press, Washington DC, pp 459–474.

NOTE: Important general information is contained in PART II, Chapter 5

Klebsiella

GUIDELINE

Coliforms detected in a water supply may include* Klebsiella *spp.

GENERAL DESCRIPTION

Klebsiella spp are inherently environmental organisms that survive and sometimes multiply in suitable waters. They are associated with roots of plants and can grow to high levels on the leaves of vegetables. They are frequently present in raw waters, and can increase to high levels in waters containing pulp mill wastes.

They are also found in the faeces of a significant proportion of healthy people.

K. pneumoniae and *K. oxytoca* are significant opportunistic pathogens in hospitals, but the relationship between infections and drinking water is at best dubious, given the wide distribution of members of this genus in the environment.

The genus is heterogenous and has been difficult to classify. Four species are now included: *K. pneumoniae, K. oxytoca, K. planticola*, and *K. terrigena*. A fifth species, *K. mobilis*, has been proposed, but it remains controversial whether this should be classified in this genus or that of *Enterobacter* (Grimont *et al* 1991).

As the organisms have similar sensitivity to disinfection to *E. coli* and some bacterial enteric pathogens, their presence in drinking water indicates that disinfection has been inadequate.

AUSTRALIAN SIGNIFICANCE

Klebsiella spp have been detected in Australian drinking water, but there is no evidence that they have caused disease.

METHOD OF DETECTION AND IDENTIFICATION

Klebsiella spp are gram-negative nonsporing oxidase-negative rod-shaped bacteria, capable of aerobic and facultatively anaerobic growth in the presence of bile salts or other surface active agents with similar growth-inhibiting properties. They are able to ferment lactose, with the production of acid and gas within 48 hours at 35–37°C.

Most *Klebsiella* spp can be quantified in water by either multiple tube dilution, or membrane filtration methods (AS1095.4.1), which are followed by suitable tests for identification of the genus.

HEALTH CONSIDERATIONS

Klebsiella may colonise patients in hospital, being spread mainly by the frequent handling which occurs in intensive care units. Those most at risk are people with impaired defence mechanisms, such as the elderly or the very young, people with burns or excessive wounding, those undergoing immunosuppressive therapy, or those with acquired immune deficiency syndrome (AIDS). From colonisation, invasive infections may occur. On rare occasions *Klebsiella* may cause infections, including destructive pneumonia, in apparently healthy people. These problems appear to be associated with *K. pneumoniae* and *K. oxytoca*.

NOTE: Important general information is contained in PART II, Chapter 5

DERIVATION OF GUIDELINE

No guideline value is established, if used for operational monitoring, numbers should be established on a system specific basis, taking into consideration relevant historical data and an understanding of the characteristics of the system. *Klebsiella* spp form a significant proportion of the organisms identified as coliforms in standard tests for indicator bacteria, and these organisms are thus covered by the guideline for coliforms.

REFERENCES

AS1095.4.1 (1981). Microbiological examination of water for dairy purposes. Microbiological methods for the dairy industry. Australian Standard, Standards Association of Australia, Sydney, NSW.

Grimont F, Grimont PAD and Richard C (1991). The genus *Klebsiella*. In: Balows A, Truper HG, Dworkin M, Harder W and Schleifer KH, *The prokaryotes*. Springer-Verlag Publishers, 2nd edition, New York, United States, pp 1217–1224 and 1249–1261.

Legionella

GUIDELINE

No guideline value has been set for* Legionella *in drinking water.

GENERAL DESCRIPTION

The family Legionellaceae contains a single genus, *Legionella*, with 26 currently reported species, of which *L. pneumophila* serogroup 1 is most frequently associated with human disease. Other serogroups of *L. pneumophila* and occasionally other Legionellae have also been reported to cause disease.

Legionella organisms are widespread in natural sources of freshwater and may also be found in soils. They occur commonly in man-made water systems, particularly in hot water and cooling water systems.

Legionella spp appear to infect humans by inhalation, and their presence in drinking water per se seems irrelevant until they are amplified by growing in specific sites under specific conditions (usually thermal enrichment), from which infective aerosols, and droplet nuclei, may be created.

Conditions in cooling towers, spas, warm water systems in buildings, hot water systems operated below 60°C, or 'dead legs' of hot water systems operated at higher temperatures, may favour the growth of *Legionella* organisms. Spraying water in cooling towers or water agitated in spas may then produce aerosols; water from hot water systems can also form aerosols in showers, through nozzle heads, or by splashing in sinks, baths etc.

Legionella organisms can be ingested by the trophozoites of certain amoebae *(Acanthamoeba, Hartmanella, Valkampfia and Naegleria)* and then grow intracellularly and become incorporated in their cysts. This may explain the difficulty in eradicating *Legionella* organisms from water systems, and it could be a factor in the aetiology of Pontiac fever.

AUSTRALIAN SIGNIFICANCE

Legionella spp have been found in cooling tower waters in many parts of Australia. However, very few *Legionella* organisms have been isolated from drinking waters. No published reports are available on the presence of *L. pneumophila* in drinking waters.

TREATMENT OF DRINKING WATER

Treatment of water with chlorine or chloramines will eliminate these organisms.

METHOD OF IDENTIFICATION AND DETECTION

Legionella spp are gram-negative, rod-shaped, nonsporing bacteria that require L-cysteine for growth and primary isolation. Cellular fatty acids in *Legionella* organisms are unique for gram-negative bacilli in that they contain primarily branched chains.

An Australian Standard has been developed for the detection of *Legionella* organisms in water (AS3896 1991).

Isolation of *Legionella* spp from environmental samples may require pre-concentration if numbers are low. Immunofluorescence techniques may also be used to detect *Legionella* spp in the environment.

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Legionella spp are not known to cause disease by the ingestion of drinking water.

Legionella infections can lead to two types of disease: legionellosis and Pontiac fever. The epidemic form of legionellosis associated with a common infection source is also known as Legionnaires' disease. This is a form of pneumonia with an incubation period usually of 3 to 6 days. Males are more frequently affected than females, and most cases occur in the 40 to 70 year age group. Risk factors include smoking, alcoholism, cancer, diabetes, chronic respiratory or kidney disease, and severe immunosuppression, as in transplant recipients. Ten per cent or more of cases are fatal, even though Legionnaires' disease can be treated effectively by antibiotics such as erythromycin and rifampicin.

Pontiac fever is a milder disease with a high attack rate. The incubation period is 5 hours to 3 days, and symptoms are similar to those of influenza: fever, headache, nausea, vomiting, aching muscles and coughing. No fatal cases have been reported and few outbreaks have been recognised, possibly because the nonspecific nature of the symptoms of the disease hinders its detection.

Infection through human-made water systems such as cooling towers and hot water supplies proceeds through inhalation of aerosols which are small enough to penetrate lungs and be retained by the alveoli – the degree of risk depending on four factors: the density of the bacteria in their source, the extent of aerosol generation, the number of inhaled bacteria, and the susceptibility of the exposed individual.

The number of inhaled bacteria depends on the size of the aerosol generated (<5 μm being most dangerous), the dispersal of the aerosol in the air, and the duration of the exposure. Host defence is important in determining whether exposure to *Legionella* organisms will lead to clinical disease, and differences in susceptibility largely explain the fact that in some cases, high counts of L. pneumophila in water systems have been reported in the absence of disease, whereas in other cases similar or lower counts have been associated with epidemics. It is also likely, although not yet adequately proven, that differences in virulence between strains account partly for these observations.

ADVICE ON DISINFECTION

It is not necessary to monitor water systems for *Legionella* spp routinely or to disinfect all environmental sites where Legionellae are detected. The following are generally accepted indications for disinfection:

- sites which are implicated in an outbreak of Legionnaires' disease or Pontiac fever
- hospital wards housing high-risk patients, such as organ transplant units
- buildings in which the water system has not been used for some time and where high numbers are likely to be found.

Vulnerable systems should be designed and maintained in such a way that colonisation by *Legionella* spp is prevented or minimised. The main points to consider are:

- preventing the accumulation of sludge, scale, rust, algae and slime and removing such deposits regularly
- maintaining hot water temperatures permanently above 60°C or at intervals above 70°C, and keeping cold water supplies below 20°C
- selecting materials in contact with water which do not release nutrients that support the growth of *Legionella* spp.

These measures are preferable to, and more effective than, the use of biocides to control *Legionella* organisms in water supplies within buildings; however, biocides are essential to prevent the build-up

of microbial slimes in airconditioning systems that use wet evaporative cooling towers. Such systems should be kept clean and well maintained. They should be inspected weekly for fouling and accumulated slime, scale and corrosion, and thoroughly cleaned and disinfected twice yearly. Biocides are best used intermittently in clean systems.

DERIVATION OF GUIDELINE

No specific guideline value can be established for *Legionella* spp. The absence of test mechanisms does not guarantee the total absence of the organism. Warm-water handling systems should always be regarded as being at risk of contamination by *Legionella* spp.

REFERENCE

AS 3896, (1991). Waters – Examination for legionellae. Australian Standard, Standards Association of Australia, Sydney, NSW.

NOTE: Important general information is contained in PART II, Chapter 5

Mycobacterium

GUIDELINE

No guideline value has been set for* Mycobacterium *in drinking water.

GENERAL DESCRIPTION

Tap water has long been known to harbour saprophytic *Mycobacterium* (Collins *et al* 1984); in fact one of the most commonly occurring species, *M. gordonae,* is also known as the 'tap water bacillus'. Opportunistic pathogenic species have also been isolated from tap water. *Mycobacterium* spp may accidentally contaminate clinical material during and after collection, or during processing in the laboratory, which may give a false indication of mycobacterial infection in patients under investigation.

A link between the occurrence of *Mycobacterium* in drinking water and disease has been suggested in specific incidents. In an investigation of endemic *M. kansasii* infections in Czechoslovakia from 1968, a peak incidence was shown in a small, densely populated district with workers engaged in mining and heavy or power industry. The organism could also be isolated from shower outlets in collieries, and it was shown later that the drinking water system in the whole region was contaminated. It was suggested that spread of *Mycobacterium* from drinking water occurred via aerosols. In Rotterdam, the Netherlands, the frequent isolation of *M. kansasii* from clinical specimens prompted an investigation of the water supply system. The organisms were frequently isolated from tap water and exhibited the same phage type and weak nitratase activity as clinical strains. The increase in number of isolations of the *M. avium* complex in Massachusetts, United States, has also been attributed to their incidence in drinking water.

In all these cases there is only circumstantial evidence of a causal relationship between the occurrence of bacteria in drinking water and human disease. The low infectivity of environmental *Mycobacterium* does not warrant standards or eradication programs.

The ecology of opportunistic *Mycobacterium* spp in water supplies is poorly understood. The bacteria have been isolated infrequently from treated water or mains water but appear to multiply within the plumbing system in buildings as well as in taps. Increased isolation frequencies have been associated with higher temperatures (hot water systems or cold water pipes in the vicinity of central heating). Older buildings appear to be more frequently colonised than new ones and transport of drinking water over long distances also seems to increase the numbers of *Mycobacterium* spp.

AUSTRALIAN SIGNIFICANCE

It has been suggested that cases of *M. kansasii* infection in Portland, Victoria, were associated with the presence of the organism on cooling structures in the town's water supply.

TREATMENT OF DRINKING WATER

Free available chlorine residuals of 0.5–1 mg/L are sufficient to control mycobacterial densities in the distribution system.

NOTE: Important general information is contained in PART II, Chapter 5

METHOD OF IDENTIFICATION AND DETECTION

Mycobacterium spp are rod-shaped bacteria with a high lipid content in cell walls, which enables them to retain specific dyes in staining procedures that employ an acid wash. They are therefore often referred to as acid-fast bacteria. All *Mycobacterium* spp are characterised by slow growth (generation times under optimum circumstances 2 to 20 hours), but within this range they are divided into 'slow' and 'rapid' growers. Analytical procedures have not been developed specifically for drinking water, although clinical methods can be used (Balows *et al* 1991).

HEALTH CONSIDERATIONS

Evidence from some localities suggests that the presence of certain environmental *Mycobacterium* in drinking water may be associated with opportunistic infection in a minority of susceptible people.

Most pathogenic species of *Mycobacterium* are found among the slow growers. These comprise the pathogenic species *M. tuberculosis, M. bovis, M. africanum* and *M. leprae*, which are not transmitted by water and have only human or animal reservoirs. Other *Mycobacterium* spp, which have been referred to as 'atypical' *Mycobacterium* spp, have environmental reservoirs. Although many are considered nonpathogenic, several species are opportunistic pathogens for humans. The most important species are the slow growers *M. kansasii, M. marinum, M. avium, M. intracellulare, M. scrofulaceum* and *M. xenopi*, and the rapid growers *M. chelonae* and *M. fortuitum*.

Strictly pathogenic *Mycobacterium* spp are associated with classic diseases such as tuberculosis and leprosy. The environmental *Mycobacterium* spp may cause a range of diseases including tuberculous lung disease and disseminated infections which may also involve the skeleton *(M. kansasii, M. avium* complex), infections of lymph nodes (MAIS complex), and infections of the skin and soft tissues *(M. marinum, M. fortuitum* complex). Diseases caused by opportunistic pathogenic *Mycobacterium* are not normally transmitted from person to person but are usually the result of environmental exposure in combination with predisposing factors such as dust retained in the lungs, surgical wounds, or immunosuppression by medication (e.g. transplantation patients) or underlying disease (e.g. AIDS, malignancies). *Mycobacterium* spp are generally resistant to many antimicrobial agents; hence, effective treatment may be difficult.

DERIVATION OF GUIDELINE

There are insufficient data to establish a guideline value for *Mycobacterium* in water.

When epidemiological associations between the presence of *Mycobacterium* spp in drinking water and infections in the community can be demonstrated, an investigation into the source of the contamination, and its removal, should be carried out.

REFERENCES

Balows A, Truper HG, Dworkin M, Harder W and Schleifer KH (1991). *The prokaryotes*. Springer-Verlag Publishers, 2nd edition, New York, United States, pp 1217–1224 and 1249–1261.

Collins CH, Grange JM and Yates MD (1984). Mycobacteria in water. *Journal of Applied Bacteriology*, 57, 193–211.

Pseudomonas aeruginosa

GUIDELINE

No guideline value has been established for* Pseudomonas aeruginosa *in drinking water.

GENERAL DESCRIPTION

Pseudomonas aeruginosa is commonly found in faeces, soil, water and sewage. It cannot be used as an indicator of faecal contamination, as it is not universally present in faeces and sewage, and it may also multiply in an enriched aquatic environment and on the surface of suitable organic materials in contact with water. Its presence, however, can be used to assess the general cleanliness of water distribution systems and the quality of bottled waters.

P. aeruginosa has also been found in various foods.

AUSTRALIAN SIGNIFICANCE

Though *P. aeruginosa* occurs in Australian drinking water supplies, it has only been associated with cases of folliculitis (inflammation of the hair follicles) in health-spa whirlpools.

TREATMENT OF DRINKING WATER

Free available chlorine residuals of 0.2–0.5 mg/L are generally sufficient to control *P. aeruginosa* in water.

METHOD OF IDENTIFICATION AND DETECTION

P. aeruginosa is a member of the family Pseudomonadaceae and is a polarly-flagellated, gram-negative rod. When grown in suitable media it is capable of producing pigments, the most significant of which are the nonfluorescent phenazine pigments, pyocyanin and fluorescin. Pigment may not be produced by strains of *P. aeruginosa* recovered from clinical specimens and the ability to produce pigment may be lost on subculture. Like other fluorescent pseudomonads in natural waters, *P. aeruginosa* strains produce catalase and oxidase, produce ammonia from arginine, use citrate as the sole source of carbon, and are aerobic.

P. aeruginosa can grow at 41–42°C (AS 1095.4.1.13 1981). The blue-green pigment produced differs from the fluorescent pale green pigment (fluorescin) produced by other species of fluorescent pseudomonads found in water. The organism can also grow anaerobically in stab cultures of nitrate agar.

HEALTH CONSIDERATIONS

P. aeruginosa is a classical opportunistic pathogen. It rarely becomes established in, and even more rarely infects, the intact host but colonises damaged systems, for example burn wounds, the respiratory tract of people with underlying disease, physically damaged eyes etc. From these it may invade the body, causing destructive lesions or septicaemia. Immunosuppressed people, particularly those with low polymorph counts, are at risk. Contaminated 'irrigation' fluids or pharmaceutical agents (e.g. eye drops) delivered to damaged areas have caused severe infection.

While it is clearly undesirable for water supplies to hospitals to have high counts of this organism (or other opportunistic pathogens), a direct association of hospital infections with drinking water sources is yet to be established.

High counts of this organism in spa and swimming pool water have been linked with rashes and superficial infections of the outer ear canal (Calderon and Mood 1982, Jones and Bartlett 1985).

NOTE: Important general information is contained in PART II, Chapter 5

DERIVATION OF GUIDELINE

Owing to the widespread occurrence of the organism and its opportunistic pathogenicity, it is difficult to set a guideline for drinking water. However, the presence of the organism in drinking water may indicate a serious deterioration in bacteriological quality, often accompanied by taste, odour and turbidity complaints associated with low rates of flow and increased water temperatures.

REFERENCES

AS 1095.4.1.13, (1981). Examination of water for *Pseudomonas aeruginosa* by membrane filtration. Australian Standard, Microbiological methods for the dairy industry. Standards Association of Australia, Sydney, NSW.

Calderon R and Mood EW (1982). An epidemiological assessment of water quality and 'swimmer's ear'. *Archives of Environmental Health*, 73, 300–305.

Jones F and Bartlett CLR (1985). Infections associated with whirlpools and spas. *Journal of Applied Microbiology* (symposium supplement, microbial aspects of water management), 61s–66s.

Burkholderia pseudomallei

(Added and endorsed 2001)

GUIDELINE

No guideline value has been established for* Burkholderia pseudomallei *in drinking water.

GENERAL DESCRIPTION

Burkholderia pseudomallei, which causes the disease melioidosis, is a motile gram-negative bacillus commonly found in soil and muddy water in tropical regions. *B. pseudomallei* can survive in water for prolonged periods in the absence of nutrients, and is acid tolerant (Wuthiekanun *et al* 1995).

Melioidosis is most common in northern Australia and South-East Asia. Infection usually results from contact with soil or surface-accumulated water (muddy water). Exposure to environmental *B. pseudomallei* after heavy rainfall presents the greatest risk. Most infection appears to be through skin cuts or abrasions; however, infection may also occur via other routes, particularly through inhalation or ingestion. The relative importance of these routes of infection is not known.

AUSTRALIAN SIGNIFICANCE

Melioidosis is an endemic disease in northern Australia and although generally a tropical illness it has been detected in the southwest of Western Australia (Golledge *et al* 1992). The first human case was diagnosed in Australia in 1950. Melioidosis is reported with increasing frequency in the Top End of the Northern Territory and *B. pseudomallei* is the most common organism isolated in fatal community-acquired pneumonia. Cases appear throughout the year but peak during the rainy season (Currie 2000).

Two outbreaks of melioidosis have been reported in Australia: in 1990–91 in the Northern Territory and in 1997 in Western Australia (Inglis *et al* 1999). In the latter outbreak, indistinguishable isolates of B. pseudomallei were cultured from cases and the potable water supply (Inglis *et al* 1999, 2000).

MANAGEMENT

Standard disinfection procedures should be sufficient to eliminate *B. pseudomallei* from water supplies.

METHOD OF IDENTIFICATION AND DETECTION

Selective culture techniques have been described (Brook *et al* 1997). Confirmation of identity has traditionally been done by biochemical tests (Inglis *et al* 1998) but polymerase chain reaction (PCR) based methods may be more accurate. Genetic typing can be performed by several methods, including ribotyping and pulsed field gel electrophoresis (Haase *et al* 1995; Inglis *et al* 2000).

HEALTH CONSIDERATIONS

Melioidosis is a potentially fatal disease. Pneumonia is the most common presentation. Many patients present with milder forms of pneumonia, which respond well to appropriate antibiotics, but some may present with a severe septicaemic pneumonia. Other symptoms include skin abscesses or ulcers, abscesses in internal organs and unusual neurological illnesses such as brainstem encephalitis and acute paraplegia. Individuals without symptoms or known history of disease may also be positive on serological testing. Late onset disease, including acute septicaemia, can occur months or years after initial exposure.

NOTE: Important general information is contained in PART II, Chapter 5

Although melioidosis can occur in healthy children and adults, it mainly occurs in people whose defences against infection are impaired, due either to an underlying condition (e.g. diabetes, chronic renal or lung disease, or alcoholic liver disease), or to poor general health associated with poor nutrition or living conditions.

DERIVATION OF GUIDELINE

No guideline is proposed for *B. pseudomallei* because there is limited evidence for the involvement of drinking water in its transmission in Australia. The numbers of organisms that would be significant for human health are unknown.

If a water supply is implicated as a possible source of melioidosis, investigations should be undertaken to assess whether the supply has been well managed and continually disinfected. The supply should be tested for the presence of the organisms.

REFERENCES

Brook MD, Currie B and Desmarchelier PM (1997). Isolation and identification of *Burkholderia pseudomallei* from soil using selective culture techniques and the polymerase chain reaction. *Journal of Applied Microbiology,* 82, 589–596.

Currie BJ (2000). The epidemiology of melioidosis in Australia and Papua New Guinea. *Acta Tropica*, 74, 121–127.

Haase A, Smith-Vaughan H, Melder A, Wood Y, Janmaat A, Gilfedder J, Kemp D and Currie B (1995). Subdivision of *Burkholderia pseudomallei* ribotypes into multiple types by RAPD analysis provides new insights into its epidemiology. *Journal of Clinical Microbiology*, 33, 1687–1690.

Inglis TJJ, Garrow SC, Adams C, Henderson M, Mayo M and Currie BJ (1999). Acute melioidosis outbreak in Western Australia. *Epidemiology and Infection,* 123, 437–443.

Inglis TJJ, Garrow SC, Henderson M, Clair A, Sampson J, O'Reilly L and Cameron B (2000). Outbreak strain of *Burkholderia pseudomallei* traced to water treatment plant. *Emerging Infectious Diseases*, 6, 56–59.

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Wuthiekanun V, Smith MD and White NJ (1995). Survival of *Burkholderia pseudomallei* in the absence of nutrients. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 89, 491.

Salmonella

GUIDELINE

Escherichia coli *(or alternatively thermotolerant coliforms) are used to indicate the possible presence of* Salmonella *spp. If explicitly sought,* Salmonella *spp should not be detected. If detected, advice should be sought from the relevant health authority.*

GENERAL DESCRIPTION

Salmonella spp are widely distributed in the environment and gain entry into water systems though faecal contamination from livestock, native animals, drainage waters and incompletely treated waste discharges.

Faecal contamination of water which is inadequately treated or inadequately disinfected is the main cause of waterborne outbreaks of salmonellosis.

AUSTRALIAN SIGNIFICANCE

Salmonella has been isolated from a number of source waters in Australia and occasionally from reticulated waters. However, published associations between the isolation of *Salmonella* from drinking water and health effects in the community are mainly anecdotal.

Most illnesses resulting from *Salmonella* infection are derived from contaminated foodstuffs, e.g. poultry and livestock. Waterborne *Salmonella* spp play only a minor role in causing disease.

TREATMENT OF DRINKING WATER

Treatment by disinfection using chlorine is usually effective against *Salmonella* spp, provided the water has low turbidity.

METHOD OF IDENTIFICATION AND DETECTION

The numbers of *Salmonella* in water can be determined by concentration followed by enrichment, isolation and confirmation (AS 1095.4.1.9 1981).

HEALTH CONSIDERATIONS

Salmonella spp, with the exception of those that cause enteric fever in humans (Lloyd 1983), are pathogens of animals, which provide important reservoirs for the infection of humans.

Salmonella enterica serovar Typhi, however, is a specific human pathogen. In particular, *S. enterica* serovar Typhi, *S. enterica* serovar Paratyphi A, and *S. enterica* serovar Paratyphi B are able to invade tissues and cause a septicaemia with high temperature rather than diarrhoea. This is known as enteric fever. In humans, most of the other serovars cause a transient intestinal infection which results in acute gastroenteritis with diarrhoea. Certain serovars are highly pathogenic for humans, while others appear nonpathogenic. Many *Salmonella* infections are symptomless.

Epidemiological and volunteer studies show that the infective dose of *Salmonella* varies considerably. Method of intake, individual host susceptibility, and virulence of the particular strain are important in determining the dose required to produce an infection.

NOTE: Important general information is contained in PART II, Chapter 5

Waterborne outbreaks due to substantial contamination are usually characterised by rapid onset. The majority of cases develop over a period of a few days, and these may be followed by secondary cases. The spatial distribution of infections in major outbreaks is often strongly correlated with the water supply system.

DERIVATION OF GUIDELINE

The presence of faecal indicator bacteria is useful to determine the possible presence of *Salmonella* spp. However, as with many other pathogens, *Salmonella* spp may occasionally be present when indicators are absent, particularly where a supply may have been subject to faecal contamination by amphibians (frogs) and reptiles. It is also important, therefore, to test directly for Salmonellae if contamination is suspected.

The direct effect on the community of noncompliance with the guideline will depend on the *Salmonella* species involved. The numbers of *Salmonella* may be amplified through contamination of foodstuffs.

REFERENCES

AS 1095.4.1.9, (1981). Examination of water for Salmonellae. Australian Standard, Microbiological methods for the dairy industry. Standards Association of Australia, Sydney, NSW.

Lloyd B (1983). *Salmonella*, enteric fever and salmonelloses. In: Feachem RG, Bradley DJ *et al* (editors). *Health aspects of excreta and wastewater management.* Chichester, John Wiley and Sons, pp 251–286.

Shigella

GUIDELINE

***Escherichia coli* (or alternatively thermotolerant coliforms) are used to indicate the presence of pathogenic *Shigella* spp. If explicitly sought, pathogenic *Shigella* spp should not be detected. If detected, advice should be sought from the relevant health authority.**

GENERAL DESCRIPTION

Bacteria of the genus *Shigella* cause bacillary dysentery. Although shigella infection is not often waterborne, major outbreaks resulting from waterborne transmission have been described. The isolation of *Shigella* spp from drinking water indicates recent human faecal contamination, but this occurs only rarely. This possibly indicates the limitations of the method rather than absence of the organisms, as there is no useful enrichment or selective medium for isolation of these bacteria. Techniques used have been designed for isolation of *Salmonella* spp and are not optimal for *Shigella* spp.

AUSTRALIAN SIGNIFICANCE

No conclusive evidence for the transmission of shigellosis through water supplies in Australia has been reported. The incidence of infection by *Shigella* in Australia is low except in central Australia, and among travellers returning from abroad.

TREATMENT OF DRINKING WATER

Standard disinfection procedures eliminate *Shigella* spp from water, provided that turbidity is low.

METHOD OF IDENTIFICATION AND DETECTION

Shigella spp are gram-negative, nonsporing, nonmotile rods, growing both aerobically and anaerobically. Metabolism is both respiratory and fermentative; acid, but usually not gas, is produced from glucose but lactose is seldom fermented. Catalase is usually produced, except by *Shigella dysenteriae* type 1, while oxidase is produced by one serotype only. Nitrates are reduced to nitrites (APHA method 9260 E 1992).

Shigella spp are serotyped on the basis of their somatic O antigens. Both group and type antigens are distinguished, group antigenic determinants being common to a number of related types. Serological typing is adequate for all species except *S. sonnei*.

HEALTH CONSIDERATIONS

Shigella spp have a low infective dose and are highly pathogenic for humans. Characteristic bloody diarrhoea results from the invasion of the colonic mucosa by the bacterium; the process is probably highly species-specific. *Shigella* spp have no natural hosts other than the higher primates, and effectively, humans are the only source of infection in the community. Among the enteric bacterial pathogens, Shigellae seem to be the best adapted to cause human disease. Transmission occurs directly between susceptible individuals, and the infectious dose is lower than for other bacteria.

NOTE: Important general information is contained in PART II, Chapter 5

DERIVATION OF GUIDELINE

The isolation of *Shigella* spp from drinking water indicates recent human faecal contamination and, in view of the extreme virulence of the organisms, is of crucial public health significance.

The effect on the community of noncompliance with the guideline will depend on the *Shigella* strain involved, the numbers, and the susceptibility of the population. Cases of shigellosis will almost certainly result.

REFERENCE

APHA Method 9260E, (1992). Detection of pathogenic bacteria: *Shigella*. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington DC.

Vibrio

GUIDELINE

Escherichia coli *(or alternatively thermotolerant coliforms) are used to indicate the presence of pathogenic* Vibrio *spp. If explicitly sought, pathogenic* Vibrio *spp should not be detected. If detected, advice should be sought from the relevant health authority.*

GENERAL DESCRIPTION

Vibrio species may be waterborne. Cholera (*V. cholerae* 01), for example, is usually a water-associated disease and numerous such outbreaks have been documented. Food-borne outbreaks, however, are also common and person-to-person transmission may occur under conditions of extreme crowding and poor hygiene. The transmission of cholera has been extensively reviewed, and although water is undoubtedly an important vehicle for transmission, many aspects of the epidemiology of cholera remain open to debate (Miller *et al* 1985). There is evidence to suggest that in some circumstances, *V. cholerae*, including serotype 01, may occur naturally in some surface waters.

AUSTRALIAN SIGNIFICANCE

Vibrio spp have been isolated from a number of source waters in Queensland, but not from reticulated waters. There are no published associations between the isolation of Vibrios from source water and health effects in the community.

TREATMENT OF DRINKING WATER

Standard disinfection procedures eliminate *V. cholerae* 01 (the source of the classic cholera epidemics) from reticulated water, provided turbidity is low.

METHOD OF IDENTIFICATION AND DETECTION

Vibrio spp are nonsporing, slightly curved gram-negative rods, motile by a single polar flagellum. Their metabolism is both respiratory and fermentative without the production of gas, while their growth is aerobic and facultatively anaerobic. Both catalase and oxidase are formed and nitrates are reduced to nitrites (APHA method 9260H 1992).

HEALTH CONSIDERATIONS

Vibrio cholerae is a well-defined species frequently found in source waters. While cases of diarrhoea are caused by other types, only the serovar 01 is associated with the classical cholera symptoms in which a proportion of cases suffer fulminating and severe watery diarrhoea. The 01 serovar has been further divided into 'classical' and 'El Tor' biotypes, the latter distinguished by (*inter alia*) the ability to produce a dialysable, heat-labile haemolysin, active against sheep and goat red blood cells.

When present in large numbers in the intestinal mucosa, *V. cholerae* 01 produces an enterotoxin (cholera toxin) that alters the ionic fluxes across the mucosa with resulting catastrophic loss of water and electrolytes in liquid stools.

Almost all the organisms that are known to cause epidemic cholera are members of the serogroup 01, though the very similar *V. mimicus* (sucrose nonfermenter) has been isolated from cases of clinical cholera.

NOTE: Important general information is contained in PART II, Chapter 5

DERIVATION OF GUIDELINE

The isolation of *V. cholerae* 01 from water used for drinking is of major public health importance. However, other serogroups of *V. cholerae* are part of the normal flora of some waters. *V. cholerae* and other pathogenic *Vibrio* spp should be absent from drinking water supplies.

REFERENCES

APHA Method 9260H, (1992). Detection of pathogenic bacteria: *Vibrio cholerae*. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington DC.

Miller CJ, Drasar BJ and Feachem RG (1985). Cholera epidemiology in developed and developing countries: New thoughts on transmission, seasonality and control. *Lancet*, i, 261–263.

Yersinia

GUIDELINE

***Escherichia coli* (or alternatively thermotolerant coliforms) are used to indicate the presence of *Yersinia*. If explicitly sought, pathogenic *Yersinia* spp should not be detected. If they are detected, advice should be sought from the relevant health authority.**

GENERAL DESCRIPTION

The genus *Yersinia* is currently placed in the family Enterobacteriaceae and comprises seven species. Strains of *Y. enterocolitica* can cause gastrointestinal disease if ingested.

A special feature of *Y. enterocolitica* and *Y. enterocolitica*-like organisms is their ability to grow at temperatures as low as 4°C. Accordingly, long survival of these organisms in water habitats can be demonstrated. For example, *Y. enterocolitica* was detected in distilled water for over 18 months at 4°C. Such long survival makes it difficult to find the origin of contamination.

Many domestic and wild animals are considered to be possible reservoirs of *Y. enterocolitica*, due to the high isolation rates of the organism from such sources. Wild animals, particularly hares and foxes, are probably a source of the bacteria, and swine have been implicated as a source of serotypes involved in human infections. The major vehicle of transmission is probably food, especially meat and meat products, milk and dairy products (Lloyd 1983). While *Y. enterocolitica* has also been isolated from a variety of environmental samples, especially from water, the isolated serotypes differ from those associated with human disease.

Ingestion of contaminated food and water is probably the most likely route of transmission of *Y. enterocolitica* Direct transmission from person to person and from animals to people also occurs, but its relative importance has not been clarified. Further research is needed to define the epidemiological importance of 'environmental' strains of *Y. enterocolitica*.

AUSTRALIAN SIGNIFICANCE

The prevalence of notified cases of *Yersinia* infection varies between states. There has been a marked increase in the number of cases recorded in South Australia in recent years.

TREATMENT OF DRINKING WATER

Standard disinfection procedures are sufficient to avoid transmission of *Yersinia*, provided the water has a low turbidity when treated. Free chlorine in the range required for water disinfection (0.2–0.5 mg/L) for 10 minutes at pH 7 completely eradicates the bacterium. Ozone eradicates the organism after contact with 0.05 mg/L for 1 minute, regardless of pH.

METHOD OF IDENTIFICATION AND DETECTION

Y. enterocolitica is a gram-negative rod, motile at 25°C but nonmotile in cultures grown at 37°C (APHA Method 9260K 1992).

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Some serovars of *Y. enterocolitica* are human pathogens. Atypical strains within *Y. enterocolitica,* isolated most frequently from environmental samples, are separated as *Y. enterocolitica*-like organisms. They are not pathogenic for humans and can be subdivided into *Y. intermedia, Y. frederekseni, Y. kristensenii,* and *Y. aldovae* by biochemical means.

Yersiniosis generally presents as an acute gastroenteritis with diarrhoea, but other human diseases caused by *Y. enterocolitica* are also known. *Y. enterocolitica* may be waterborne.

DERIVATION OF GUIDELINE

Water samples yielding *Y. enterocolitica* often show only light coliform contamination. One study indicated that 25% of *Y. enterocolitica*-positive samples were negative for both total and thermotolerant coliforms. Other studies showed a close relation between faecal pollution and *Y. enterocolitica* isolation rates. As it is not possible, at this stage, to determine an infectious dose, *Y. enterocolitica* should be absent from drinking water supplies.

REFERENCES

APHA Method 9260K, (1992). Detection of pathogenic bacteria: *Yersinia enterocolitica.* Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington DC.

Lloyd B (1983). *Yersinia* and yersiniosis. In: Feachem RG, Bradley DJ *et al* (eds). *Sanitation and disease: Health aspects of wastewater management*. Chichester, John Wiley and Sons, pp 327–330.

Microorganisms · Protozoa

Acanthamoeba

GUIDELINE

No guideline value is set for* Acanthamoeba *species in drinking water.

GENERAL DESCRIPTION

Acanthamoeba spp are small free-living amoebae that are common in aquatic environments and are among the predominant protozoa in soil. Several of approximately 20 known species are virulent, causing the cerebral infection granulomatous amoebic encephalitis (GAE), or the corneal infection amoebic keratitis, or both. One or both diseases have occurred in most temperate and tropical regions of the world. *Acanthamoeba* spp may also be significant as host cells for the proliferation and dispersal of *Legionella* species.

The relative importance of water as a source of infection is unknown. The wide distribution of *Acanthamoeba* in the natural environment makes soil, airborne dust and water all likely sources. Delays in the diagnosis of GAE and keratitis cases have made it difficult to investigate possible sources of infection, while the lack of a stable classification of *Acanthamoeba* inhibits identification of individual isolates, including the matching of amoebae from infections with organisms from the environment.

Regular monitoring for *Acanthamoeba* is not appropriate, but these organisms need to be considered when planning the maintenance of eyewash stations that use mains water.

AUSTRALIAN SIGNIFICANCE

Amoebic keratitis has been recorded in New South Wales, Queensland, South Australia, Victoria and Western Australia (e.g. Roussel *et al* 1985). Currently, four cases of GAE have been diagnosed in Australia (Victoria and Western Australia, e.g. Harwood *et al* 1988). Data have also been collected on the diversity and density of *Acanthamoeba* species in water and sediments, mainly in South Australia; the organisms are likely to proliferate over a wide temperature range in water where organic carbon levels promote significant bacterial production. Contamination of environments that may become sources of infection (swimming and spa pools, cooling towers etc) cannot be assumed to originate with organisms from the water supply, given the wide distribution of *Acanthamoeba* in the natural environment.

TREATMENT OF DRINKING WATER

Acanthamoeba species are usually less numerous in surface source waters than *Naegleria* species, but often contaminate piped water supplies at a low level, even when chlorine is present. Their cysts are among the most resistant of protozoan cells to oxidative disinfectants, making removal difficult at the levels of disinfectant generally used for drinking water. In any case, control of *Acanthamoeba* may be most important in specialised uses of water: distribution in hospitals, renal dialysis or industrial eye-wash stations.

METHOD OF IDENTIFICATION AND DETECTION

Detection of amoebae, concentrated from water samples, requires relatively simple growth media and standard laboratory incubation facilities. Identification of *Acanthamoeba* species is more specialised. These amoebae are most likely to be significant in specific investigations of sources of infection, when comparison with reference strains would be essential to their identification.

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Acanthamoeba species are opportunistic pathogens. GAE usually occurs in immunocompromised patients, secondary to infection of another organ (often lungs or subcutaneous tissue). Most cases have been recognised at post-mortem after protracted illness, making any investigation of the circumstances of infection difficult. Amoebic keratitis occurs in two groups of people: those who sustain a corneal lesion before or at the time of infection and who often have outdoor occupations (Roussel *et al* 1985); and people who wear contact lenses. A specific source of infection has rarely been confirmed, but circumstances suggest that the first group are often infected by cysts from airborne dust or soil, while tap water, used incorrectly to wash lenses, may often be the source for the second group.

DERIVATION OF GUIDELINE

No guideline value is proposed for *Acanthamoeba* species, given the uncertainty about sources of infection, but water authorities should be aware of the direct health significance of these organisms and their possible role in the ecology of *Legionella*.

REFERENCES

Harwood CR, Rich GE, McAleer R and Cherian G (1988). Isolation of *Acanthamoeba* from a cerebral abscess. *Medical Journal of Australia,* 148, 47–49.

Roussel TJ, Badenoch PR, Chandraratnam E and Coster DJ (1985). Acanthamoebic keratitis in a healthy Australian man. *Medical Journal of Australia*, 143, 615–617.

Cryptosporidium

(Revised and endorsed 2000)

GUIDELINE

The implementation of a multiple barrier approach operating from catchment to tap to minimise the risk of* Cryptosporidium *contamination is recommended; with protection of catchments from human and animal wastes a priority. No guideline value is set for* Cryptosporidium *due principally to the lack of a method to identify human infectious strains in drinking water. Routine monitoring of distribution systems is not recommended; however, investigative testing may be required in response to events that could increase the risk of contamination by* Cryptosporidium*. Such events could include heavy rainfall leading to a marked increase in turbidity and numbers of* Cryptosporidium *in source water, sub-optimal operation of treatment processes or treatment plant failures. Investigative and event-based testing of source waters is recommended.

If detected in drinking water the relevant health authority should be advised immediately. All necessary measures to assess and minimise public health risks should be implemented as soon as possible. These could include: further sampling to confirm the presence and source of the organisms, testing for the presence of viable organisms and the specific presence of* Cryptosporidium parvum*, the issuing of advice (including boil-water notices) to the public and enhanced surveillance to detect possible increases in cryptosporidiosis in the community.

GENERAL DESCRIPTION

In recent years, *Cryptosporidium* has come to be regarded as the most important waterborne human pathogen in developed countries. Over 30 outbreaks associated with drinking water have been reported in North America and Britain, with the largest infecting an estimated 403 000 people (Mackenzie *et al* 1994). Although the importance of this organism has been established, there are large gaps in knowledge, particularly in association with testing water for the presence of human infectious species.

Cryptosporidium is an obligate parasite with a complex life cycle involving intracellular development in the gut wall, with sexual and asexual reproduction. Thick-walled oocysts, shed in faeces, are responsible for transmission. Concentrations of oocysts as high as 14 000 per litre in raw sewage and 5800 per litre in surface water have been reported (Madore *et al* 1987). Oocysts are robust and can survive for weeks to months in fresh water.

There are a number of species of *Cryptosporidium* with *C. parvum* identified as the cause of disease (cryptosporidiosis) in humans. *C. parvum* infections have been identified in a wide range of mammals but transmission to humans has only been shown to occur from a few host species. There are currently no established methods to identify human infectious organisms in water. Cattle and sheep, particularly young animals, and human waste have been identified as important sources of human infections. It has been reported that infected calves can excrete up to 10 billion oocysts in one day. Waterborne outbreaks of cryptosporidiosis have been attributed to inadequate or faulty treatment and contamination by human or livestock (particularly cattle) waste.

Consumption of contaminated drinking water is only one of several mechanisms by which transmission (faecal-oral) can occur. Recreational waters, including swimming pools, are also emerging as an important source of cryptosporidiosis but, excluding outbreaks, direct contact with a human carrier is a likely route of transmission. Transmission of *Cryptosporidium* can also occur by contact with infected farm animals, possibly domestic pets and occasionally through contaminated food.

NOTE: Important general information is contained in PART II, Chapter 5

AUSTRALIAN SIGNIFICANCE

The most publicised incident of drinking water contamination in Australia occurred in July-September 1998 in Sydney. High numbers of *Cryptosporidium* and *Giardia* (see Fact Sheet) were reported for treated water, and boil-water notices were issued for 3 million residents. No increase in illness was detected in association with the contamination despite increased epidemiological surveillance. The incident highlighted the lack of a method to determine whether detected organisms are infective for humans.

Cryptosporidiosis is a notifiable condition in several states and territories. Sporadic cases are generally believed to be caused by person to person contact, but in the summer of 1997–98 there were outbreaks of illness attributed to contaminated swimming pools in the Australian Capital Territory, Queensland, New South Wales and Victoria. In South Australia, a relatively large number of illnesses were recorded in 1990–91 but no source was identified (Weinstein *et al* 1993). The only known outbreak of illness associated with drinking water occurred in Victoria, when a mixture of infections due to *Cryptosporidium* and *Giardia* followed contamination of a private water supply by overflow from a septic tank (Lester 1992).

PREVENTION OF CONTAMINATION OF DRINKING WATER

A multiple barrier approach operating from catchment to tap should be implemented to minimise the risk of contamination by *Cryptosporidium*. Protection of water catchments from contamination by human and animal wastes should be a priority. Water from unprotected catchments is likely to be subject to contamination by *Cryptosporidium* and treatment including effective filtration will be required to remove these organisms to ensure a safe supply. The lower the quality of source water, the greater the reliance on water treatment processes.

Sanitary surveys of water catchments for potential contamination sources should be undertaken, together with investigative and event-based testing of source water for *Cryptosporidium* to assess risk factors for contamination, to provide a basis for catchment management to reduce these risks and to determine the level of water treatment required. It has been reported that increases in turbidity associated with rainfall events may signal increased numbers of *Cryptosporidium* (Atherholt *et al* 1998).

Groundwater from confined aquifers or from depth should be free from contamination by *Cryptosporidium*. However, bores need to be well maintained and protected from intrusion of surface and subsurface contamination. Integrity should be monitored using traditional indicators of faecal contamination.

Cryptosporidium oocysts are extremely resistant to chlorine and will not be killed by concentrations that can be practically used in drinking water. Other disinfectants such as ozone are more effective (Bouchier 1998). Recent developments have suggested that particular types of ultraviolet light disinfection may be effective against *Cryptosporidium* when assessed using animal models of infectivity. However, the scientific evidence is incomplete and further investigations are required before clear guidance can be provided on the applicability of the identified technologies to water supplies.

Due to their small size, *Cryptosporidium* oocysts (4–6 µm) can challenge removal by granular media-based filtration processes. However, well designed and operated systems can provide a high level of removal. Membrane filtration processes that provide a direct physical barrier can represent a viable alternative for the effective removal of *Cryptosporidium*. The design and operation of water treatment plants should be carefully examined where *Cryptosporidium* oocysts are suspected or known to be present in the raw water, to ensure that required performance is achieved and maintained. For granular

media-based systems, particular attention should be paid to ensuring optimum coagulation/flocculation, monitoring of turbidity from all filters, appropriate handling of backwash water, minimising turbidity increases during filter start ups and operation of filters to avoid sudden flow surges (see Badenoch 1995; Bouchier 1998).

The performance of filtration plants should be monitored continuously and treated water of a constant quality should be produced irrespective of the quality of raw water.

Filtration plants should be operated by trained and skilled personnel. Failure of water treatment processes, including failure to meet specified targets for turbidity (or particle counts), should be regarded as representing a potential risk of oocyst contamination of the drinking water supply.

The integrity of distribution systems should be maintained. The use of unroofed treated water storages within distribution systems should be avoided as these could allow the entry of contamination from birds and small animals. Backflow prevention policies should be applied and faults and burst mains should be repaired in a manner that will prevent ingress of contamination.

METHOD OF IDENTIFICATION AND DETECTION

Although advances continue to be made, the most pressing need is for a reliable and efficient method to recover and identify viable human infectious *C. parvum*. Many quantification methods suffer from poor recovery efficiencies. Tests for viability require validation and methods for identification of *C. parvum* are in development. There are currently no established methods to identify human infectious organisms in water. It is likely to be some time before these issues are all resolved.

At this time, there is insufficient information to prescribe a standard method for testing water for the presence of *Cryptosporidium*. Most quantitative methods involve concentration of relatively large volumes of water and fluorescent staining of the concentrated material. The use of any method should incorporate exacting quality control procedures and include determination of recovery efficiencies. Where practicable, it is preferable to use methods that can also give an indication of the likelihood of viability (e.g. by detection of intracellular structures or membrane integrity) and the presence of *C. parvum* (e.g. by detection of RNA sequences).

HEALTH CONSIDERATIONS

Infection of normally healthy people by *Cryptosporidium* can result in self-limiting diarrhoea that usually resolves within a week but can last for a month or more. Illness varies according to age and immune status, and infections in severely immunocompromised people can be life threatening (Bouchier 1998; CDR 1999).

DERIVATION OF GUIDELINE

No guideline value is proposed for *Cryptosporidium* and routine monitoring of distribution systems including outlets from water treatment plants is not recommended because of the lack of a reliable and efficient method for the identification of human infectious *C. parvum*. In addition, current risk assessment models suggest that impractically large volumes of water would need to be tested to provide meaningful indications of health risk (Haas *et al* 1996).

Investigative testing of drinking water may be required if *Cryptosporidium* contamination is suspected. This could occur in association with a major rainfall event leading to a marked decrease in water quality and a marked increase in the numbers of *Cryptosporidium* in source water, sub-optimal operation of treatment processes, a breakdown in treatment plant operations or a fault within the distribution system. Monitoring may also be required in response to suspected waterborne cryptosporidiosis.

NOTE: Important general information is contained in PART II, Chapter 5

Any incident of concern that leads to the testing of distribution systems for *Cryptosporidium* should be notified immediately to the relevant health authority. If *Cryptosporidium* is detected in finished water, the relevant health authority should again be notified immediately.

Comprehensive protocols should be developed by water and health agencies to deal with *Cryptosporidium* in drinking water and should describe approaches for interpreting the health and operational significance of oocyst detections. In responding to incidents or detection, the health authority may choose to do so in consultation with the water authority and/or an expert panel. Credible public communication is essential. Responses could include: further sampling to confirm the presence and source of the organisms; testing for the presence of viable organisms and the specific presence of *C. parvum;* the issuing of advice, including boil-water notices, to the public; and enhanced surveillance to detect possible increases in community cryptosporidiosis.

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MacKenzie WR, Hoxie NJ, Proctor ME, Gradus MS, Blair KA, Paterson DE, Kazmicrczak JJ, Addiss DG, Fox KR, Rose JB, Davis JP (1994). A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply. *New England Journal of Medicine*, 331, 161–167.

Madore MS, Rose JB, Gerba CP, Arrowood MJ, Sterling CR. (1987). Occurrence of *Cryptosporidium* oocysts in sewage effluents and selected surface waters. *Journal of Parasitology*, 73, 702–5.

Weinstein P, Macaitis M, Walker C, Cameron S (1993). Cryptosporidial diarrhoea in South Australia: an exploratory case-control study of risk factors for transmission. *Medical Journal of Australia*, 158, 117–119.

Giardia

(Revised and endorsed 2000)

GUIDELINE

The implementation of a multiple barrier approach operating from catchment to tap to minimise the risk of* Giardia *contamination is recommended; with protection of catchments from human and animal wastes a priority. No guideline value is set for* Giardia *due principally to the lack of a method to identify human infectious strains in drinking water. Routine monitoring of distribution systems is not recommended; however, investigative testing may be required in response to events that could increase the risk of contamination by* Giardia*. Such events could include heavy rainfall leading to a marked increase in turbidity and numbers of* Giardia *in source water, sub-optimal operation of treatment processes or treatment plant failures. Investigative and event-based testing of source waters is recommended.

If detected in drinking water the relevant health authority should be advised immediately. All necessary measures to assess and minimise public health risks should be implemented as soon as possible. These could include further sampling to confirm the presence and source of the organisms, testing for the presence of viable organisms, increased disinfection, the issuing of advice (including boil-water notices) to the public and enhanced surveillance to detect possible increases in giardiasis in the community.

GENERAL DESCRIPTION

Although known as a human parasite for 200 years, *Giardia* has only been regarded seriously as an agent of disease since the 1960s and has been identified as an important waterborne pathogen. *Giardia* has been associated with many outbreaks of illness associated with drinking water, particularly in North America. Although the importance of this organism has been established there are large gaps in knowledge, particularly in association with testing water for the presence of human infectious species.

Giardia has a relatively simple life cycle involving two stages: a flagellate that multiplies in the intestine, and an infective thick-walled cyst that is shed intermittently but in large numbers in faeces. Concentrations of cysts as high as 88 000 per litre in raw sewage and 240 per litre in surface water have been reported (Wallis *et al* 1996). Cysts are robust and can survive for weeks to months in fresh water.

There are a number of species of *Giardia* but human infections (giardiasis) are usually assigned to one, *Giardia intestinalis (= Giardia lamblia* and *Giardia duodenalis). G. intestinalis* infections have been reported from domestic and wild animals but the host range of human infectious species is uncertain. Although substantial advances have been made in the sampling and counting of cysts, there are currently no established methods to identify human infectious organisms in water. Waterborne outbreaks of giardiasis have generally been linked to consumption of untreated or unfiltered surface water and contamination with human waste.

Consumption of contaminated drinking water is only one of several mechanisms by which transmission (faecal-oral) can occur. Recreational waters, including swimming pools, are also emerging as an important source of giardiasis. However, excluding outbreaks the most likely route of transmission is by direct contact with a human carrier. Transmission of *Giardia* can also occur by contact with infected animals and occasionally through contaminated food.

NOTE: Important general information is contained in PART II, Chapter 5

AUSTRALIAN SIGNIFICANCE

Outbreaks of giardiasis in Australia often involve close communal groups. In day-care centres, for instance, as many as 20% of children may carry *Giardia* without symptoms (Grimmond *et al* 1988). Infection is endemic and is significant among children and adults in the wider community, and sources of this infection are difficult to identify. Giardiasis is notifiable in some states and territories.

The most publicised incident of drinking water contamination in Australia occurred in July-September 1998 in Sydney. High numbers of *Cryptosporidium* (see Fact Sheet) and *Giardia* were reported for treated water, and boil-water notices were issued for 3 million residents. No increase in illness was detected in association with the contamination despite increased epidemiological surveillance. An epidemiological study in Queensland showed no correlation between infection and source of drinking water, point-of-use treatment (boiling or filtration) or recreational contact with water (Boreham and Phillips 1986). Another study identified contact with septic tank waste or contaminated soil as a possible mechanism of infection (Boreham *et al* 1981). An outbreak of illness associated with drinking water was reported in Victoria when mixed infections due to *Cryptosporidium* and *Giardia* followed contamination of a private water supply by overflow from a septic tank (Lester 1992).

PREVENTION OF CONTAMINATION OF DRINKING WATER

A multiple barrier approach operating from catchment to tap should be implemented to minimise the risk of contamination by *Giardia*. Protection of water catchments from contamination by human and animal wastes should be a priority, particularly for those supplies that cannot provide adequate disinfection to kill *Giardia*. Water from unprotected catchments is likely to be subject to contamination by *Giardia* and treatment including effective filtration or enhanced disinfection will be required to remove these organisms, to ensure a safe supply. The lower the quality of source water, the greater the reliance on water treatment processes.

Sanitary surveys of water catchments for potential contamination sources should be undertaken, together with investigative and event-based testing of source water for *Giardia* to assess risk factors for contamination, to provide a basis for catchment management to reduce these risks and to determine the level of water treatment required. It has been reported that increases in turbidity associated with rainfall events may signal increased numbers of *Giardia* (Atherholt *et al* 1998).

Groundwater from confined aquifers or from depth should be free from contamination by *Giardia*. However, bores need to be well maintained and protected from intrusion of surface and subsurface contamination. Integrity should be monitored using traditional indicators of faecal contamination.

Giardia cysts are more resistant than enteric bacteria to chlorine but they are not as resistant as *Cryptosporidium*. The time required for a 90% (1 $\log_{10}$) kill at 1 mg/L free chlorine is of the order of 25–35 minutes. Other disinfectants such as ozone are more effective. The United States Environmental Protection Agency (USEPA) has published C.*t* tables specifying chlorine concentrations (C) and contact times *(t)* required to inactivate *Giardia* cysts over a range of conditions (see USEPA 1999). In addition, C.*t* tables were provided for chloramines, ozone and chlorine dioxide. Ensuring that disinfectant concentrations and contact times are at all times greater than the values specified in the C.*t* tables provides a practical means of ensuring that *Giardia* cysts are inactivated and are not a threat to public health.

The USEPA National Primary Drinking Water Standards prescribe comprehensive treatment (including filtration and disinfection) of most surface waters to protect drinking water from contamination by *Giardia*. Operational procedures in water treatment plants should be carefully examined where *Giardia* cysts are suspected or known to be present in the raw water, to ensure that optimum removal is achieved and maintained. Filtration plants should be operated by trained and skilled personnel.

The integrity of distribution systems should be maintained. The use of unroofed treated water storages within distribution systems should be avoided as these could allow the entry of contamination from birds and small animals. Backflow prevention policies should be applied and faults and burst mains should be repaired in a manner that will prevent ingress of contamination.

METHOD OF IDENTIFICATION AND DETECTION

Although advances continue to be made, the most pressing needs are for reliable and efficient methods to recover and identify viable human infectious *Giardia*. Many quantification methods suffer from poor recovery efficiencies, and tests for viability require validation. There are currently no established methods to identify human infectious organisms in water. It is likely to be some time before these issues are all resolved.

At this time, there is insufficient information to prescribe a standard method for testing water for the presence of *Giardia*. Most methods in use involve concentration of relatively large volumes of water and fluorescent staining of the concentrated material. The use of any method should incorporate exacting quality control procedures and include determination of recovery efficiencies. Where practicable, it is preferable to use a method that can also give an indication of the likelihood of viability (e.g. by detection of intracellular structures or membrane integrity).

HEALTH CONSIDERATIONS

Infection by *Giardia* may reduce absorption of nutrients and cause diarrhoea. In most cases, illness is self limiting but in some cases chronic infection with intermittent diarrhoea can occur. Specific treatments are available.

DERIVATION OF GUIDELINE

No guideline value is proposed for *Giardia*, and routine monitoring of distribution systems including outlets from water treatment plants is not recommended because of the lack of a reliable and efficient method for the identification of human infectious organisms. In addition, current risk assessment models suggest that inordinately large volumes of water would need to be tested to provide meaningful indications of health risk.

Investigative testing of drinking water may be required if *Giardia* contamination is suspected. This could occur in association with a major rainfall event leading to a marked decrease in water quality and a marked increase in the numbers of *Giardia* in source water, sub-optimal operation of treatment processes, a breakdown in treatment plant operations or a fault within the distribution system. Monitoring may also be required in response to suspected waterborne giardiasis.

Any incident of concern that leads to the testing of distribution systems for *Giardia* should be notified immediately to the relevant health authority. If *Giardia* is detected in finished water, the relevant health authority should again be notified immediately.

Comprehensive protocols should be developed by water and health agencies to deal with *Giardia* in drinking water and should describe approaches for interpreting the health and operational significance of cyst detections. In responding to incidents or detection, the health authority may choose to do so in consultation with the water authority and/or an expert panel. Credible public communication is essential. Responses could include further sampling to confirm the presence and source of the organisms; testing for the presence of viable organisms; increased disinfection; the issuing of advice, including boil-water notices, to the public; and enhanced surveillance to detect possible increases in community giardiasis.

NOTE: Important general information is contained in PART II, Chapter 5

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Naegleria fowleri

GUIDELINE

No guideline value is set for* Naegleria fowleri *in drinking water, but an 'action level' is recommended for water supplies likely to be contaminated. If the organism is detected, advice should be sought from the relevant health authority.

GENERAL DESCRIPTION

Naegleria fowleri is a free-living, thermophilic amoeboflagellate which causes the waterborne disease primary amoebic meningoencephalitis (PAM). This rare but fatal condition has followed use of water for swimming, or domestic bathing. The organism occurs naturally in freshwater of suitable temperature, feeding on bacteria. Its occurrence is only indirectly related to human activity, inasmuch as such activity may modify temperatures or promote bacterial production. PAM has been reported from many countries, usually associated with thermally polluted environments, geothermal water or heated swimming pools. *N. fowleri* is almost exclusively aquatic, and water is the only known source of infection. Numerous nonvirulent *Naegleria* species are known in Australia.

AUSTRALIAN SIGNIFICANCE

PAM cases have been recorded from South Australia, Western Australia, Queensland and New South Wales; *Naegleria fowleri* has been detected in water in each of these states and in the Northern Territory. Australia is the only country where *N. fowleri* has been detected in public water supplies (Dorsch *et al* 1983). Most of the available data on the density of *N. fowleri* in water relates to water supplies in South Australia (including the highest reported densities). In temperate Australia, significant seasonal cycles of density occur, from below one organism per litre to hundreds or thousands per litre in poorly disinfected water (Robinson and Christy 1984). *N. fowleri* detected at water temperatures below 18°C is likely to be present as cysts, which are not infectious, but which may seed a suitable environment.

TREATMENT OF DRINKING WATER

Free chlorine or chloramines at 0.5 mg/L or higher will control *N. fowleri*, provided that the disinfectant persists throughout the water supply system. Chloramination is the preferred process in extensive rural water supplies, owing to its stability (Robinson and Christy 1984).

METHOD OF IDENTIFICATION AND DETECTION

Detection of amoebae, concentrated from water samples, requires relatively simple growth media and standard laboratory incubation facilities. Identification of *Naegleria* species, particularly recognition of *N. fowleri,* is more specialised. In routine or investigative analyses, presence of any thermophilic amoebae (able to grow at 42°C or above) is evidence that conditions are suitable for *N. fowleri* should it be introduced. If samples include any *Naegleria*, remedial action should be taken immediately without waiting for specific identification.

Prospective studies directed at water supplies that are susceptible to colonisation by *N. fowleri* can be valuable since the mortality rate of infection is so high, but universal monitoring is not appropriate.

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

N. fowleri is apparently an accidental pathogen. Its unusual route of infection (intranasal) means that PAM is associated with bathing rather than with ingesting water. Treatment is rarely effective, even in cases diagnosed early, and PAM is almost invariably fatal. Most Australian victims have been children (Dorsch *et al* 1983).

Recreational bathing presents the greatest risk of infection by *N. fowleri*, owing to the nature and duration of exposure, but domestic bathing can also lead to infection (Dorsch *et al* 1983). Public water supplies can therefore be important as sources of contamination of public or private swimming pools, or as direct sources of infection. The infectious dose is unknown, but the frequency of infections has been low, even in populations that seem to have been widely and repeatedly exposed. A density of around 100 organisms per litre may present an immediate risk of infection but rapid density changes of this free-living organism can occur (Robinson and Christy 1984).

DERIVATION OF GUIDELINE

No guideline value is proposed for *N. fowleri*, given its irregular distribution in Australia and its dependence on relatively high water temperatures. However, any water supply that seasonally exceeds 30°C or that continually exceeds 25°C can support the growth of *N. fowleri*. In such cases, a periodic prospective study would be valuable, but regular monitoring is not warranted unless *N. fowleri* is detected. A density of 2 organisms per litre (or detection in a 500 mL sample) is an appropriate threshold for action, given the rapid density changes that can occur. Other thermophilic *Naegleria* can be useful 'proxy' organisms for *N. fowleri*, allowing early remedial action.

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Microorganisms · Toxic Algae

Cylindrospermopsin

(Added and endorsed 2001)

GUIDELINE

Due to the lack of adequate data, no guideline value is set for concentrations of cylindrospermopsin. However, given the known toxicity of cylindrospermopsin, the relevant health authority should be advised immediately if blooms of* Cylindrospermopsis raciborskii *or* Aphanizomenon ovalisporum *are detected in sources of drinking water.

GENERAL DESCRIPTION

Cylindrospermopsin is a cyclic guanidine alkaloid cytotoxin with a molecular weight of 415, produced by the freshwater cyanobacteria *Cylindrospermopsis raciborskii, Aphanizomenon ovalisporum* and *Umezakia natans*. It was first characterised and named from an Australian isolate of *C. raciborskii* (Ohtani *et al* 1992). Subsequently, cylindrospermopsin has been detected in two other cyanobacteria; *Umezakia natans* in Japan (Harada *et al* 1994; Terao *et al* 1994); and *Aphanizomenon ovalisporum* in Israel (Banker *et al* 1997) and Australia (Shaw *et al* 1999). In pure form, cylindrospermopsin is predominantly a hepatotoxin, although extracts of *C. raciborskii* administered to mice induce pathological symptoms in the kidneys, spleen, thymus, heart and eye. Other structural variants of cylindrospermopsin have been isolated from *C. raciborskii* , including a deoxycylindrospermopsin (Norris *et al* 1999).

The production of toxins and therefore the presence of toxicity in individual populations of some cyanobacterial species is known to be variable (Chorus and Bartram 1999 Chapter 3). In the case of *C. raciborskii* however, the majority of the strains tested so far in Australia appear to produce cylindrospermopsin. It is therefore likely that most blooms of *C. raciborskii* encountered will have some degree of toxicity. The limited data on the natural breakdown of cylindrospermopsin in natural waters indicated that the half-life was 11 and 15 days for two dams in Queensland, respectively (Chiswell *et al* 1999).

AUSTRALIAN SIGNIFICANCE

Cylindrospermopsin is believed to have been the causative agent in the Palm Island 'mystery disease' poisoning incident in Queensland in 1979, in which 148 people were hospitalised (Byth 1980). It was subsequently shown that water from Solomon Dam on Palm Island contained blooms of toxic *Cylindrospermopsis raciborskii* (Hawkins *et al* 1985). *C. raciborskii* has been found in many water supply reservoirs in northern, central and southern Queensland. Although *C. raciborskii* and *A. ovalisporum* are both considered to be predominantly tropical/subtropical in terms of habitat, with most Australian blooms occurring in Queensland, *C. raciborskii* also occurs in the Murray-Darling River system (Baker and Humpage 1994). *C. raciborskii* is not a scum-forming organism, but forms dense bands below the water surface in stratified lakes, while *A. ovalisporum* may form thick brown surface scums (Shaw *et al* 1999). Although no reports of human poisoning attributable to cylindrospermopsin have appeared since the Palm Island incident, recent cattle deaths in Queensland are attributed to this toxin (Saker *et al* 1999).

NOTE: Important general information is contained in PART II, Chapter 5

TREATMENT OF DRINKING WATER

The first line of defence against cyanobacteria is catchment management to minimise nutrient inputs to source waters. Source water management techniques for control of cyanobacterial growth include flow maintenance in regulated rivers; water mixing techniques for both the elimination of stratification and the reduction of nutrient release from sediments in reservoirs; and the use of algicides in dedicated water supply storages. Destratification has been used to attempt to reduce bloom intensities of *C. raciborskii* in reservoirs in Queensland; however, it has not yet been possible to critically determine the efficacy of this treatment method. It should be noted that algicides will disrupt cells and liberate intracellular toxins. Algicide use should be in accordance with local environment and chemical registration regulations. In situations where multiple offtakes are available, the selective withdrawal of water from different depths can minimise the intake of localised high cell densities at a particular depth.

Water treatment techniques can be highly effective for removal of both cyanobacterial cells and cylindrospermopsin with the combination of the appropriate technology. In contrast to other cyanotoxins, a high proportion of cylindrospermopsin in actively growing *C. raciborskii* blooms may be found free in the water, (i.e. not cell-bound) (Chiswell *et al* 1999). Depending upon the circumstances then, only the proportion of cylindrospermopsin that is cell-bound can be removed by coagulation and filtration in a conventional treatment plant (Chorus and Bartram 1999 Chapter 9). It should be noted that treatment of water containing cyanobacterial cells with oxidants such as chlorine or ozone, while killing cells, will result in the release of free toxin. Therefore, the practice of prechlorination or preozonation is not recommended without a subsequent step to remove dissolved toxins. Cylindrospermopsin is readily oxidised by a range of oxidants including ozone and chlorine. Adequate contact time and pH control need to be achieved to ensure optimum removal of these compounds, and this will be more difficult to achieve in the presence of whole cells (Chorus and Bartram 1999 Chapter 9). Cylindrospermopsin is also adsorbed from solution by both granular activated carbon and powdered activated carbon. Boiling is not effective for the destruction of cylindrospermopsin. Based on current knowledge, the recommended best-practice treatment scheme for removal of cylindrospermopsin would include conventional treatment (coagulation/filtration) followed by an adsorption or oxidation step.

METHOD OF IDENTIFICATION AND DETECTION

Animal bioassays (mouse tests) have been used to determine the toxicity of *C. raciborskii* (Falconer *et al*1999; Seawright *et al* 1999). These tests provide a definitive indication of toxicity, although they cannot be used for precise quantification of compounds in water. Instrumental analytical techniques are available for determining the presence of cylindrospermopsin in water including high performance liquid chromatography (HPLC) with ultraviolet detection (Harada *et al* 1994), and HPLC-mass spectrometry (MS) MS/MS (Eaglesham *et al* 1999).

Cyanobacteria are detected by light microscopy, identified using morphological characteristics and counted per standard volume of water (Hotzel and Croome 1999). Standard protocols for sampling and monitoring cyanobacteria are given by Jones *et al* (in press), and practical keys for the identification are provided in Baker and Fabbro (1999).

HEALTH CONSIDERATIONS

The major pathological effects of cylindrospermopsin are liver and kidney damage, together with injury to the lining of the gastrointestinal tract and blood vessels (Falconer *et al* 1999; Seawright *et al* 1999). Cylindrospermopsin is a slow-acting toxin, commonly requiring between 5 and 7 days to produce maximum toxic effect in experimental animals. The 24-hour intraperitoneal (ip) LD_{50} for mice is 2 mg/kg, while the 5-day ip LD_{50} is 0.2 mg/kg (Terao 1994). The 5-day LD_{50} for mice by oral administration is approximately 6 mg/kg (Seawright *et al* 1999).

DERIVATION OF GUIDELINE

There are currently insufficient animal toxicity data to establish a guideline value for cylindrospermopsin.

NOTIFICATION PROCEDURE

It is recommended that a notification procedure be developed by water and health authorities for blooms of *C. raciborskii or A. ovalisporum*.

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NOTE: Important general information is contained in PART II, Chapter 5

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Microcystins

(Added and endorsed 2001)

GUIDELINE

Based on health considerations, the concentration of total microcystins in drinking water should not exceed 1.3 µg/L expressed as microcystin-LR toxicity equivalents (TE).

GENERAL DESCRIPTION

Microcystins are a large group of hepatotoxic peptides that are produced by a range of cyanobacteria. This group of cyanotoxins includes in excess of 60 different structural variants of cyclic heptapeptides (consisting of seven amino acids in a ring structure), with molecular weights in the range 800–1100 (Chorus and Bartram 1999 Chapter 3). The best characterised and one of the most toxic variants of microcystin is microcystin-LR. Most of the structural variants of microcystin are highly toxic within a narrow range, although some nontoxic variants have been identified (Chorus and Bartram 1999 Chapter 3).

Microcystins are most commonly produced by species of the genus *Microcystis*, from which the toxins originally derived their name. However, these toxins have now been shown to be produced by species of the planktonic genera *Anabaena, Microcystis, Planktothrix (Oscillatoria), Nostoc*, and *Anabaenopsis,* and also by a terrestrial (soil) species *Haphalosiphon hibernicus,* indicating the potential for widespread occurrence in the environment. The majority of human and animal microcystin-related poisonings worldwide are nevertheless associated with the presence of *Microcystis*.

The toxicity of individual populations of *M. aeruginosa* is known to be variable, and one extensive survey of the toxicity across the Murray-Darling Basin indicated that 56% of field samples tested were hepatotoxic (Baker and Humpage 1994). A natural population may consist of a mixture of toxic and nontoxic strains, and this is believed to be the reason why population toxicity may vary over time and between samples (Chorus and Bartram 1999 Chapter 3).

These cyanotoxins are largely water-soluble and are therefore, with a few exceptions, unable to easily penetrate biological membranes. Microcystins are considered to enter the bloodstream of mammals from the intestine predominantly through the bile acid transport system. Subsequently, the absorbed toxins are concentrated into liver cells, and cause hepatoenteritis. The half-lives for breakdown of microcystins in natural water have been shown to vary from 5 to 20 days (Jones *et al* 1994).

AUSTRALIAN SIGNIFICANCE

Microcystins are the most significant drinking water quality issue in relation to cyanobacterial blooms in southeastern Australia. Microcystins are produced predominantly by *M. aeruginosa* in Australia. They can occasionally be produced by *Anabaena* spp, but this appears to be rare in Australia.

The conditions that favour the growth of cyanobacteria and lead to blooms are usually a combination of nutrient enrichment (largely phosphorus but also nitrogen), warm temperatures and calm stable water conditions, such as those occurring in slow-flowing rivers and thermally stratified lakes. The water supply problems associated with cyanobacteria include offensive tastes and odours, and the production of toxins.

NOTE: Important general information is contained in PART II, Chapter 5

TREATMENT OF DRINKING WATER

The first line of defence against cyanobacteria is catchment management to minimise nutrient inputs to source waters. Source water management techniques for control of cyanobacterial growth include flow maintenance in regulated rivers; water mixing techniques for both the elimination of stratification and the reduction of nutrient release from sediments in reservoirs; and the use of algicides in dedicated water supply storages. It should be noted that algicides will disrupt cells and liberate intracellular toxins. Algicide use should be in accordance with local environment and chemical registration regulations. In situations where multiple offtakes are available, the selective withdrawal of water from different depths can minimise the intake of high surface accumulations of cyanobacterial cells.

Water treatment techniques can be highly effective for removal of both cyanobacterial cells and microcystins with the combination of the appropriate technology. As with other cyanotoxins, a high proportion of microcystins remain intracellular unless cells are lysed or damaged, and can therefore be removed by coagulation and filtration in a conventional treatment plant (Chorus and Bartram 1999 Chapter 9). It should be noted that treatment of water containing cyanobacterial cells with oxidants such as chlorine or ozone, while killing cells, will result in the release of free toxin. Therefore, the practice of prechlorination or preozonation is not recommended without a subsequent step to remove dissolved toxins.

Microcystins are readily oxidised by a range of oxidants including ozone and chlorine. Adequate contact time and pH control need to be achieved to ensure optimum removal of these compounds, and this will be more difficult to achieve in the presence of whole cells (Chorus and Bartram 1999 Chapter 9). Microcystins are also adsorbed from solution by both granular activated carbon and less efficiently by powdered activated carbon. (Chorus and Bartram 1999 Chapter 9). Boiling is not effective for destruction of microcystins. If treatment is instituted in response to the presence of toxin-producing cyanobacteria, the effectiveness of the process will need to be confirmed by testing for toxin in the product water.

METHOD OF IDENTIFICATION AND DETECTION

Animal bioassays (mouse tests) have traditionally been used for detecting the presence of the entire range of cyanotoxins including microcystins. These tests provide a definitive indication of toxicity, although they cannot be used for precise quantification of compounds in water or for determining compliance with the guideline value. A number of techniques are available for determining microcystins in water (Chorus and Bartram 1999 Chapter 13). It is necessary to select an analytical technique that provides for quantitative comparison to the guideline value in terms of toxicity equivalents. The technique most suitable in this regard is high performance liquid chromatography (HPLC) when quantitative standards are available. The use of HPLC may still involve estimation of the concentration and therefore toxicity of some microcystins in a sample against microcystin-LR as the analytical standard, and in this case a slight overestimate of total microcystins (as microcystin-LR, toxicity equivalents) may result.

Cyanobacteria are detected by light microscopy; identified using morphological characteristics and counted per standard volume of water (Hotzel and Croome 1999). Standard protocols for sampling and monitoring cyanobacteria are given by Jones *et al* (in press), and practical keys for the identification are provided in Baker and Fabbro (1999).

HEALTH CONSIDERATIONS

The mechanism of toxicity for microcystins involves inhibition of protein phosphatase enzymes in eucaryotic cells. Within the liver, this biochemical effect leads to disruption of hepatocyte (liver cell) skeletal structure and cell integrity. This can lead to more widespread disintegration of liver integrity and haemorrhage in the case of acute toxicity from exposure to a high dose.

There is a significant body of reports describing animal poisonings from ingesting water that contains *Microcystis*, with some examples confirming hepatotoxicity and the associated presence of microcystins (NHMRC 1994). Significant human illness has been strongly associated with exposure to microcystins in recreational waters (Turner *et al* 1990). Recently, in a major incident in Brazil, over 70 deaths were ascribed to accidental intravenous exposure of kidney dialysis patients to microcystins in dialysis water (Jochimsen *et al* 1998).

In experimental animal studies, microcystin-LR can produce extreme acute toxicity. In mice the LD_{50} for the intraperitoneal route is in the range of 0.025 to 0.15 mg/kg bodyweight, with the commonly accepted value of 0.05 mg/kg, and 5 and 10.9 mg/kg bodyweight for oral administration for two different strains of mice. Even higher values have been demonstrated in rats (Chorus and Bartram 1999 Chapter 4).

Microcystins promote the growth of tumours in experimental animals (Falconer 1991; Nishiwaki-Matsushima *et al* 1992). The significance of this for humans, who may be subject to chronic exposure via drinking water, is unclear. Microcystins have been implicated as causing liver damage in an Australian population exposed via reticulated town water supply where the source water contained blooms of *Microcystis* (Falconer *et al* 1983). Overall, the evidence for carcinogenicity of microcystins is considered inadequate in humans and limited in animals (Chorus and Bartram 1999 Chapter 4). Microcystins are currently regarded as nongenotoxic.

DERIVATION OF GUIDELINE

$$1.3\ \mu g/L = \frac{40\ \mu g/kg\ bodyweight\ per\ day \times 70\ kg \times 0.9}{2\ L/day \times 1000}$$

where:

- 40 µg/kg body weight per day is the no observed adverse effect level (NOAEL) from a 13-week ingestion study with microcystin-LR in mice, based on liver histopathology and serum enzyme level changes (Fawell *et al* 1994)
- 70 kg is the average weight of an adult
- 0.9 is the proportion of total daily intake attributed to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor derived from extrapolation of an animal study to humans (10 for interspecies variability, 10 for intraspecies variability and 10 for limitations in the database, related particularly to the lack of data on chronic toxicity and carcinogenicity).

The guideline is derived for total microcystins and expressed as microcystin-LR toxicity equivalents (TE). This is because the total microcystin concentration should be considered in relation to potential health impacts.

The World Health Organization (WHO) has recently undertaken an evaluation of the health-related information for cyanobacterial toxins (Gupta 1998; WHO 1998; Chorus and Bartram 1999 Chapter 5). It was concluded that there are insufficient data to allow a guideline value to be derived for any cyanobacterial toxins other than microcystin-LR. The guideline recommended by the WHO for drinking water is 1 µg/L (rounded figure) for total microcystin-LR (free plus cell-bound), based on the Fawell *et al* (1994) subchronic study. This guideline value for microcystin-LR is provisional because the database is regarded as limited (WHO 1998).The approach being taken for guideline derivation here is essentially similar to that used by WHO (Chorus and Bartram 1999 Chapter 5). The same ingestion study in mice was used to calculate the NOAEL. The Australian guideline of 1.3 µg/L total microcystin (as microcystin-LR (TE)) differs from the WHO provisional guideline of 1 µg/L microcystin-LR, due to the incorporation of a different average body weight for an adult (70 kg versus 60 kg) and to a difference with regard to the proportion of the daily intake of microcystin being attributed to the consumption of drinking water. The proportion for the Australian situation is regarded to be 0.9, which is higher than the value of 0.8 selected by WHO. This is due to lower potential exposure in Australia from other environmental sources, such as contaminated bathing water, and via dietary supplements potentially containing microcystins.

In situations where *M. aeruginosa* occurs in drinking water supplies and toxin monitoring data are unavailable, cell numbers can be used to provide a preliminary orientation to the potential hazard to public health. As an indication, for a highly toxic population of *M. aeruginosa* (toxin cell quota of 0.2 pg total microcystins/cell), a cell density of approximately 6500 cells/mL is equivalent to the guideline of 1.3 µg/L microcystin-LR (TE), if the toxin were fully released into the water. This number is indicative only, and for health risk assessment, toxin determination is required. There are insufficient data to give guidance for the equivalent indicative cell numbers of microcystin containing *Anabaena* spp in Australian waters.

NOTIFICATION PROCEDURE

It is recommended that a notification procedure should be developed by water and health authorities. A tiered alert levels framework, as suggested by Chorus and Bartram (1999 Chapter 6), should be considered.

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NOTE: Important general information is contained in PART II, Chapter 5

Nodularin

(Added and endorsed 2001)

GUIDELINE

Due to the lack of adequate data, no guideline value is set for concentrations of nodularin. However, given the known toxicity of nodularin, the relevant health authority should be advised immediately if blooms of* Nodularia spumigena *are detected in sources of drinking water.

GENERAL DESCRIPTION

Nodularin is a cyclic pentapeptide hepatotoxin produced by the cyanobacterium *Nodularia spumigena*. Nodularin is structurally similar to microcystins and exerts similar toxicity to microcystin-LR at its main target site in the liver.

Nodularin is found only in the cyanobacterium *N. spumigena* and although a few variants of nodularin occur (Chorus and Bartram 1999 Chapter 3), these are likely to be either rare or nontoxic, and are therefore not considered here. The production of toxins and therefore the presence of toxicity in individual populations of some cyanobacterial species is known to be variable (Chorus and Bartram 1999 Chapter 3). In the case of *N. spumigena* however, the majority of the strains tested so far in Australia appear to produce nodularin. It is therefore likely that most blooms of *N. spumigena* encountered will have some degree of toxicity.

AUSTRALIAN SIGNIFICANCE

The cyanobacterium *N. spumigena* is primarily regarded as a brackish water species and forms blooms in estuarine lakes in Australia, New Zealand and Europe. It can also occur in brackish inland lakes in Australia (Wood 1975). In addition to these saline environments, there are also frequent blooms of toxic *N. spumigena* in freshwater lakes of the lower River Murray, South Australia (Baker and Humpage 1994). This is a relatively unique circumstance where *N. spumigena* blooms in freshwater, and is of particular importance as the water is used for potable supplies, irrigation and stock watering. Lake Alexandrina in South Australia was the site of the first scientifically documented animal poisoning by *N. spumigena*, and indeed by any cyanobacterium (Francis 1878). It is likely that these poisonings and the toxic effects described by Francis were due to nodularin. Low numbers of *N. spumigena* have also been recorded in the other (freshwater) river systems of the Murray-Darling Basin. The limited geographic scope for blooms of this organism in freshwater in Australia makes the occurrence of nodularin a relatively minor public health threat with respect to drinking water.

TREATMENT OF DRINKING WATER

The first line of defence against cyanobacteria is catchment management to minimise nutrient inputs to source waters. Source water management techniques for control of cyanobacterial growth include flow maintenance in regulated rivers; water mixing techniques for both the elimination of stratification and the reduction of nutrient release from sediments in reservoirs; and the use of algicides in dedicated water supply storages. It should be noted that algicides will disrupt cells and liberate intracellular toxins. Algicide use should be in accordance with local environment and chemical registration regulations. In situations where multiple offtakes are available, the selective withdrawal of water from different depths can minimise the intake of high surface accumulations of cyanobacterial cells.

NOTE: Important general information is contained in PART II, Chapter 5

Water treatment techniques can be highly effective for removal of both cyanobacterial cells and nodularin with the combination of the appropriate technology. As with other cyanotoxins, a high proportion of nodularin remains intracellular unless cells are lysed or damaged, and can therefore be removed by coagulation and filtration in a conventional treatment plant (Chorus and Bartram 1999 Chapter 9). It should be noted that treatment of water containing cyanobacterial cells with oxidants such as chlorine or ozone, while killing cells, will result in the release of free toxin. Boiling is not effective for destruction of nodularin. Therefore, the practice of prechlorination or preozonation is not recommended without a subsequent step to remove dissolved toxins.

Nodularin is readily oxidised by chlorine, but has not been evaluated with ozone. Adequate contact time and pH control need to be achieved to ensure optimum removal of these compounds, and this will be more difficult to achieve in the presence of whole cells (Chorus and Bartram 1999 Chapter 9). Nodularin is also adsorbed from solution by powdered activated carbon. If treatment is instituted in response to the presence of toxin-producing cyanobacteria, the effectiveness of the process will need to be confirmed by testing for toxin in the product water.

METHOD OF IDENTIFICATION AND DETECTION

Animal bioassays (mouse tests) have traditionally been used for detecting the presence of the entire range of cyanotoxins including nodularin. These tests provide a definitive indication of toxicity, although they cannot be used for precise quantification of compounds in water. A number of techniques are available for determining nodularin in water (Chorus and Bartram 1999 Chapter 13). These include screening techniques based on enzyme-linked immunosorbent assay (ELISA), protein phosphatase inhibition assays, and quantitative techniques such as high performance liquid chromatography (HPLC). The analytical techniques based on liquid chromatography (HPLC, liquid chromatography mass spectroscopy) offer good quantitative information on toxin concentrations, especially as chemical standards for nodularin are commercially available.

Cyanobacteria are detected by light microscopy, identified using morphological characteristics and counted per standard volume of water (Hotzel and Croome 1999). Standard protocols for sampling and monitoring cyanobacteria are given by Jones *et al* (in press), and practical keys for their identification are provided in Baker and Fabbro (1999).

HEALTH CONSIDERATIONS

There are no reports of human health effects from consumption of water containing nodularin and/or *N. spumigena*. In addition, there are no human or animal studies of toxicity by oral exposure to nodularin. Nodularin is at least as hepatotoxic as microcystin for intraperitoneal exposure in experimental animals and, given its identical mode of action, can be regarded as presenting at least the same risk to human health as microcystin if ingested in drinking water. Nodularin is also known to accumulate in mussels in estuaries, and the consumption of contaminated shellfish therefore represents a potential alternative route of human exposure (Falconer *et al* 1992).

DERIVATION OF GUIDELINE

There are insufficient animal toxicity data to establish a guideline value for nodularin.

As there are some similarities between the toxicity of nodularin and microcystins, the guideline for microcystins could be used to derive cell numbers of *N. spumigena* that represent a preliminary indication of the potential hazard. The only available monitoring data for nodularin in freshwater indicated that the upper range for cell numbers of *N. spumigena* was 50 000–80 000 cells/mL, and this correlated with nodularin levels of 1.0–1.7 µg/L (Heresztyn and Nicholson 1997). Based on this limited data, nodularin levels of around 1.3 µg/L would be associated with cell densities of 40 000–100 000 cells/mL. It is recommended that notification and further assessment occur where cell numbers of *N. spumigena* exceed 40 000 cells/mL.

NOTIFICATION PROCEDURE

It is recommended that a notification procedure should be developed by water and health authorities. A tiered alert levels framework, as suggested by Chorus and Bartram (1999 Chapter 6), should be considered.

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NOTE: Important general information is contained in PART II, Chapter 5

Saxitoxins

(Added and endorsed 2001)

GUIDELINE

Due to the lack of adequate data, no guideline value is set for concentrations of saxitoxins. However, given the known toxicity of saxitoxins, the relevant health authority should be advised immediately if blooms of Anabaena circinalis are detected in sources of drinking water.

GENERAL DESCRIPTION

There are three types of cyanobacterial neurotoxins, anatoxin a, anatoxin a-s and the saxitoxins. The saxitoxins include saxitoxin, neosaxitoxin, C-toxins and gonyautoxins (Chorus and Bartram 1999 Chapter 3). The anatoxins seem unique to cyanobacteria, while saxitoxins are also produced by various dinoflagellates under the name of paralytic shellfish poisons (PSPs). A number of cyanobacterial genera can produce neurotoxins, including *Anabaena, Oscillatoria, Cylindrospermopsis, Cylindrospermum, Lyngbya* and *Aphanizomenon,* but to date in Australia, neurotoxin production has only been detected from Anabaena circinalis, and the Australian isolates appear to produce only saxitoxins (Velzeboer *et al* 1998). As with most toxic cyanobacteria, *A. circinalis* tends to proliferate in calm stable waters, particularly in summer when thermal stratification reduces mixing.

The toxicity of individual populations of *A. circinalis* is known to be variable, and one extensive survey of the toxicity across the Murray-Darling Basin indicated that 54% of field samples tested were neurotoxic (Baker and Humpage 1994). A natural population may consist of a mixture of toxic and nontoxic strains and this is believed to be the reason why population toxicity may vary over time and between samples (Chorus and Bartram 1999 Chapter 3).

The saxitoxins are a group of carbamoyl and decarbamoyl alkaloids that are either nonsulfated (saxitoxins), singly-sulfated (gonyautoxins) or doubly-sulfated (C-toxins). The various types of toxins vary in potency, with saxitoxin having the highest toxicity. The prevalent toxins in Australian blooms of *A. circinalis* are the C-toxins. These can convert in the environment or by acidification or boiling to more potent toxins (Negri *et al* 1997; Ravn *et al* 1995). The half-lives for breakdown of a range of different saxitoxins in natural water have been shown to vary from 9 to 28 days, and gonyautoxins may persist in the environment for more than 3 months (Jones and Negri 1997).

AUSTRALIAN SIGNIFICANCE

Blooms of *A. circinalis* have been recorded in many rivers, lakes, reservoirs and dams throughout Australia, and *A. circinalis* is the most common organism in riverine blooms in the Murray-Darling Basin (Baker and Humpage 1994). In temperate parts of Australia, blooms typically occur from late spring to early autumn. The first reported neurotoxic bloom of *A. circinalis* in Australia occurred in 1972 (May and McBarron 1973). The most publicised bloom occurred in late 1991 and extended over 1000 km of the Darling-Barwon River system in New South Wales (NSWBGATF 1992). A state of emergency was declared, with a focus on providing safe drinking water to towns, communities and landholders. Stock deaths were associated with the occurrence of the bloom but there was little evidence of human health impacts. A bloom of *A. circinalis* in a dam in New South Wales was shown to have caused sheep deaths (Negri *et al* 1995).

Relatively low numbers of *A. circinalis* (below 2000 cells/mL) can produce offensive tastes and odours in drinking water due to the production of odourous compounds such as geosmin.

NOTE: Important general information is contained in PART II, Chapter 5

TREATMENT OF DRINKING WATER

The first line of defence against cyanobacteria is catchment management to minimise nutrient inputs to source waters. Source water management techniques for control of cyanobacterial growth include flow maintenance in regulated rivers; water mixing techniques for both the elimination of stratification and the reduction of nutrient release from sediments in reservoirs; and the use of algicides in dedicated water supply storages. It should be noted that algicides will disrupt cells and liberate intracellular toxins. Algicide use should be in accordance with local environment and chemical registration regulations. In situations where multiple offtakes are available, the selective withdrawal of water from different depths can minimise the intake of high surface accumulations of cyanobacterial cells.

Water treatment techniques can be highly effective for removal of both cyanobacterial cells and saxitoxins with the combination of the appropriate technology. As with other cyanotoxins, a high proportion of saxitoxins remain intracellular unless cells are lysed or damaged, and can therefore be removed by coagulation and filtration in a conventional treatment plant (Chorus and Bartram 1999 Chapter 9). It should be noted that treatment of water containing cyanobacterial cells with oxidants such as chlorine or ozone, while killing cells, will result in the release of free toxin. Therefore the practice of prechlorination or preozonation is not recommended without a subsequent step to remove dissolved toxins.

Both powdered activated carbon (PAC) and granular activated carbon (GAC) can be effective for removal of saxitoxins, dependent upon the selection of the correct carbon type. Ozone and normal doses of chlorine may not be entirely effective for the destruction of saxitoxins. Boiling is not effective for destruction of saxitoxins. If treatment is instituted in response to the presence of toxin-producing cyanobacteria, the effectiveness of the process will need to be confirmed by testing for toxin in the product water.

METHOD OF IDENTIFICATION AND DETECTION

The established method for measuring toxicity due to the presence of saxitoxins/PSPs is the mouse bioassay (Hollingworth and Wekell 1990), which provides a result in terms of equivalence to g saxitoxin activity (STX-eq). This is the standard method used in association with the shellfish industry and recognised by Food Standards Australia New Zealand. The analytical technique of high performance liquid chromatography (HPLC) with postcolumn derivatisation can be used to quantify a range of saxitoxins in both water and cell material where appropriate standards are available (Rositano *et al* 1998; Chorus and Bartram 1999 Chapter 13). This information can then be used to derive an estimate of total toxins in terms of saxitoxin equivalents using a conversion based on specific mouse toxicities given by Oshima (1995) (see Rositano *et al* 1998).

Cyanobacteria are detected by light microscopy; identified using morphological characteristics and counted per standard volume of water (Hotzel and Croome 1999). Standard protocols for sampling and monitoring cyanobacteria are given by Jones *et al* (in press), and practical keys for the identification are provided in Baker and Fabbro (1999).

HEALTH CONSIDERATIONS

There is no evidence of human health effects caused directly by consuming water containing saxitoxin-producing cyanobacteria or PSP-producing dinoflagellates. There are however, numerous reports of human toxicity associated with consumption of shellfish containing relatively high concentrations of PSPs (Kao 1993). Paralytic shellfish poisoning is an acute disorder that can lead to paraesthesia of the mouth and throat progressing to the neck and extremities, dizziness, weakness, ataxia and muscular paralysis with associated symptoms including nausea, vomiting, thirst and tachycardia. Symptoms can occur within 5 minutes and in fatal cases death occurs within 2–12 hours. In nonfatal cases intoxication generally resolves within 1–6 days. The toxin is rapidly cleared by urinary excretion. There are no known chronic effects but long-term animal studies are lacking.

In addition, it has been shown that saxitoxins can accumulate in the Australian freshwater mussel *Alathyria condola* by filter feeding on *A. circinalis* (Negri and Jones 1995), and the consumption of contaminated shellfish from water affected by *A. circinalis* blooms therefore represents a potential alternative route of human exposure.

DERIVATION OF GUIDELINE

There are insufficient animal toxicity data to establish a guideline value. An analysis of data from reported events of paralytic shellfish poisoning found that most cases of illness were associated with consumption of in excess of 200 µg STX-eq. per person. A health alert value of 3 µg STX-eq/L of drinking water was calculated for acute exposure associated with occurrence of intermittent blooms of cyanobacteria (Fitzgerald *et al* 1999). Based on Australian monitoring data this would require cell densities exceeding 20 000 cells/mL. Water associated with cell densities of this magnitude would normally be malodorous and unpalatable, with the threshold for offtastes in water being 1000–2000 cells/mL.

NOTIFICATION PROCEDURES

It is recommended that a notification procedure should be developed by water and health authorities. A tiered alert levels framework, as suggested by Chorus and Bartram (1999 Chapter 6), should be considered.

NOTE: Important general information is contained in PART II, Chapter 5

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Microorganisms · Viruses

Adenovirus

GUIDELINE

No guideline value has been set for adenovirus in drinking water. If adenovirus is specifically sought, it should not be detected. If detected, advice should be sought from the relevant health authority.

GENERAL DESCRIPTION

Adenoviruses generally infect conjunctival, respiratory and intestinal epithelium in addition to regional lymphoid tissue. Prolonged excretion of viruses from both the pharynx and the intestinal tract has been described and several serovars have been isolated from sewage, rivers, lakes, groundwater and water used for drinking and swimming. Waterborne transmission occurs by the faecal-to-oral route, by inhalation of adenovirus aerosols into the lower respiratory tract, and by eye contact when the conjunctival surface is mildly irritated.

Some of these viruses are endemic and exist as latent infections of the tonsils and adenoids. Others are usually associated with epidemics of acute respiratory and ocular disease in closed communities such as boarding schools and military camps. Whereas the relevance of adenoviruses to disease was initially determined by the isolation of serovars in cell cultures, later investigations with electron microscopy discovered specific serovars of adenoviruses that could not be cultivated. These include the only types (40 and 41) that have been associated with gastroenteritis. For all practical purposes, they remain uncultivable.

AUSTRALIAN SIGNIFICANCE

Adenovirus has not been detected in Australian drinking water. This may be because of the difficulties associated with detection and the limited number of studies carried out in this country.

METHOD OF IDENTIFICATION AND DETECTION

The number of adenoviruses in treated water is likely to be low and detection involves concentration of the viruses from large volumes of water, often exceeding 1000 litres. The final volume of the concentrate should be as small as possible. This is then inoculated into cell cultures. The infected cells form plaques and from the numbers of these, the number of virus particles in the original sample can be calculated.

The presence of the virus in faeces or other samples may also be detected by electronmicroscopy.

TREATMENT OF DRINKING WATER

Conventional water treatment should result in a water that is essentially virus-free, except where the intake water has a high virus load. This would occur where the intake water receives partially treated or untreated sewage. In such cases, other processes, such as some of the membrane technologies, may have to be used to ensure removal of the viruses.

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Some species of adenovirus cause pharyngitis, conjunctivitis, or pharyngoconjunctival fever. Several large outbreaks of pharyngoconjunctival fever have been associated with swimming pools (Foy *et al* 1968, Cabelli 1978, Di Angelo *et al* 1979). Outbreaks of infection are probably more likely to occur in enclosed or indoor pools, with children being more susceptible. The presence of the viruses in swimming pools is due to poor operation, maintenance and cleaning.

Adenoviruses are among the viral agents associated with acute nonbacterial infectious gastroenteritis. Serovars 40 and 41, which are not readily cultivable, are the varieties responsible. These fastidious adenoviruses have been found in many parts of the world and are probably the second most important cause of gastroenteritis (after rotavirus) in young children. They tend to be endemic rather than epidemic, although outbreaks have occurred. Cytopathogenic adenovirus can easily be detected in all kinds of water. Therefore, waterborne transmission has also been suspected for the fastidious varieties (Bitton *et al* 1986).

DERIVATION OF GUIDELINE

The infectious dose for many viruses may be as low as one particle. Many tentative guidelines give figures of one particle per 1000 litres of water, but testing for viruses is difficult and results can be variable. Although no guideline value has been established, *E. coli* (or thermotolerant coliforms) is generally used as an indicator.

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Enteroviruses

GUIDELINE

No guideline value has been set for enteroviruses in drinking water. If enteroviruses are specifically sought, they should not be detected. If detected, advice should be sought from the relevant health authority.

GENERAL DESCRIPTION

Enteroviruses have a worldwide distribution. Within temperate climates most major epidemics occur during the later summer months, whereas in the tropics, disease can occur throughout the year.

The viruses shed in the faeces of infected individuals are spread by the faecal-oral route. They occur in water either through faecal contamination or by discharge of sewage effluents (Dahling 1989).

While waterborne transmission is probable, it has not been proven. The part played by low-level transmission has also been suspected but not proven. There is a suggestion that small numbers of viruses present intermittently or continuously in drinking water cause symptomless infections, and that these are spread by person-to-person contact to cause outbreaks of disease that have no apparent connection with water.

The virus can also be spread on unwashed foods, particularly in areas where raw sewage is used as fertiliser, or it may be transmitted on the feet of vectors such as houseflies. Infants, with their faeces contained in diapers, also provide a major route of dissemination, particularly in day-care centres.

AUSTRALIAN SIGNIFICANCE

Enteroviruses have not been detected in Australian drinking water. This may be because of the difficulties associated with detection and the limited number of studies carried out in this country. They have been detected in drinking water in many other countries, both developed and developing.

METHOD OF IDENTIFICATION AND DETECTION

The number of enteroviruses in treated water is likely to be low and detection involves concentration of the virus from large volumes of water, often exceeding 1000 litres. The final volume of the concentrate should be as small as possible; this is then inoculated into cell cultures. The infected cells form plaques and from the number of these, the number of virus particles in the original sample can be calculated.

The presence of the viruses in faeces or other samples may be detected using electronmicroscopy.

TREATMENT OF DRINKING WATER

Conventional water treatment should result in water that is essentially virus-free except where the intake water has a high virus load. This would occur where the intake water receives partially treated or untreated sewage. In such cases, other processes, such as some of the membrane technologies, may have to be used to ensure removal of the viruses.

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Enterovirus infections may be manifested by sore throat, rashes, aseptic meningitis, gastrointestinal symptoms, paralysis, cardiac symptoms, and conjunctivitis (Bitton 1986, Rao 1986). Most infections, however, are mild or even symptomless. Serious or clinical disease occurs in between 1 in 100 and 1 in 1000 infections.

DERIVATION OF GUIDELINE

The infectious dose for many viruses may be as low as one particle. Many tentative guidelines give figures of one particle per 1000 litres of water, but testing for viruses is difficult and the results can be variable. Although no guideline value has been established, *E. coli* (or thermotolerant coliforms) has generally been used as an indicator of water quality. The vaccine strains of poliovirus and some of the bacteriophages have been proposed as indicators, but are not widely used.

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Hepatitis viruses

GUIDELINE

No guideline value has been set for hepatitis viruses in drinking water. If hepatitis viruses are specifically sought, they should not be detected. If detected, advice should be sought from the relevant health authority.

GENERAL CONSIDERATIONS

There are several viruses which can cause hepatitis. The most important in relation to water and wastewater are Hepatitis A (a picornavirus) and Hepatitis E (a calcivirus).

Hepatitis A and hepatitis E viruses are shed in the faeces of infected individuals, and occur in water either by faecal contamination or by discharge of sewage effluent. Although there are some unexplained features about hepatitis E, the viruses are spread by the faecal-oral route, and waterborne transmission has been proven (Belabbes *et al* 1985, Gerba *et al* 1985).

Epidemics can usually be traced to contaminated water or food (hepatitis A). Hepatitis A has been detected in polluted rivers and in drinking water (Nedachin *et al* 1989). Several very large outbreaks of drinking water transmitted hepatitis have been recognised in India, China, Morocco, the Soviet Union, and Algeria.

Hepatitis B, C and D are spread by contact with body fluids of infected individuals, and waterborne transmission would not be expected.

AUSTRALIAN SIGNIFICANCE

Hepatitis viruses have not been detected in Australian drinking water. This may be because of the difficulties associated with detection and the limited number of studies carried out in this country.

METHOD OF IDENTIFICATION AND DETECTION

The number of hepatitis viruses in treated water is likely to be low and detection would require concentration of the virus from large volumes of water, often exceeding 1000 litres. The final volume of the concentrate would have to be as small as possible. Detection by PCR techniques is possible but still only available in specialised laboratories. The implication that water supplies may be involved in outbreaks of hepatitis A or hepatitis E infection depends on epidemiological evidence.

The presence of the viruses in faeces or other samples may be detected using electronmicroscopy.

TREATMENT OF DRINKING WATER

Conventional water treatment should result in water that is essentially virus free except where the intake water has a high virus load. This would occur where the intake water receives partially treated or untreated sewage. In such cases other processes, such as some of the membrane technologies, may have to be used to ensure their removal.

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Hepatitis A virus and enterically transmitted hepatitis E (also known as HEV) cause infections of the liver with a typical illness consisting of lassitude, anorexia, weakness, nausea, vomiting, headache, abdominal discomfort, fever, dark urine, and jaundice. Hepatitis, if mild, may require only rest and restricted activities for a week or two, but severe cases can be much more debilitating. In the case of hepatitis A, fatal cases are exceptional and chronic liver disease has not been shown to occur. HEV infection in pregnant women has a high mortality rate.

DERIVATION OF THE GUIDELINES

The infectious dose for many viruses may be as low as 1 particle. Many tentative guidelines give figures of one particle per 1000 litres of water, but testing for viruses is difficult and results can be variable. Although no guideline has been established, *E. coli* (or thermotolerant coliforms) is generally used as an indicator of water quality. The vaccine strains of poliovirus and some of the bacteriophages have been proposed as indicators but are not widely used.

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Norwalk virus

GUIDELINE

No guideline value has been set for Norwalk virus in drinking water. If specifically sought, Norwalk virus should not be detected. If detected, advice should be sought from the relevant health authority.

GENERAL CONSIDERATIONS

Electronmicroscopy has shown that faecal specimens from people with nonbacterial gastroenteritis may contain many 'small round viruses' ranging in size from 20 to 40 nm. The first to be described was the Norwalk agent, detected in volunteers fed filtered faecal suspension from an outbreak of winter vomiting disease. Morphologically similar viruses known as Hawaii, Wollan, Ditchling, Parramatta, Snow Mountain and Montgomery County agents were subsequently found. Definitive classification has been delayed by failure to culture these viruses.

A prospective epidemiological study among city dwellers receiving a bacteriologically satisfactory drinking water showed that the group receiving conventionally treated water had 25% more gastrointestinal symptoms than those receiving water treated by reverse osmosis (Payment *et al* 1991). The observed symptoms were compatible with infection caused by the Norwalk-type viruses, which were probably incompletely removed from the sewage-contaminated river water used as the source.

AUSTRALIAN SIGNIFICANCE

Norwalk virus has not been detected in Australian drinking water. This may be because of the difficulties associated with detection and the limited number of studies carried out in this country.

Outbreaks of disease caused by Norwalk virus have been linked to oysters, and have occurred when oyster beds have been contaminated by sewage.

METHOD OF IDENTIFICATION AND DETECTION

The presence of the virus in faeces or other samples may be detected using electronmicroscopy.

TREATMENT OF DRINKING WATER

Conventional water treatment should result in water that is essentially virus-free except where the intake water has a high virus load. This would occur where the intake water receives partially treated or untreated sewage. In such cases other processes, such as some of the membrane technologies, may have to be used to ensure removal of the viruses.

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Norwalk virus infects the villi of the jejunum. Viruses are shed in stools during the first 72 hours after the onset of illness and are transmitted by the faecal-to-oral route. Water has been responsible for about 40 per cent of all Norwalk-related outbreaks; this has included drinking water supplies, recreational bathing water, and water used for growing shellfish (Goodman *et al* 1982).

The Norwalk virus usually causes rapid, self-limiting epidemics of gastroenteritis which last 24–48 hours (Baron *et al* 1982, Kaplan *et al* 1982). The epidemics tend to be community-wide and involve school-age children, family contacts and adults. Roughly one third of such outbreaks can be attributed to the Norwalk virus. Infections result in delayed gastric emptying, nausea, vomiting and abdominal cramps. About half of infected persons have associated diarrhoea; some have fever and chills. A transient lymphopenia also has also been observed.

DERIVATION OF GUIDELINE

The infectious dose for many viruses may be as low as one particle. Many tentative guidelines give figures of one particle per 1000 litres of water, but testing for viruses is difficult and the result can be variable. Although no guideline value has been established, *E. coli* (or thermotolerant coliforms) has generally been used as an indicator of water quality. The vaccine strains of poliovirus and some of the bacteriophages have been proposed as indicators but are not widely used.

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Rotavirus, para-rotaviruses and reovirus (Reoviridae)

GUIDELINE

No guideline value has been set for Reoviridae in drinking water. If specifically sought, Reoviridae should not be detected. If detected, advice should be sought from the relevant health authority.

GENERAL DESCRIPTION

The family Reoviridae contains two important genera, reovirus and rotavirus. These are among the most widespread of all viruses in nature. They are passed in the faeces of infected individuals and may find their way into water by faecal contamination or by discharge of sewage effluent (Bates *et al* 1984, Basch *et al* 1988, Dahling *et al* 1989).

Rotaviruses and orthoreoviruses have been detected in sewage, rivers and lakes, and treated drinking water. Transmission occurs via the faecal-to-oral route. Cases of infection tend to be sporadic but several large waterborne outbreaks have been reported. The rotaviruses have considerable public health significance as a common cause of acute diarrhoea, particularly in young children. They infect and multiply in mature or differentiated enterocytes located on the villi of the duodenum and small intestine. They are excreted in large numbers with as many as 10^{10} virus particles per gram of faeces for approximately 8 days after onset of symptoms.

AUSTRALIAN SIGNIFICANCE

Reoviridae have not been detected in Australian drinking water. This may be because of the difficulties associated with detection and the limited number of studies carried out in this country.

METHOD OF IDENTIFICATION AND DETECTION

The number of viruses in treated water is likely to be low and detection requires concentration of the viruses from large volumes of water, often exceeding 1000 litres. The final volume of the concentrate should be as small as possible; this is then inoculated into cell cultures. The infected cells form plaques and from the number of these, the number of virus particles in the original sample can be calculated.

The presence of the virus in faeces or other samples may be detected using electronmicroscopy.

TREATMENT OF DRINKING WATER

Conventional water treatment should result in water that is essentially virus-free except where the intake water has a high virus load. This would occur where the intake water receives partially treated or untreated sewage. In such cases other processes, such as some of the membrane technologies, may have to be used to ensure removal of the viruses (Gerba *et al* 1984).

NOTE: Important general information is contained in PART II, Chapter 5

HEALTH CONSIDERATIONS

Reoviruses have not been proved to cause any disease in humans, although they have been isolated from cases of respiratory infections and gastroenteritis.

Rotaviruses are responsible for a large proportion of severe episodes of diarrhoea in small children and infants, and they also cause gastroenteritis in the elderly. They are responsible for as much as 50% of the gastroenteritis in hospitalised paediatric patients during the cooler months of the year in temperate climates. Acute infection is characterised by the abrupt onset of severe watery diarrhoea with fever and vomiting; dehydration and metabolic acidosis may develop, resulting in death if untreated. Children aged 6 to 24 months old are the most severely affected. The para-rotaviruses have been responsible for major outbreaks in adults in China.

DERIVATION OF GUIDELINE

The infectious dose for many viruses may be as low as 1 particle. Many tentative guidelines give figures of one particle per 1000 litres of water, but testing for viruses is difficult and results can be variable. Although no guideline has been established, the *E. coli* (or thermotoerant coliforms) is generally used as an indicator of water quality. The vaccine strains of poliovirus and some of the bacteriophages have been proposed as indicators but are not widely used.

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Physical and Chemical Characteristics

Acrylamide

GUIDELINE

Based on health considerations, the concentration of acrylamide in drinking water should not exceed 0.0002 mg/L.

GENERAL DESCRIPTION

Acrylamide occurs as a minor impurity in polyacrylamide. It may be present in drinking water through the use of polyacrylamides as flocculant aids in water treatment, and through the use of grouting agents containing polyacrylamide. Overseas studies have reported concentrations of up to a few micrograms per litre in drinking water.

When nonionic or anionic polyacrylamides are used in water treatment at a typical dose level of 1 mg/L, the maximum theoretical concentration of acrylamide has been estimated at 0.0005 mg/L, with practical concentrations 2–3 times lower. Residual levels of acrylamide from the use of cationic polyacrylamides may be higher.

Concern over the health effects of acrylamide has led some countries to introduce tight restrictions on its use for water treatment.

Polyacrylamide is used in food processing and exposure to acrylamide may also occur from this source.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Acrylamide has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Acrylamide can be removed from drinking water by adsorption onto granular activated carbon. It is not removed effectively by conventional water treatment or with powdered activated carbon.

MEASUREMENT

Acrylamide can be analysed using high performance liquid chromatography with ultraviolet detection (Brown and Rhead 1979). The sample is brominated to form 2,3-dibromopropionamide, which is extracted with ethyl acetate and analysed. The limit of determination is 0.0002 mg/L.

HEALTH CONSIDERATIONS

Acrylamide is readily absorbed following ingestion or inhalation, or through the skin, and it forms a number of metabolites. It can accumulate in nervous system tissues and blood. The results of animal studies indicate that it is largely excreted as metabolites in urine and bile. It can cross the placenta.

An extensive review and summary of the human and animal toxicity data for acrylamide is available (IPCS 1985).

Humans exposed for a short time to well water contaminated with up to 400 mg/L of acrylamide showed effects including confusion, disorientation, memory disturbances and hallucinations. They recovered fully within 4 months. Long-term occupational exposure has resulted in skin irritation, fatigue, foot weakness and sensory changes.

NOTE: Important general information is contained in PART II, Chapter 6

In animals, acrylamide is well established as a neurotoxicant. Short- and long-term effects are similar, with exposure causing paralysis in the hind limbs of cats, dogs and rats at doses from 5 mg/kg body weight per day. The animals recovered completely when short-term exposure stopped. Acrylamide can also impair reproductive organs in rats, cats and dogs at the same dose.

Animal studies indicate that acrylamide is a carcinogen. Male rats receiving low oral doses (0.5 mg/kg body weight per day) for 2 years had increased incidence of scrotal, thyroid and adrenal tumours. Female rats exposed for 18 months had increased tumours of the mammary glands, central nervous system, thyroid and uterus. Mice exposed to higher doses for 8 weeks showed an increased incidence of lung adenomas.

Several studies have reported that acrylamide is not mutagenic in bacteria, but induces gene mutations and chromosomal aberrations in mammalian cells both *in vitro* and *in vivo*.

The International Agency for Research on Cancer (IARC) has concluded that acrylamide is probably carcinogenic to humans (Group 2A, inadequate evidence in humans, sufficient evidence in experimental animals, and supporting mechanistic evidence) (IARC 1994).

DERIVATION OF GUIDELINE

The guideline value for acrylamide of 0.0002 mg/L is based on a consideration of health effects in relation to the limit of determination for analysis using commonly available techniques.

Health based derivations can be determined as follows:

i) $$0.0007 \text{ mg/L} = \frac{0.2 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 0.2 mg/kg body weight per day is the no effect level from a 93-day drinking water study using rats (Burek *et al* 1980). Longer-term studies only identify lowest effect levels, which are significantly higher than the no effect level used in the calculation.
- 70 kg is the average weight of an adult.
- 0.1 is the proportion of total daily intake attributable to the consumption of water.
- 2 L/day is the average amount of water consumed by an adult.
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for a less than lifetime study). An additional factor of 10 for carcinogenicity was not applied as tumours occur at doses above those that cause neurotoxic effects. The use of this safety factor was recommended by the NHMRC Standing Committee on Toxicity.

ii) On the basis of a drinking water study using rats (Johnson *et al* 1986), the excess cancer risk of lifetime consumption of water with an acrylamide concentration of 0.00005 mg/L (50 ng/L) was conservatively estimated by the WHO, using a linear multistage model, at one additional cancer per million people.

The guideline value was set at the limit of determination because this is within the values derived from health considerations, and provides an adequate degree of protection. This is consistent with the general approach adopted for compounds that are known genotoxic carcinogens (see Section 6.3.4). The higher WHO guideline value of 0.0005 mg/L is based on an estimated lifetime risk of one additional cancer per 100 000 people.

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Aldrin and dieldrin

GUIDELINE

Aldrin and dieldrin should not be detected in drinking water. If present in drinking water, aldrin and dieldrin would not be a health concern unless their combined concentration exceeded 0.0003 mg/L (300 ng/L).

If they are detected, remedial action should be taken to stop contamination. The limit of determination is 0.00001 mg/L (10 ng/L).

GENERAL DESCRIPTION

Aldrin and dieldrin were widely used in agriculture until their use began to be restricted in the 1970s. They remain highly effective insecticides for soil-dwelling pests and for the protection of wood structures against termites and wood borers. Although their manufacture has now ceased and they are no longer registered for use in Australia, they may be detected occasionally because of their persistence in the environment.

In soil, aldrin is oxidised slowly to dieldrin. In temperate climates, approximately 75% of aldrin is oxidised within a year, with more rapid oxidation occurring in tropical climates. Dieldrin breaks down only very slowly, with a half-life in soil of about 5 years.

Aldrin and dieldrin have occasionally been detected in water supplies overseas, but concentrations are normally less than 0.00001 mg/L (10 ng/L). In Europe and the United States, dieldrin has been detected in some foods, including human milk.

From the 1970s, the Australian Market Basket Surveys have shown a progressive decline in the amounts of aldrin and dieldrin detected in food. There has been a corresponding decline in contamination of human milk and adipose tissue since that period (NHMRC 1992). The 1990 Australian Market Basket Survey reported very small amounts of dieldrin residue in only one food product tested, and none was detected in human milk (NHMRC and NFA 1991).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Aldrin and dieldrin have occasionally been detected in large water storages. The maximum concentration reported is less than 0.001 mg/L, but the frequency of detection has dropped markedly since 1980.

TREATMENT OF DRINKING WATER

Aldrin and dieldrin can be removed from drinking water using granular activated carbon.

MEASUREMENT

Aldrin and dieldrin can be analysed by extraction with a nonpolar solvent such as pentane followed by gas chromatography with electron capture detection (APHA Method 6630 Part B 1992). The limit of determination is about 0.00001 mg/L (10 ng/L).

HEALTH CONSIDERATIONS

Aldrin and dieldrin are absorbed by the oral, inhalation and dermal routes. They accumulate in fatty tissue, from which they can be mobilised into blood with potential toxic effects. Dieldrin is metabolised in the liver and excreted in faeces.

NOTE: Important general information is contained in PART II, Chapter 6

Extensive reviews and summaries of the human and animal toxicology of aldrin and dieldrin are available (JMPR 1977, IARC 1987, IPCS 1989, NHMRC 1992).

The principal public health concern regarding aldrin and dieldrin arises from their ability to bioaccumulate. Environmental, mainly dietary, exposure leads to the presence of dieldrin in low concentrations in the human body. The results of extensive clinical and epidemiological studies indicate that these body burdens do not present a health hazard to humans (IPCS 1989). Aldrin and dieldrin are neurotoxic in humans at high doses. The threshold concentration of dieldrin in blood giving rise to neurotoxic effects is approximately 0.15-0.2 mg/L.

In long-term studies with animals, dogs have been reported to be more sensitive to aldrin and dieldrin than rats. Female beagle dogs fed dieldrin for 2 years had an increased liver-to-body-weight ratio at doses of 0.05 mg/kg body weight per day. Aldrin and dieldrin are hepatotoxic in rodents.

A number of long-term studies have shown that aldrin and dieldrin can produce malignant and/or benign tumours in mice, but not in rats or hamsters. These compounds are not teratogenic but do increase neonatal mortality when fed to pregnant rats and mice (NHMRC 1992).

Aldrin and dieldrin were not mutagenic in a majority of test systems.

The International Agency for Research on Cancer has concluded that aldrin and dieldrin are not classifiable as to their carcinogenicity to humans (Group 3, inadequate evidence in humans, limited evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The health-based guideline value of 0.0003 mg/L for aldrin and dieldrin was determined as follows:

$$0.0003 \text{ mg/L} = \frac{0.0001 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day}}$$

where:

- 0.0001 mg/kg body weight per day is the maximum ADI based on a no effect level from long-term studies with rats and dogs of 0.025 mg/kg body weight per day (JMPR 1977)
- 70 kg is the weight of an adult
- 0.1 gives a guideline value based on 10% of the ADI
- 2 L/day is the amount of water consumed by an adult.

The maximum ADI value includes adequate safety factors. No additional safety factors are necessary.

The guideline value applies to the total concentration of aldrin and dieldrin.

The WHO guideline value of 0.00003 mg/L (30 ng/L) was determined using 1% of the ADI to allow for increased exposure from other sources. Such a low percentage of the ADI was considered inappropriate for Australia, where the use of these pesticides has been severely restricted.

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NOTE: Important general information is contained in PART II, Chapter 6

Aluminium

(Revised and endorsed 2001)

GUIDELINE

Based on aesthetic problems caused by post-flocculation, the concentration of acid-soluble aluminium in drinking water should not exceed 0.2 mg/L. Water authorities are strongly encouraged to keep acid-soluble aluminium concentrations as low as possible, preferably below 0.1 mg/L.

No health-based guideline is set for aluminium at this time but this issue will be kept under review.

GENERAL DESCRIPTION

Aluminium may be present in water through natural leaching from soil and rock, or from the use of aluminium salts as coagulants in water treatment.

Aluminium is used in many industrial and domestic products including antacids, antiperspirants and food additives, and in vaccines. It is commonly used by the food industry for food containers and packaging, and many cooking utensils are made from aluminium.

Surveys in the United States and the United Kingdom have reported aluminium concentrations in natural water sources of 0.014–1.2 mg/L. Concentrations in some Australian water sources can be considerably higher due to the presence of clay minerals (aluminosilicates); for example, up to 18 mg/L in the Murray River. Residual aluminium concentrations in treated water depend on the concentration in the water source, the alum dose used, the pH, and the filtration efficiency.

Where alum is used as a coagulant in water treatment, post-flocculation effects can occur if the soluble aluminium concentration in the treated water exceeds 0.2 mg/L. Depending on pH, a whitish gelatinous precipitate of aluminium hydroxide can be formed in the distribution system which may result in customer complaints about 'milky coloured' water. Aluminosilicates in source water are very insoluble and do not cause post-flocculation problems.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, the concentration of aluminium varies from 0.01 mg/L to 0.9 mg/L, with typical concentrations of approximately 0.1 mg/L for fully treated supplies.

TREATMENT OF DRINKING WATER

Aluminium concentrations in drinking water can be reduced using the conventional water treatment practices of flocculation and filtration. A well-operated water filtration plant (even using aluminium as a flocculant) can achieve aluminium concentrations in the finished water of less than 0.1 mg/L.

MEASUREMENT

The term 'soluble' should be taken to mean truly soluble, not 'filterable through a 0.45 µm pore size filter'. Finely suspended aluminosilicate clay particles can pass through a 0.45 µm filter but are not truly soluble and will not cause post-flocculation problems.

NOTE: Important general information is contained in PART II, Chapter 6

Acid-soluble aluminium is determined after acidifying the sample to pH 1.5–2, followed by filtration through a 0.45 µm membrane filter. If analysis of the filtrate by the normal method (e.g. graphite furnace atomic absorption spectroscopy, APHA Method 3500-Al Part B 1992) gives a result above the guideline value, the filtrate should be re-analysed using the catechol violet colorimetric method (APHA Method 3500-Al Part E 1992), which provides a better estimate of the reactive aluminium component. The limit of determination for the latter method is approximately 0.01 mg/L.

Based on experience with their water supplies, authorities may choose to monitor total aluminium concentration and perform specific assays for acid-soluble aluminium only if total aluminium concentration exceeds 0.1 mg/L.

HEALTH CONSIDERATIONS

It has been estimated that for Australian adults, the intake of aluminium from food and beverages is approximately 5–7 mg/day. Drinking water contributes less than 2% of the total daily intake, and only 0.3–0.4% of the aluminium in water is absorbed by the body. Recent studies have shown that the bioavailability (i.e. uptake into the bloodstream) of aluminium in drinking water is similar to that of food (Stauber *et al* 1999).

The metabolism of aluminium in humans is poorly understood. Studies indicate that less than 1% of dietary aluminium is absorbed by the gastrointestinal tract, with the remainder excreted in faeces. The small amount absorbed passes into the blood stream. Some aluminium accumulates in bone, liver and brain tissue but most is removed from the blood stream by the kidneys and excreted. In healthy adults, the total accumulated body load of aluminium has been estimated at about 35 mg. Whether this remains constant with age has not been determined.

There is considerable evidence that aluminium is neurotoxic. Kidney dialysis patients, in whom the gut barrier is bypassed, can accumulate aluminium in their blood resulting in an encephalopathy known as dialysis dementia. Investigations have established a correlation between the concentration of aluminium in water used to prepare dialysis fluid and the incidence of dialysis dementia. If this condition is not too far advanced it responds to chelation therapy. It appears that dialysis patients are much more susceptible to aluminium in dialysis fluid than from other sources such as food and antacids. Aluminium has also been linked to other conditions associated with the use of dialysis units including osteomalacia (a softening of the bones) and anaemia. Reverse osmosis or deionisation units are now used to treat dialysis water before use, and aluminium concentrations are kept below 0.01 mg/L.

Aluminium has been associated with two severe neurodegenerative diseases: Parkinsonism dementia (PD) and amyotrophic lateral sclerosis (ALS). Both conditions have a high incidence amongst the Chamorro people of Guam, an area where aluminium is naturally present in food and drinking water. ALS is common in the Pacific, Western New Guinea and the Kii peninsula of Japan. Both PD and ALS are characterised by loss of motor function and the presence of neurofibrillary tangles in the brain. One hypothesis suggests that chronic nutritional deficiencies of calcium and magnesium lead to increased absorption of aluminium, resulting in its deposition in neurons of the brain (Garruto and Yase 1986; Garruto *et al* 1990). There was an appreciable decrease in the incidence of these conditions when the areas became westernised, with associated changes in dietary habits, importing of food and improvements to the water supply.

Elevated concentrations of aluminium have been found in the autopsied brains of people who had suffered Alzheimer's disease, in regions of the brain containing large numbers of the neurofibrillary tangles which are characteristic of the disease, and aluminium has been proposed as one of a number of causal agents (Perl and Brody 1980). There have been a number of epidemiological studies to determine

if aluminium in drinking water plays a role in Alzheimer's disease. Although some studies indicated that a tentative link may exist, more recent evidence (Martyn *et al* 1997) suggests that aluminium in drinking water is not associated with increased risk of Alzheimer's disease.

A number of animal studies of aluminium toxicity have been undertaken although there has been very little research done using aged animals. Most studies have used rats fed or injected with large amounts of aluminium and have reported only minor changes to bodyweight, with some behavioural changes and locomotor effects. Elevated concentrations of aluminium have been reported in the brain, liver and kidneys. The studies are not adequate to set a reliable no observable adverse effect level (NOAEL).

Aluminium is not generally thought to be mutagenic or genotoxic, although aluminium has been shown to bind to DNA of a number of animal species and has displayed mutagenic activity in some, but not all, tests using bacteria. Ingestion of aluminium is not known to cause cancer in humans or animals.

The NHMRC Standing Committee on Toxicity has reviewed the toxicological data for aluminium and concluded that there are insufficient data to set a NOAEL.

DERIVATION OF GUIDELINE

Post-flocculation problems (described above) associated with the use of alum as a coagulant may occur if acid-soluble aluminium exceeds 0.2 mg/L. As the alum floc is soluble in dilute acid (pH 1.5–2), post-flocculation problems will generally be avoided if the acid-soluble concentration of aluminium is below 0.2 mg/L. Water authorities are strongly encouraged to keep acid-soluble aluminium concentrations as low as possible, preferably below 0.1 mg/L. Well operated water filtration plants, even those using aluminium salts as flocculants, should have little difficulty in achieving this.

A guideline value lower than 0.2 mg/L may need to be adopted by some water authorities, depending on the amount of naturally occurring organic material in the water.

Although data are insufficient to set a guideline value based on health considerations, there is public concern over the possible health effects of aluminium. This issue should be reviewed when further studies are undertaken.

REFERENCES

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Ammonia

GUIDELINE

Based on aesthetic considerations (corrosion of copper pipes and fittings), the concentration of ammonia (measured as ammonia) in drinking water should not exceed 0.5 mg/L.

No health-based guideline value is set for ammonia.

GENERAL DESCRIPTION

Ammonia dissolves rapidly in water to form an equilibrium mixture of free ammonia and the ammonium cation. It may be present in unchlorinated drinking water due to contamination of source water or through microbial metabolism. Ammonia is used in conjunction with chlorine to form chloramines to disinfect water supplies. Some residual will be present in the water, particularly if the chlorinator is not operating properly.

Ammonia is used commercially in animal feeds and fertilisers, and in the manufacture of fibres, plastics and explosives. Ammonia products are widely used as cleaning agents and food additives.

Most uncontaminated source waters have ammonia concentrations below 0.2 mg/L. High concentrations (greater than 10 mg/L) have been reported where water is contaminated with animal waste. Ammonia is unlikely to be detected in chlorinated supplies as it reacts quickly with free chlorine.

Ammonia in water can result in the corrosion of copper pipes and fittings, causing copper stains on sanitary ware. It is also a food source for some microorganisms, and can support nuisance growths of bacteria and algae, often with a resultant increase in the nitrite concentration.

The odour threshold of ammonia in water is 1.5 mg/L.

Ammonia can be an important indicator of pollution as it can be formed as an intermediate product in the breakdown of nitrogen-containing organic compounds, or of urea from human or animal excrement.

Food can contain substantial amounts of ammonia/ammonium and is the principal source of intake.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies concentrations of ammonia range up to 0.4 mg/L, but are generally less than 0.02 mg/L.

TREATMENT OF DRINKING WATER

Ammonia concentrations in drinking water supplies can be reduced by chemical or biological oxidation of ammonia to nitrate.

MEASUREMENT

The concentration of ammonia in water can be determined by a number of methods including colorimetric, titrimetric and potentiometric techniques. For determination of low concentrations, the phenate colorimetric method is commonly used (APHA 4500-NH_3 Parts D or H, 1992). The limit of determination for this method is 0.02 mg/L. Alternatively, the ammonia selective electrode method can be used (APHA 4500-NH_3 Part F, 1992) with a limit of determination of 0.03 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

Both of these methods determine the total free ammonia and ammonium ion measured as ammonia (NH_3).

HEALTH CONSIDERATIONS

Ammonia is an important metabolite in humans and animals. It is formed in the liver by the deamination of amino acids, and in the gastrointestinal tract by the breakdown of food by enzymes and bacterial flora.

Only an extremely small proportion of the ammonia absorbed in the intestinal tract originates directly from food or water. The major part is formed in the gut as a byproduct of the breakdown of food. Almost all ammonia is absorbed. It is then transported to the liver and used mostly in the urea cycle.

An extensive review and summary of the human and animal toxicity data for ammonia is available (IPCS 1986).

Ammonia has a toxic effect on humans only if the intake becomes higher than the detoxification capacity of the body. At doses above 32 mg ammonium per kilogram body weight per day (over 1000 mg/L) ammonium chloride influences the metabolism by shifting acid-base equilibrium, affecting glucose tolerance and reducing tissue sensitivity to insulin.

In studies with animals, high doses of ammonia (over 100 mg/kg body weight per day) have generally not produced any significant toxic effects. Ammonium hydroxide did not result in an increase in the incidence of cancer when given to mice in their drinking water over a lifetime; however, there is some evidence that ammonia may act with cancer-causing compounds to increase the incidence of tumours.

Ammonia and ammonium chloride have shown mutagenicity in some tests with bacteria and animal cells.

DERIVATION OF GUIDELINE

Ammonia concentrations above 0.5 mg/L may attack copper pipes and fittings, or result in nuisance growths of microorganisms. Concentrations of ammonia that may cause health effects are unlikely to occur in drinking water supplies; accordingly, no health based guideline is set.

REFERENCES

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Antimony

GUIDELINE

Based on health considerations, the concentration of antimony in drinking water should not exceed the limit of determination of 0.003 mg/L.

GENERAL DESCRIPTION

Antimony, as the trivalent (Sb(III)) or pentavalent (Sb(V)) salts, has occasionally been detected in natural source waters. Occurrences are more common in areas near lead or copper smelting operations. Antimony-tin solder is beginning to replace lead solder and hence exposure to antimony in drinking water may increase in the future.

Antimony alloys and compounds are used in semiconductors, batteries, anti-friction compounds, ammunition, cable sheathing, and flame-proofing compounds. Antimony salts are used in glass, and in the manufacture of ceramics and pottery.

Studies overseas have generally found low concentrations in drinking water, typically less than 0.005 mg/L, but higher concentrations have been reported occasionally.

There are few data available on antimony concentrations in food. The United States Agency for Toxic Substances and Disease Registry has suggested that average daily consumption of antimony in food is about 0.018 mg.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Australian drinking water supplies have not been routinely monitored for antimony.

TREATMENT OF DRINKING WATER

There are no published methods for removal of antimony from drinking water.

MEASUREMENT

The concentration of antimony in drinking water can be determined by hydride generation followed by analysis using atomic absorption spectroscopy. The limit of determination is approximately 0.001 mg/L. Alternatively, graphite furnace atomic absorption spectroscopy can be used with a limit of determination of 0.003 mg/L (APHA Method 3500-Sb Part B 1992).

HEALTH CONSIDERATIONS

Studies using rats have shown that about 15% of antimony is absorbed by the gastrointestinal tract. It is distributed mainly to the liver, spleen and heart, and to the thyroid and adrenal glands, and it is excreted in faeces and urine.

There have been a number of studies on the effects of long-term human exposure to antimony. One early study of adult male workers in an antimony smelter reported no adverse effects after persistent exposure over periods from 2 to 13 years. A more recent study where workers were exposed for 9 to 31 years to dust containing antimony trioxide and antimony pentoxide reported respiratory and eye problems as well as staining of the front tooth surface. A dermatitis condition was observed in more than half of the exposed workers. Other studies have reported heart irregularities, lung cancer, and spontaneous abortions among female workers.

NOTE: Important general information is contained in PART II, Chapter 6

The toxicity of antimony to animals varies considerably depending on the compound used. No adverse effects have been associated with long-term exposure of rats to antimony trioxide. However, potassium antimony tartrate reduced the animals' lifespan, and antimony was found to accumulate in the heart, liver, kidney and spleen. It also affected blood glucose and cholesterol concentrations.

Animal studies have shown that antimony can cross the placenta. It may cause sterility, fewer offspring, and fetal damage.

Studies using male and/or female rats have reported that inhalation of concentrates of antimony trioxide and antimony ore increased the incidence of lung tumours in females. In ingestion studies on rats and mice, antimony did not appear to cause tumours.

Trivalent and pentavalent antimony salts have demonstrated mutagenic activity in tests with bacteria. They also induced chromosome aberrations in cultured mammalian cells.

The International Agency for Research on Cancer has concluded that antimony trioxide is possibly carcinogenic to humans by the inhalation route (Group 2B, inadequate evidence in humans, sufficient evidence in animals); and antimony trisulfide is not classifiable as to its carcinogenicity to humans (Group 3, inadequate evidence in humans and limited evidence in animals) (IARC 1989).

DERIVATION OF GUIDELINE

The guideline value for antimony in drinking water was derived as follows:

$$0.003 \text{ mg/L} = \frac{0.43 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 500}$$

where:

- 0.43 mg/kg body weight per day is the lowest effect level based on decreased lifespan and altered blood levels of glucose and cholesterol in a lifetime study using rats (Schroeder *et al* 1970)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 500 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 5 because a lowest effect level was used instead of a no effect level).

The WHO guideline value of 0.005 mg/L was derived from this calculation but rounded up.

REFERENCES

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Arsenic

GUIDELINE

Based on health considerations, the concentration of arsenic in drinking water should not exceed 0.007 mg/L.

GENERAL DESCRIPTION

Arsenic is a naturally occurring element which can be introduced into water through the dissolution of minerals and ores (where it exists mainly in the sulfide form), or from industrial effluent, atmospheric deposition (through the burning of fossil fuels and waste incineration), drainage from old gold mines, or the use of some types of sheep dip. Natural sources can make a significant contribution to the arsenic concentration in drinking water. Pentavalent arsenic (As(V)) is generally the most common form in well-oxygenated surface waters, but under reducing conditions, such as those found in deep lake sediments or groundwaters, the trivalent form (As(III)) predominates.

Arsenic compounds have commercial and industrial uses as alloying agents in the manufacture of transistors, lasers and semiconductors, and in the processing of glass, pigments, textiles, paper, metal adhesives, ceramics, wood preservatives, ammunition and explosives. They are also used in the hide-tanning process, and to a limited extent as feed additives, pesticides and pharmaceuticals. Although inorganic forms of arsenic are the most common, organic arsenic compounds are also used.

In natural waters the concentration of arsenic is generally less than 0.005 mg/L, although some countries have reported very high concentrations, particularly in groundwater supplies.

Food is a significant source of arsenic intake. The average Australian adult dietary intake of arsenic is approximately 0.04 mg per day. Arsenic is concentrated by many species of fish and shellfish, and is present in poultry and livestock. Concentrations in vegetables are usually an order of magnitude less than those found in fish and meat. It is difficult to make direct comparisons between the arsenic intake from food and water because the biological availability differs markedly. For example, a major portion of the arsenic in fish is present as highly complexed forms that are biologically unavailable, or as simple organic compounds (arsenobetaine and arsenocholine) that are essentially nontoxic.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies concentrations of arsenic range up to 0.015 mg/L, with typical values usually less than 0.005 mg/L.

TREATMENT OF DRINKING WATER

Arsenic can be removed from drinking water using conventional coagulation processes. It is desirable to convert trivalent arsenic to the pentavalent form before treatment by oxidation using chlorine or potassium permanganate. Lime softening can also be effective for removal from hard waters but the efficiency is dependent on pH and valence state.

MEASUREMENT

The arsenic concentration in drinking water can be determined by hydride generation followed by atomic absorption spectroscopy. The limit of determination is approximately 0.001 mg/L. Alternatively, graphite furnace atomic absorption spectroscopy can be used with a limit of determination of approximately 0.005 mg/L (APHA Method 3500-As Part B 1992).

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

The health considerations apply mainly to the inorganic arsenic compounds, as they are more likely than the organic compounds to be present in drinking water supplies.

Although the results of studies indicate that arsenic may be essential for a number of animal species, there is no evidence that it is essential for humans.

Soluble arsenic salts are readily absorbed by the gastrointestinal tract. After absorption inorganic arsenic binds to haemoglobin, and is deposited in the liver, kidney, lungs, spleen, and skin. Inorganic arsenic does not appear to cross the blood-brain barrier but can cross the placenta. Approximately 45-85% of ingested arsenic is excreted in the urine within 1 to 3 days.

Extensive reviews and summaries of the human and animal toxicity data for arsenic are available (IPCS 1981, WHO 1988).

A number of epidemiological studies have looked at the effects of drinking water with high concentrations of arsenic (greater than 0.3 mg/L). Effects attributed to consumption of such water over periods of 5 to 25 years include skin lesions, skin cancer, vascular disease, effects on the nervous system, and possibly cancer of other organs (USEPA 1988).

The carcinogenicity of arsenic has not been confirmed in animal studies, but arsenic has shown tumour-promoting activities in animals. It did not exhibit mutagenic activity in tests with bacteria or mammalian cells, but chromosome damage has been reported.

The International Agency for Research on Cancer has concluded that arsenic is carcinogenic to humans (Group 1, sufficient evidence of carcinogenicity in humans) (IARC 1987).

DERIVATION OF GUIDELINE

The guideline value was derived as follows:

$$0.007 \text{ mg/L} = \frac{0.002 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day}}$$

where:

- 0.002 mg/kg body weight per day is the maximum tolerable intake for arsenic by humans from all sources (WHO 1988)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult.

The maximum tolerable daily intake value for arsenic includes adequate safety factors. No additional safety factors are necessary.

The WHO guideline value of 0.01 mg/L was based on a calculation that estimated an additional lifetime risk of six skin cancers per 10 000 people. It was recognised that this calculation may overestimate the actual risk because of confounding factors in the base study used, and because only a small fraction of skin cancers (1–14%) are fatal. Due to these difficulties, a different approach was used to that of WHO, resulting in a slightly lower guideline value.

REFERENCES

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NOTE: Important general information is contained in PART II, Chapter 6

Asbestos

GUIDELINE

Data are insufficient to determine a guideline value for asbestos in drinking water.

GENERAL DESCRIPTION

Asbestos is a general term for certain fibrous silicate minerals. It can be present in drinking water from the dissolution of asbestos-containing minerals, industrial effluent, atmospheric deposition, and deterioration of asbestos cement pipes commonly used in water distribution systems.

The chemical and crystalline structure of asbestos results in products with a high tensile strength, durability, flexibility, and heat and chemical resistance. Asbestos has been used in construction materials such as asbestos cement pipes and sheets, electrical and thermal insulation, brake linings and clutch pads.

The extent of asbestos contamination of food has not been well studied because of the lack of a simple and reliable analytical method. Limited data indicate that the amount in food may be 10 times higher than that found in drinking water.

Studies in the United States and Canada have reported typical asbestos fibre numbers in drinking water of less than 1 MFL (million fibres per litre). Severe deterioration of asbestos cement pipes has been known to produce fibre numbers of up to 2000 MFL.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Australian drinking water supplies have not been routinely monitored for asbestos; however, fibre numbers are probably similar to those reported overseas.

TREATMENT OF DRINKING WATER

Asbestos fibre numbers can be reduced by the standard water treatment processes of coagulation and filtration.

MEASUREMENT

Asbestos can be analysed using transmission electron microscopy with identification of the fibres by selected-area electron diffraction. This procedure is both costly and time consuming and is not suitable for routine analysis. The limit of determination is about 0.3 MFL.

HEALTH CONSIDERATIONS

The health hazards associated with inhalation of asbestos have been recognised for a long time. They include asbestosis, cancer of the bronchial tubes, malignant mesothelioma, and possibly cancers of the gastrointestinal tract and larynx (IPCS 1986).

In contrast, there has been little evidence that ingested asbestos causes cancer. A number of quite extensive epidemiological studies have been carried out on the effects of asbestos in the water supply. On the basis of these data there is no demonstrated excess risk of cancer even with high numbers of asbestos fibres in drinking water.

NOTE: Important general information is contained in PART II, Chapter 6

It is not clear whether asbestos fibres ingested in drinking water can pass through the walls of the gastrointestinal tract in sufficient numbers to cause adverse effects. Experiments with laboratory animals indicate that penetration, if it occurs at all, is extremely limited.

Animal studies on the carcinogenic effects of ingested asbestos have been inconclusive.

Asbestos did not exhibit mutagenic activity in tests with bacteria but has induced chromosomal aberrations, malignant transformation of mammalian cells *in vitro*, and various biochemical alterations associated with tumour promoters.

The International Agency for Research on Cancer has concluded that asbestos is carcinogenic to humans by the inhalation route (Group 1, sufficient evidence of carcinogenicity in humans) (IARC 1987).

DERIVATION OF GUIDELINE

There are insufficient data to set a guideline value for asbestos in drinking water. It is unlikely, however, that the numbers of asbestos fibres present in most drinking water supplies would be a health concern. The weight of evidence indicates that ingested asbestos is not hazardous to health.

The guideline should be reviewed as soon as more toxicological data are available.

REFERENCES

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Atrazine

(Revised and endorsed 2001)

GUIDELINE

Atrazine should not be detected in drinking water. If present in drinking water, atrazine would not be a health concern unless the concentration exceeded 0.04 mg/L.

If it is detected, then remedial action should be taken to stop contamination. The practical limit of determination is 0.0001 mg/L.

GENERAL DESCRIPTION

Atrazine is used as a selective pre- and post-emergent herbicide for the control of weeds in a number of crops. It is also used in forestry and for nonselective weed control on noncrop areas.

Atrazine can be degraded in surface water by photolysis and the action of microorganisms. Hydrolysis and microbial degradation also take place in soil, the extent depending mainly on temperature, moisture and pH. Half-lives of 20–50 days have been reported under laboratory conditions at 20–25°C (IPCS 1996). Degradation half-lives of atrazine in soil ranged from 12 to 213 days over a wide geographical range of forestry sites in Australia; degradation rates were primarily dependent upon soil temperature (FHMG 2000).

Due to its mobility in soil, atrazine has been found in surface and groundwater in the vicinity of agricultural areas, and may occur at higher concentrations in agricultural run-off. It has also been found in some drinking water supplies in a number of countries. There is quite an extensive database on atrazine levels in soil and water (e.g. IARC 1991).

Atrazine metabolites have been found in plants grown in soil treated with atrazine, and in ground and surface water, but atrazine has not been found on food crops.

Following best practice when using herbicides should prevent atrazine being present in the drinking water supply. The 1997 review of atrazine by the National Registration Authority for Agricultural and Veterinary Chemicals (NRA 1997) imposed significant restrictions on the use of atrazine around water catchment areas; these restrictions are detailed on product labels.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Atrazine has rarely been found in Australian reticulated supplies. It has been reported in groundwater supplies at concentrations up to 0.002 mg/L in an area where atrazine was used over a 10-year period to suppress weed growth in irrigation channels (at application rates of 2–4 kg per hectare per year).

From available monitoring data, it appears that the major metabolites of atrazine (desethylatrazine, desisopropylatrazine, diaminochlorotriazine, hydroxyatrazine) may constitute approximately 50% of the total atrazine-derived triazine compounds in some ground and surface water samples (Lerch *et al* 1998). This has been taken into account in deriving the guideline value.

TREATMENT OF DRINKING WATER

Atrazine can be removed from drinking water using activated carbon.

NOTE: Important general information is contained in PART II, Chapter 6

MEASUREMENT

Atrazine can be extracted from water using a nonpolar solvent (such as pentane) or by solid phase extraction, and analysed with gas chromatography using nitrogen-phosphorus detection (AOAC Method 991.07 1990). The limit of determination is approximately 0.0001 mg/L.

HEALTH CONSIDERATIONS

Studies in humans and animals indicate that orally administered atrazine is well absorbed from the gastrointestinal tract and that the majority is metabolised in the body and rapidly eliminated in the urine. Other studies have shown that dermally applied doses of atrazine undergo only limited absorption through the skin (circa 10%) (IARC 1991; NRA 1997).

No signs or symptoms of poisoning in humans have been reported from ingestion of atrazine. Acute toxicological studies in laboratory animals suggest that atrazine and its major metabolites are not highly hazardous substances, and other rodent studies have shown that they are not teratogenic or embryotoxic (HSDB 1999; IARC 1991; NRA 1997). Atrazine does not have any adverse effects on the reproductive cycle of rats (NRA 1997).

In regard to cancer studies, a public health assessment of atrazine was performed by the Therapeutic Goods Administration of the Department of Health and Ageing as part of Australia's Existing Chemicals Review Program (ECRP). The study concluded that atrazine was not a genotoxic carcinogen and that an earlier onset of mammary tumours in the Sprague-Dawley (SD) strain of rats at high doses was due to a hormonal effect. The pattern of hormone levels (oestrogen) in ageing SD rats differs from that in another rat strain tested (Fischer-344) and in humans; hence, the atrazine effect in SD rats is unlikely to be an appropriate surrogate for the assessment of human risk for mammary tumour development (NRA 1997). Consistent with Australia's review of atrazine, the International Agency for Research on Cancer (IARC) concluded that, despite there being sufficient evidence in animals for the carcinogenicity of atrazine, there is strong evidence that its mechanism of cancer induction is not relevant to humans (IARC 1999). Hence, atrazine was reported as not classifiable as to its carcinogenicity to humans (IARC Classification Group 3).

DERIVATION OF GUIDELINE

The health-based guideline value of 0.04 mg/L for atrazine was determined as follows:

$$0.04 \text{ mg/L} = \frac{0.005 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.5}{2 \text{ L/day} \times 2}$$

where:

- 0.005 mg/kg body weight per day is the acceptable daily intake (ADI) determined by the Therapeutic Goods Administration (NRA 1997)
- 70 kg is taken as the average weight of an adult
- 0.5 is a proportionality factor based on the conservative assumption that at least 50% of the ADI will arise from the consumption of drinking water; atrazine has not been detected in the Australian food supply
- 2 L/day is the estimated amount (maximum) of water consumed by an adult
- 2 is an extra safety factor to take into consideration the likely presence of metabolites of atrazine which have a similar toxicity profile to parent atrazine and which may constitute about 50% of the total atrazine-derived compounds.

The ADI value also includes a safety factor of 100 (10 for interspecies variation and 10 for human variability).

The WHO guideline value of 0.002 mg/L was determined using an additional safety factor of 10 for potential oncogenicity. The data were not considered adequate to include this factor in the derivation of the Australian guideline value.

Because of the use pattern of these herbicides (just before or after crop emergence) it was considered unlikely that residues would be present in food. The 1992 Australian Market Basket Survey (AMBS) (NFA* 1992,) reported assays for atrazine and simazine in meat and cereal foods. No residues of either herbicide were detected. This finding is in agreement with US data; in over 30 years of use, atrazine has not been detected in edible portions of plants or livestock nor has it been detected in American market-basket surveys (NRA, 1997).

Thus it may be concluded that exposure of the population to atrazine in food is very unlikely.

(*Now Food Standards Australia New Zealand, or FSANZ)

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NOTE: Important general information is contained in PART II, Chapter 6

(Hard copies of the summary review may be obtained from the NRA, or full copies of the review at http://www.nra.gov.au/chemrev/chemrev.shtml. The toxicology and public health component of this review was conducted by the Therapeutic Goods Administration of the Department of Health and Ageing.)

Barium

GUIDELINE

Based on health considerations, the concentration of barium in drinking water should not exceed 0.7 mg/L.

GENERAL DESCRIPTION

Barium in drinking water is primarily from natural sources. Some barium salts such as the chloride and nitrate are soluble in water; others, including the carbonate, fluoride, phosphate and sulfate, are insoluble.

Barium compounds have a wide variety of industrial applications. They are used in the plastics, rubber, electronics, steel, optical, and textile industries. They are also used in ceramic glazes and enamels, in glass and paper making, as a lubricant additive, in pharmaceuticals and cosmetics, and as a rodenticide.

The concentration of barium in drinking water overseas is usually low, typically less than 0.02 mg/L.

Most foods contain small quantities of barium. The major dietary sources are milk, potatoes and flour. Some cereal products and nuts can contain large amounts. It has been estimated that average dietary intake is approximately 1 mg per day, with food contributing more than 80% of total intake.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies the concentration of barium ranges up to 0.3 mg/L, with typical concentrations usually less than 0.005 mg/L.

TREATMENT OF DRINKING WATER

Conventional water treatment using alum or ferric coagulation is not effective in removing barium from drinking water. Lime softening can remove more than 90%.

MEASUREMENT

The barium concentration in drinking water can be determined using inductively coupled plasma emission spectroscopy (APHA Method 3500-Ba Part C 1992), or atomic absorption spectroscopy (APHA Method 3500-Ba Part B 1992). For both methods the limit of determination is approximately 0.01 mg/L.

HEALTH CONSIDERATIONS

The degree of absorption from the gastrointestinal tract depends on the solubility of the barium compound, and on other factors including age. In a study using rats, barium was absorbed more effectively in very young rats compared with older rats. After absorption, barium is deposited in bone and teeth. It can cross the placenta in humans.

At high concentrations, barium causes strong vasoconstriction (constriction of blood vessels), peristalsis (contractions of the alimentary canal), convulsions and paralysis. Repeated exposures to contaminated table salt in China are believed to have caused recurrent outbreaks of transient paralysis known as 'Pa-Ping' disease.

NOTE: Important general information is contained in PART II, Chapter 6

An extensive review and summary of the human and animal toxicity data for barium is available (IPCS 1990).

A number of epidemiological studies have been carried out on the effects of barium in drinking water on cardiovascular disease. No adverse effects were found with barium concentrations up to 7 mg/L. In a study using a small number of volunteers, no adverse effects were observed after 8 weeks' exposure to drinking water with up to 10 mg/L barium.

Long-term studies with rats have shown that relatively low doses of barium in drinking water can result in significant and persistent increases in systolic blood pressure. This has significance for humans as an increase in systolic blood pressure can increase the risk of heart attack.

There is no evidence that barium causes cancer. Barium chloride is not mutagenic in tests with bacteria and does not damage DNA.

DERIVATION OF GUIDELINE

The guideline value of 0.7 mg/L was set after consideration of the following points:

- The most sensitive epidemiological study identified a no adverse effect level of 7.3 mg/L (Brenniman and Levy 1985). The study was based on 1100 people exposed to barium concentrations in drinking water from 2 mg/L to 10 mg/L over a lifetime. Applying a safety factor of 10 for intraspecies variations gives 0.7 mg/L.
- Data from animal studies support the value determined from the epidemiological study.

REFERENCES

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APHA Method 3500-Ba Part C, (1992). Barium: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Brenniman GR and Levy PS (1985). Epidemiological study of barium in Illinois drinking water supplies. Advances in Modern Environmental Toxicology, Princeton Publishing Co., New Jersey, Vol IX, 231–249.

IPCS (1990). Barium. Environmental Health Criteria, 107. World Health Organization, International Programme on Chemical Safety.

Benzene

GUIDELINE

No safe concentration for benzene in drinking water can be confidently set. However, for practical purposes the concentration should be less than 0.001 mg/L, which is the limit of determination.

GENERAL DESCRIPTION

Benzene is present in petrol, and motor vehicle emissions constitute the main source of benzene in the environment. The major sources of benzene in water are atmospheric deposition, chemical plant effluent and underground petrol storage tank leakage. When released to surface waters, benzene rapidly volatilises to the air. In overseas studies benzene has been detected in the Rhine in Germany at approximately 0.0003 mg/L, and occasionally in groundwater supplies in the United States. Concentrations are usually less than 0.001 mg/L, but concentrations up to 0.18 mg/L have been detected in chemical plant effluent.

Benzene is made commercially for use by the chemical industry in the production of styrene, phenol and cyclohexane. Use as a solvent has been greatly reduced in recent years.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Benzene has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Benzene concentrations are not reduced significantly during conventional water treatment processes. Benzene can be efficiently removed from drinking water using packed tower aeration or by the use of granular activated carbon.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for the analysis of benzene (USEPA Draft Method 503.1 1986). An inert gas is bubbled through the sample and benzene trapped on an adsorbent. The adsorbent is then heated and benzene analysed using gas chromatography with photoionization detection. The limit of determination is 0.001 mg/L.

HEALTH CONSIDERATIONS

Benzene is rapidly and efficiently absorbed and widely distributed throughout the body. It is metabolised predominantly into phenol by the liver, and also by bone marrow.

Human health data are mainly from studies where benzene had been inhaled. Exposure to high concentrations in air can cause death. Lower concentrations can induce toxic effects, with white blood cells being most sensitive. There is considerable evidence that occupational exposure to low benzene concentrations for periods as short as 12 months may result in leukaemia.

NOTE: Important general information is contained in PART II, Chapter 6

In animal studies, benzene caused leukaemia and other cancers when administered orally and by inhalation to rats and mice. It can also induce chromosome damage and gene mutation in mammalian cells. It was not found to be mutagenic in tests with bacteria.

The International Agency for Research on Cancer has concluded that benzene is carcinogenic to humans (Group 1, sufficient evidence of carcinogenicity in humans) (IARC 1987).

DERIVATION OF GUIDELINE

Benzene is a genotoxic human carcinogen, and there is no safe or acceptable concentration for it in drinking water. The guideline value of 0.001 mg/L is based on a consideration of health effects in relation to the limit of determination.

The WHO has calculated, using reliable exposure data from an epidemiological study (Rinsky *et al* 1981) and an extrapolation model, that a concentration of 0.001 mg/L in drinking water would entail a maximum lifetime risk of one extra case of leukaemia per million people.

The guideline value was set at the limit of determination because this is the same as the value derived from health considerations, and provides an adequate degree of protection. This is consistent with the general approach adopted for compounds which are known genotoxic human carcinogens (see Section 6.3.4).

The WHO guideline value of 0.01 mg/L was based on a calculation which estimated an additional lifetime risk of one fatal cancer per 100 000 people, rather than one per million.

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

Rinsky RA, Young RJ and Smith AB (1981). Leukemia in benzene workers. *American Journal of Industrial Medicine,* 2, 217–245.

USEPA Draft Method 503.1 (1986). Volatile organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Beryllium

GUIDELINE

Data are insufficient to set a guideline value for beryllium.

GENERAL DESCRIPTION

Beryllium can enter source water through the weathering of rocks, atmospheric deposition, and discharges. The primary source of beryllium in the environment is the burning of fossil fuels. Other less significant sources are slag and ash dumps.

Beryllium is used in a number of specialised applications including ceramic formulations, electrical and electronic components, and X-ray tubes. It is also used to stiffen the mantles of gas acetylene lamps.

Beryllium concentrations in drinking water overseas are generally very low, usually less than 0.001 mg/L.

Some foods can contain small amounts of beryllium but total dietary intake has been estimated at less than 0.015 mg per day. Drinking water probably contributes less than 30% of total beryllium intake.

Atmospheric exposure to beryllium is generally much less than from food or water, but constitutes a greater hazard. Cigarette smokers can be exposed to higher concentrations than nonsmokers.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Australian drinking water supplies have not been routinely monitored for beryllium.

TREATMENT OF DRINKING WATER

There are no published methods for the removal of beryllium from drinking water supplies.

MEASUREMENT

The concentration of beryllium in drinking water can be determined by graphite furnace atomic absorption spectroscopy or inductively coupled plasma emission spectroscopy (APHA Method 3500-Be Parts B or C 1992). The limit of determination is approximately 0.002 mg/L.

HEALTH CONSIDERATIONS

Beryllium compounds are not readily absorbed by the gastrointestinal tract since they tend to be insoluble at pH values normally found in the gut. A significant proportion of the beryllium that is absorbed is incorporated into bone and has a biological half-life of more than one year.

An extensive review and summary of the human and animal toxicity data for beryllium is available (IPCS 1990).

There are no data on the human health effects of oral exposure to beryllium. Inhalation is known to cause serious health effects, with long-term exposure resulting in pulmonary granulomatosis (a type of lung tumour).

In studies with rats, limited data indicated that long-term exposure to beryllium in drinking water produces no adverse effects. A slight decrease in body weight was reported at concentrations of 5 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

Beryllium compounds induced malignant tumours in laboratory animals when administered either by injection or inhalation; however, there is no clear evidence that the compounds are carcinogenic when administered orally. Beryllium was not mutagenic in tests with different strains of bacteria, but caused chromosomal aberrations and gene mutations in cultured mammalian cells.

The International Agency for Research on Cancer concluded that beryllium and beryllium compounds are carcinogenic to humans (Group 1, sufficient evidence of carcinogenicity in humans and sufficient evidence in animals) (IARC 1993).

Experiments with laboratory mice have shown that beryllium can cross the placenta and is foetotoxic (toxic to the fetus).

DERIVATION OF GUIDELINE

There are no suitable oral data available for establishing a guideline value for beryllium. The health effects reported in inhalation studies are localised to the lung, and are not considered to be sufficient to set a guideline value for drinking water. Feeding studies using animals generally showed no adverse effects; however, studies differed markedly in the concentrations that may cause minor effects. The data should be reviewed as soon as adequate toxicological data are available.

REFERENCES

APHA Method 3500-Be Part B, (1992). Beryllium: Atomic Absorption Spectrophotometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Be Part C, (1992). Beryllium: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1993). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Beryllium, Cadmium, Mercury, and Exposures in the Glass Manufacturing Industry. World Health Organization, International Agency for Research on Cancer 58, Lyons.

IPCS (1990). Beryllium. Environmental Health Criteria, 106. World Health Organization, International Programme on Chemical Safety.

Boron

(Revised and endorsed 2001)

GUIDELINE

Considering that boron may be an essential trace element for humans and based on an acceptable range of oral intake (AROI), a concentration of up to 4 mg/L in water would not pose a human health risk.

GENERAL DESCRIPTION

Boron can be present in drinking water through the natural leaching of boron-containing minerals, or by contamination of water sources. The environmental chemistry of boron is not well understood. In water, the predominant form is probably boric acid, which does not dissociate readily.

Boron compounds are used in glass manufacture, cleaners, wood and leather preservatives, flame retardants, cosmetic products, antiseptics, and occasionally food preservatives; and as agricultural fertilisers, algicides, herbicides and insecticides.

In other countries, concentrations of boron in uncontaminated water sources are usually less than 1 mg/L. Concentrations up to 6.5 mg/L have been reported in ground water supplies, but these higher concentrations are associated with seawater intrusion.

Boron is present naturally in many food products, with high amounts found in foods of plant origin, especially fruits, leafy vegetables, nuts and legumes. It has been estimated that intake of boron from food is about 10 times that from water. The daily consumption of boron is 10–25 mg. This value however, will vary from country to country depending on population dietary habits, geographical area and soil geochemistry. In Australia, the estimated dietary intake for boron is 2.2 mg/day (Samman *et al* 1998).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Boron is not often monitored in Australian drinking water supplies but the limited information available indicates that boron concentrations are less than 0.1 mg/L.

TREATMENT OF DRINKING WATER

The concentration of boron in drinking water can be reduced by the use of granular activated carbon, or by lime softening.

MEASUREMENT

The boron concentration in drinking water can be determined using inductively coupled plasma emission spectroscopy (APHA Method 4500-B Part D 1992). The limit of determination is approximately 0.05 mg/L.

HEALTH CONSIDERATIONS

Boron, as soluble borate (borax) or boric acid, is rapidly and completely absorbed after ingestion. It is widely distributed throughout the body and up to 90% is excreted in urine as unchanged compound.

There have been a number of reported cases of poisoning following the ingestion of high doses of boron. Symptoms include gastrointestinal disturbances, skin eruptions, and central nervous system stimulation and depression. Long-term occupational exposure to boron can lead to similar symptoms.

NOTE: Important general information is contained in PART II, Chapter 6

Short-term studies with rats and dogs reported testicular atrophy at high doses (5000 mg/kg bodyweight) of boric acid and borate. This condition was also observed in longer term studies with rats, mice and dogs over 2 years. Reproductive studies reported that rats became sterile at the highest doses. No increase in the incidence of tumours was observed in long-term studies using mice.

Tests for mutagenicity using bacteria and mammalian cells have been mostly negative. Neither boric acid nor borate induced chromosomal aberrations in mammalian cells.

Human studies have shown that boron is potentially an essential trace element that can affect the metabolism and utilisation of other substances including calcium, copper, magnesium, nitrogen, glucose, triglycerides, reactive oxygen and oestrogen (Nielson 1996). Boron may be involved in a wide range of biochemical processes and have a role in the prevention of chronic diseases such as osteoporosis, arthritis and coronary heart disease.

DERIVATION OF GUIDELINE

Using a standard toxicological approach a guideline value for boron in drinking water can be derived as follows:

$$0.6 \text{ mg/L} = \frac{9.6 \text{ mg/kg bodyweight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 60}$$

where:

- 9.6 mg/kg bodyweight per day is the no observable adverse effect level (NOAEL) from a developmental toxicity study using Sprague Dawley rats (Price *et al* 1994)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 60 is the safety factor derived from using toxicokinetic and toxicodynamic data from animal and human studies (6 for intraspecies variations and 10 for interspecies variations).

However, on the basis that boron is a potential essential trace element, an alternative approach to calculating a guideline value is proposed. The International Program on Chemical Safety (IPCS) has recommended that for all essential trace elements there is a zone for safe and adequate exposure termed the acceptable range of oral intake (AROI) (IPCS 2002). The WHO indicates that the mean minimum dietary intake for adults to avoid boron deficiency is 1.0 mg/day (WHO 1996), while the maximum tolerable daily intake calculated from the study of Price *et al* (1994) is:

$$11.2 \text{ mg/day} = \frac{9.6 \text{ mg/kg bodyweight per day} \times 70 \text{ kg}}{60}$$

On this basis, the AROI for boron is 1.0-11.2 mg/day. Food is the major source of dietary boron and in Australia it has been determined that the average dietary intake is 2.2 mg/day (Samman ***et al*** 1998). Other oral sources (e.g. from medicinal, cosmetic and consumer products) are considered minimal. Consumer products have been estimated to contribute to a geometric mean of 0.1 mg/day to total boron exposure (WHO 1998).

Based on the AROI approach, a guideline value for boron (rounded down) in drinking water was derived as follows:

$$4 \text{ mg/L} = \frac{11.2 \text{ mg/day} - 2.2 \text{ mg/day} - 0.1 \text{ mg/day}}{2 \text{ L/day}}$$

REFERENCES

APHA Method 4500-B Part D (1992). Boron: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Neilson FH (1996). Evidence for the Nutritional Essentiality of Boron. *Journal of Trace Elements in Experimental Medicine,* 9: 215–229.

Price CJ, Marc MC, Myers CB (1994). Determination of the NOAEL for developmental toxicity in Sprague-Dawley (CD) rats exposed to boric acid on gestational days 0 to 20 and evaluation of postnatal recovery through postnatal day 21. Report 65C-5657-200. Research Triangle Institute, Research Triangle Park, NC.

Samman S, Naghii MR, Lyons Wall PM and Verus AP (1998). The nutritional and metabolic effects of boron in humans and animals. *Biologic Trace Element,* 66,1–9.

IPCS (International Programme on Chemical Safety) (2002). Principles and methods for the assessment of risk from essential trace elements. Environmental Health Criteria 228. World Health Organisation, Geneva, Switzerland.

WHO (World Health Organization) (1996). Trace elements in human nutrition and health. Prepared in collaboration with the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency. World Health Organisation, Geneva, Switzerland. Chapter 13, 175-179.

WHO (World Health Organization) (1998). Guidelines for drinking-water quality. Second edition. Addendum to Volume 2. Health criteria and other supporting information. World Health Organisation, Geneva, Switzerland.

Bromate

GUIDELINE

Based on health considerations, the concentration of bromate in drinking water should not exceed 0.02 mg/L.

GENERAL DESCRIPTION

Bromate is not a normal component of water but may be formed from bromide during ozonation. Concentrations up to 0.09 mg/L have been reported in ozonated drinking water. Bromate is a strong oxidant and will probably react with organic matter in water, forming bromide as a byproduct.

Bromate is used in home hair permanent-wave neutralising solutions. Although it is used in some foods overseas, Australian Food Standards do not allow bromate to be used in food in Australia.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

It is unlikely that bromate would be present in Australian reticulated drinking water supplies unless ozonation is used for disinfection.

REMOVAL FROM DRINKING WATER

There are no published methods for the removal of bromate from drinking water supplies.

MEASUREMENT

The concentration of bromate in drinking water can be determined using ion chromatography with conductivity detection. The limit of determination is about 0.005 mg/L.

HEALTH CONSIDERATIONS

Bromate is rapidly absorbed from the gastrointestinal tract of rats. Although bromate was not subsequently detected in tissue, bromide concentrations were significantly increased in plasma, red blood cells, pancreas, kidney, stomach and small intestine.

Most cases of human poisoning from bromate are due to accidental or intentional ingestion of home permanent-wave solutions, which can contain 2–10% bromate. Toxic effects include nausea, abdominal pain and diarrhoea, central nervous system depression and pulmonary oedema, most of which are reversible. Irreversible effects include kidney failure and deafness.

In rats exposed to bromate in drinking water for 15 months, adverse effects included inhibited body-weight gain, marked kidney damage, and renal adenocarcinoma. Kidney tumours have been reported in other long-term studies using male and female rats, but not with female mice; male rats also exhibited peritoneal mesotheliomas. There is evidence that tumours occur only after a minimum total cumulative dose has been exceeded.

Bromate exhibited mutagenic activity in tests using bacteria, and caused chromosomal aberrations in cultured mammalian cells. Some evidence of DNA damage has also been reported in rats given potassium bromate.

The International Agency for Research on Cancer has concluded that bromate is possibly carcinogenic to humans (Group 2B, no data in humans but sufficient evidence in animals) (IARC 1986).

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The guideline value for bromate in drinking water was derived as follows:

$$0.02 \text{ mg/L} = \frac{30 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.2}{2 \text{ L/day} \times 10\,000}$$

where:

- 30 mg/kg body weight per day is a lowest effect level from a 15-month drinking water study using rats (Nakano *et al* 1989)
- 70 kg is the average weight of an adult
- 0.2 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 10 000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations, 10 because a lowest effect level was used instead of a no effect level and 10 for carcinogenic and mutagenic effects).

The WHO guideline value of 0.025 mg/L was based on a calculation that estimated an additional lifetime risk of seven fatal cancers per 100 000 people. It was recognised that this approach may not be appropriate if, as reported, tumours only occur above a dose threshold. The two different approaches, however, result in essentially the same guideline value.

This guideline should be reviewed when new data are available.

REFERENCES

IARC (1986). IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans: some naturally occurring and synthetic food components, furocoumarins, ultraviolet radiation and potassium bromate. World Health Organization, International Agency for Research on Cancer, 40.

Nakano K, Okada S, Toyokuni S and Midorikawa O (1989). Renal changes induced by chronic oral administration of potassium bromate or ferric nitrilotriacetate in Wistar rats. (In Japanese). *Japanese Archives of Internal Medicine,* 36, 41–47.

Cadmium

GUIDELINE

Based on health considerations, the concentration of cadmium in drinking water should not exceed 0.002 mg/L.

GENERAL DESCRIPTION

Contamination of drinking water by cadmium may occur as a result of impurities in the zinc of galvanised pipes or in solders used in fittings, water heaters, water coolers and taps. Cadmium can also be released to the environment in waste water, through contamination of fertilisers, and by metallurgical industries.

Cadmium metal is used as an anticorrosive coating on steel but its use is being phased out. Cadmium compounds are commonly used as pigments in plastics, in batteries and in some electrical components.

Cadmium concentrations in nonpolluted natural waters overseas are usually lower than 0.001 mg/L.

Food is the main source of cadmium intake. The estimated average Australian adult dietary intake of cadmium is approximately 0.03 mg per day. Smoking is a significant additional source of cadmium.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies concentrations of cadmium are usually less than 0.002 mg/L.

TREATMENT OF DRINKING WATER

Cadmium can be effectively removed from drinking water by lime softening (98% removal in the pH range 8.5 to 11.3) and coagulation with ferric chloride (90% removal above pH 8 but less effective at lower pH).

MEASUREMENT

The cadmium concentration in drinking water can be determined using graphite furnace atomic absorption spectroscopy (APHA Method 3500-Cd Part B 1992). The limit of determination is approximately 0.0002 mg/L.

HEALTH CONSIDERATIONS

Absorption of cadmium in the gastrointestinal tract depends on a number of factors including the solubility of the compounds ingested, but a healthy person typically absorbs 3-7% of ingested cadmium. This figure may be higher in people with iron, calcium and protein deficiency. Cadmium accumulates in the kidney and is only released very slowly, with a biological half-life in humans of 10 to 15 years.

An extensive review and summary of the human and animal toxicity data for cadmium is available (IPCS 1992).

In humans, long-term exposure can cause kidney dysfunction leading to the excretion of protein in the urine. This may occur, in a certain proportion of people, if the amount of cadmium exceeds 200 mg/kg renal cortex tissue; about 10% of the population is estimated to possess this sensitivity. Other effects can include osteomalacia (softening of the bones). Cases of Itai-Itai disease have been reported in Japan among elderly women exposed to highly contaminated food and water. Symptoms are similar to osteomalacia accompanied by kidney dysfunction characteristic of cadmium poisoning.

NOTE: Important general information is contained in PART II, Chapter 6

Epidemiological studies have looked for a connection between lung cancer and workplace cadmium inhalation, but the results have been inconclusive.

Long-term inhalation studies with rats have reported an increase in the incidence of tumours of the lung. No increase in the incidence of tumours was found when cadmium salts were administered orally.

There is no clear evidence that cadmium is mutagenic. Many tests have reported negative results but there have been some reports of gene mutation and chromosome abnormalities in mammalian cells. The positive results are reported as being weak and only present at high concentrations.

The International Agency for Research on Cancer has concluded that cadmium is probably carcinogenic to humans (Group 2A, limited evidence of carcinogenicity in humans and sufficient evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The guideline value for cadmium in drinking water was derived as follows:

$$0.002 \text{ mg/L} = \frac{0.0007 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day}}$$

where:

- an intake of less than 0.0007 mg/kg body weight per day will ensure that over a 70 year lifetime, cadmium in the body will be kept below the critical amount of 200 mg/kg renal cortex tissue (WHO 1989). This figure was based on calculations that take into account an absorption rate of 5%, a daily excretion rate of 0.005% of body burden, and an adequate safety factor
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult.

No additional safety factors are necessary as they have been included in the intake value.

The guideline value takes into account the higher cadmium intake, per kilogram of body weight, by infants and children.

The WHO guideline value of 0.003 mg/L is slightly different due to rounding in the calculation. The difference is not significant.

REFERENCES

APHA Method 3500-Cd Part B, (1992). Cadmium: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (International Agency for Research on Cancer) (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (International Programme on Chemical Safety) (1992). Cadmium. Environmental Health Criteria, 134. World Health Organization, International Programme on Chemical Safety.

WHO (World Health Organization) (1989). Toxicological evaluation of certain food additives and contaminants: Cadmium. The 33rd meeting of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization Food Additives Series, 24, 163-219, Geneva.

Carbon tetrachloride

GUIDELINE

Based on health considerations, the concentration of carbon tetrachloride in drinking water should not exceed 0.003 mg/L.

GENERAL DESCRIPTION

Carbon tetrachloride is not produced in drinking water as a byproduct of chlorination, but it may be present in chlorine used for disinfection. It has occasionally been found overseas as a contaminant in drinking water supplies at concentrations less than 0.003 mg/L.

The major use of carbon tetrachloride is in the commercial production of chlorofluorocarbons which are used as refrigerants, foam-blowing agents and solvents. It is also used in the manufacture of paint and plastics.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Preliminary data indicate that concentrations of carbon tetrachloride in major Australian reticulated supplies are significantly less than 0.001 mg/L.

TREATMENT OF DRINKING WATER

Carbon tetrachloride can be removed from drinking water by adsorption onto granular activated carbon.

MEASUREMENT

A solvent extraction procedure is suitable for the analysis of carbon tetrachloride (USEPA Draft Method 551 1990). Sodium chloride is added to the sample and carbon tetrachloride extracted using methyl tert-butyl ether. The extract is then analysed using gas chromatography with an electron capture detector. The limit of determination is approximately 0.000004 mg/L (4 ng/L).

HEALTH CONSIDERATIONS

Carbon tetrachloride is absorbed readily from the gastrointestinal tract, the respiratory tract and the skin. It is distributed to all major organs, with highest concentrations in fatty tissues. It is metabolised in the liver to chloroform and other products, and excreted in breath, urine and faeces.

In humans, acute inhalation can result in central nervous system depression, and kidney and liver toxicity. Occupational exposure to carbon tetrachloride by inhalation has been associated with cancer of several organs but the evidence is inconclusive. No data are available on the effects of long-term ingestion of carbon tetrachloride. In animals, the effects of long-term exposure include toxicity to the liver and kidney. Liver tumours have been reported in studies with mice, rats and hamsters, but at doses higher than those that cause liver toxicity.

Carbon tetrachloride does not exhibit any evidence of mutagenic activity in tests with bacteria or cultured liver cells.

The International Agency for Research on Cancer has concluded that carbon tetrachloride is possibly carcinogenic to humans (Group 2B, inadequate evidence in humans but sufficient evidence in animals) (IARC 1987).

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The guideline value of 0.003 mg/L for carbon tetrachloride was determined as follows:

$$0.003 \text{ mg/L} = \frac{1.2 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000} \times \frac{5}{7}$$

where:

- 1.2 mg/kg body weight per day is the no effect level based on a 90-day gavage study using mice (Condie *et al* 1986).
- 70 kg is the average weight of an adult.
- 0.1 is the proportion of total daily intake attributable to the consumption of water.
- 2 L/day is the average amount of water consumed by an adult.
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for less than lifetime study). An additional factor of 10 for carcinogenicity was not applied as tumours occur at doses that have already resulted in liver toxicity.
- 5/7 is used to convert data based on a 5 day per week gavage study to a 7-day week equivalent.

The WHO guideline value of 0.002 mg/L was based on an adult body weight of 60 kg. The difference in the guideline values is not significant.

REFERENCES

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Chlordane

GUIDELINE

Chlordane should not be detected in drinking water. If present in drinking water, chlordane would not be a health concern unless the concentration exceeded 0.001 mg/L.

If it is detected, remedial action should be taken to stop contamination. The limit of determination is 0.00001 mg/L (10 ng/L).

GENERAL DESCRIPTION

Chlordane is a broad spectrum insecticide. Until June 1995, it was used throughout Australia to protect wooden structures against termites. Its other former uses have been withdrawn.

Chlordane is highly resistant to chemical and biological degradation. Its components are relatively insoluble in water and are readily adsorbed onto soil particles. Its residues do not move readily through soil and it is unlikely to be a serious contaminant of deep water storages (IPCS 1984). Once in water, it is not subject to photodegradation, hydrolysis or biodegradation, but can be removed by adsorption onto particulate matter and bottom sediments, and by uptake by aquatic organisms.

In the United States, chlordane has rarely been detected in drinking water, and when found, concentrations were usually below 0.0001 mg/L. Food is probably the major source of exposure, although the 1990 Australian Market Basket Survey did not find residues in the foods tested (NHMRC and NFA 1991).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Chlordane has not been detected in major Australian drinking water supplies.

TREATMENT OF DRINKING WATER

There are no published reports on methods for removal of chlordane from drinking water. Granular activated carbon would probably be effective.

MEASUREMENT

Chlordane can be extracted from water using a nonpolar solvent such as pentane, and analysed using gas chromatography with electron capture detection (APHA Method 6630 Part B 1992). The limit of determination is about 0.00001 mg/L (10 ng/L).

HEALTH CONSIDERATIONS

In rats and rabbits, up to 30% of orally administered chlordane was absorbed by the gastrointestinal tract and quickly distributed throughout the body. Highest amounts were measured in fatty tissue.

Extensive reviews and summaries of the human and animal toxicology of chlordane are available (IPCS 1984, JMPR 1987, IARC 1991, NHMRC 1992).

The principal public health concern regarding chlordane arises from its ability to bioaccumulate. Chlordane is acutely neurotoxic in animals and humans. It is hepatotoxic in mice at a dose of 0.6 mg/kg body weight per day and above, but not in humans. Dogs fed chlordane over 2 years showed altered liver enzyme activity and slightly higher liver weights at high doses (375 mg/kg body weight per day) (IPCS 1984).

NOTE: Important general information is contained in PART II, Chapter 6

A dose-related increase in the incidence of hepatocellular carcinomas has been reported in mice fed chlordane at doses of 6 mg/kg body weight per day and above, but not in rats (IPCS 1984).

Chlordane has not been reported to be genotoxic or teratogenic, but did increase neonatal mortality when fed to pregnant rodents (NHMRC 1992).

The International Agency for Research on Cancer has concluded that chlordane is possibly carcinogenic to humans (Group 2B, inadequate evidence in humans, sufficient evidence in experimental animals) (IARC 1991).

DERIVATION OF GUIDELINE

The health-based guideline value of 0.001 mg/L for chlordane was determined as follows:

$$0.001 \text{ mg/L} = \frac{0.0005 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day}}$$

where:

- 0.0005 mg/kg body weight per day is the maximum ADI based on a no effect level from a long-term dietary study on rats at doses of 0.05 mg/kg body weight per day (JMPR 1986)
- 70 kg is the average weight of an adult
- 0.1 gives a guideline value based on 10% of the ADI
- 2 L/day is the average amount of water consumed by an adult.

The maximum ADI value includes adequate safety factors. No additional safety factors are necessary.

The WHO guideline value of 0.0002 mg/L was determined using 1% of the ADI to allow for increased exposure from other sources. Such a low percentage of the ADI was considered inappropriate for Australia, where chlordane has not been detected in foods or drinking water supplies.

REFERENCES

APHA Method 6630 Part B (1992). Organochlorine pesticides: Liquid-liquid extraction, gas chromatographic method I. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1991). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Occupational Exposures in Insecticide Application, and Some Pesticides. World Health Organization, International Agency for Research on Cancer, 53.

IPCS (1984). Chlordane. Environmental Health Criteria, 34. World Health Organization, International Programme on Chemical Safety.

JMPR (1986). Pesticide Residues in Food–1986. Report of the Joint FAO Panel of Experts on Pesticide Residues in Food and the Environment, and a WHO Expert Group on Pesticide Residues. Food and Agricultural Organization of the United Nations, FAO Plant Production and Protection Paper 77.

NHMRC (1992). Cyclodiene Insecticide Use in Australia. National Health and Medical Research Council, AGPS, Canberra.

NMMRC and NFA (1991). The 1990 Australian Market Basket Survey. National Health and Medical Research Council and the National Food Authority, AGPS, Canberra.

Chloride

GUIDELINE

Based on aesthetic considerations, the chloride concentration in drinking water should not exceed 250 mg/L.

No health-based guideline value is proposed for chloride.

GENERAL DESCRIPTION

Chloride is present in natural waters from the dissolution of salt deposits, and contamination from effluent disposal.

Sodium chloride is widely used in the production of industrial chemicals such as caustic soda, chlorine, and sodium chlorite and hypochlorite. Potassium chloride is used in the production of fertilisers.

The taste threshold of chloride in water is dependent on the associated cation but is in the range 200–300 mg/L. The chloride content of water can affect corrosion of pipes and fittings. It can also affect the solubility of metal ions.

In surface water, the concentration of chloride is usually less than 100 mg/L and frequently below 10 mg/L. Groundwater can have higher concentrations, particularly if there is salt water intrusion.

Food is the major source of chloride intake. All plants and animals contain chloride. The addition of salt during processing or cooking can markedly increase the chloride content.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies chloride concentrations range up to 350 mg/L. Typical values depend to a large extent on local conditions but concentrations of 150 mg/L are not uncommon in some areas.

TREATMENT OF DRINKING WATER

Chloride cannot be removed from drinking water by conventional water treatment processes. It can be removed by distillation or reverse osmosis but these are expensive to operate.

MEASUREMENT

The chloride concentration in drinking water can be determined with titrimetric techniques using silver nitrate or mercuric nitrate and colorimetric or potentiometric end-point detection (APHA Method 4500-Cl^- Parts B or C 1992). The limit of determination is approximately 1 mg/L. Ion chromatography can also be used (APHA Method 4500-Cl^- Part F 1992), with a limit of determination of 0.1 mg/L.

HEALTH CONSIDERATIONS

Chloride is essential for humans and animals. It contributes to the osmotic activity of body fluids. A normal 70 kg human body contains approximately 80 g of chloride.

Chloride is absorbed almost completely by the gastrointestinal tract. Healthy individuals can tolerate the intake of large quantities of chloride provided there is a corresponding intake of fresh water.

NOTE: Important general information is contained in PART II, Chapter 6

Little is known about the prolonged intake of large amounts of chloride by humans. Large salt intake has been reported to increase blood pressure but this is attributed to the sodium content rather than chloride. Similar results have been reported in studies with animals, although long-term data are not available.

No data are available on carcinogenic or genotoxic effects for chloride.

DERIVATION OF GUIDELINE

The guideline value is based on the taste threshold in drinking water of approximately 250 mg/L.

There are no data to suggest that chloride causes health problems; hence, no guideline value based on health considerations is warranted.

REFERENCES

APHA Method 4500-Cl^- Part B (1992). Chloride: Argentometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 4500-Cl^- Part C (1992). Chloride: Mercuric nitrate method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 4500-Cl^- Part F (1992). Chloride: ion chromatography method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Chlorinated furanones

3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone (MX)

GUIDELINE

Data are inadequate to set a guideline value for MX in drinking water.

GENERAL DESCRIPTION

The organic compound known as MX can be formed by the reaction between chlorine and naturally occurring organic matter in water. It has been identified in chlorinated humic acid solutions, after the chlorination of pulp mill effluent, and chlorinated drinking water. No other sources of MX are known.

The stability of MX is dependent on pH. Below pH 7 it is relatively stable but above pH 7 it rapidly breaks down.

Studies in the United States, the United Kingdom and Finland have found extremely low MX concentrations in drinking water. Concentrations range up to 0.000067 mg/L (67 ng/L).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Preliminary investigations indicate that concentrations of MX in Australian drinking water are likely to be similar to those found overseas.

LIMITING FORMATION IN DRINKING WATER

The presence of MX in drinking water can be minimised by removing naturally occurring organic matter from the source water, by reducing the amount of chlorine added, by the use of alternative disinfectants, or by ensuring that the pH is kept above 7.

MEASUREMENT

MX is extremely difficult to detect because of the very low concentrations and the masking effects of other substances. Analysis is by extraction on XAD resin, methylation of the concentrate, and detection on a gas chromatography/mass spectrometer system employing selected ion monitoring techniques. The procedure is not suitable for routine analysis.

HEALTH CONSIDERATIONS

There are no data on the health effects of MX in humans, nor are there any long-term or lifetime toxicity data for animals.

Studies have shown that MX is an extremely potent mutagen when applied to some strains of bacteria, and about a third of the mutagenicity of chlorinated drinking water has been attributed to this compound. Genotoxic activity has also been observed *in vitro* using cultured mammalian cells, although *in vivo* experiments showed no evidence of genotoxic activity. No carcinogenicity data are available for MX.

NOTE: Important general information is contained in PART II, Chapter 6

Chlorine dioxide
Chlorite
Chlorate

GUIDELINE

Chlorine dioxide: Based on aesthetic considerations, the concentration in drinking water should not exceed 0.4 mg/L. Chlorine dioxide would not be a health consideration unless the concentration exceeded 1 mg/L.

Chlorite: Based on health considerations, the concentration in drinking water should not exceed 0.3 mg/L.

Chlorate: Data are insufficient to set a guideline value in drinking water.

GENERAL DESCRIPTION

Chlorine dioxide is used as a disinfectant for drinking water supplies. It dissociates into chlorite and, to a lesser extent, chlorate when added to water. It is usually generated on site due to handling and transportation difficulties.

Chlorine dioxide is used commercially as a bleaching agent in paper production, paper pulp, and cleaning and tanning of leather. Chlorite is used in the production of paper, textiles and straw products, and in the manufacture of waxes, shellacs and varnishes. Chlorates have been used as herbicides and defoliants, and in the manufacture of dyes, matches, and explosives.

The taste and odour threshold for chlorine dioxide in water is 0.4 mg/L. No data are available for chlorite and chlorate.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Chlorine dioxide (chlorite) is rarely used as a disinfectant in Australian reticulated supplies. When used, the chlorite residual is maintained between 0.2 mg/L to 0.4 mg/L. It is particularly effective in the control of manganese-reducing bacteria.

REMOVAL FROM DRINKING WATER

Chlorine dioxide can be removed from drinking water by the addition of reducing agents such as sodium bisulfite (although some studies indicate that the chlorate concentration increases as a result), by exposure to sunlight, or by the use of granular activated carbon.

MEASUREMENT

The concentration of chlorine dioxide in drinking water can be determined by a modification of the DPD method (APHA Method 4500-ClO_2 Part D 1992). The limit of determination is 0.05 mg/L (as Cl_2).

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Chlorine dioxide, chlorite, and chlorate are all absorbed rapidly by the gastrointestinal tract into blood plasma and distributed to the major organs. All compounds appear to be rapidly metabolised.

In a study with human volunteers, no adverse effects were observed after drinking water with either chlorine dioxide or chlorite concentrations up to 5 mg/L for periods of 12 weeks. In the same study, consumption of high doses of chlorate was associated with a change in serum urea nitrogen and corpuscular haemoglobin.

In rats exposed before birth, high concentrations of chlorine dioxide may impair brain development. Significant depression of thyroid hormones has been observed in rats, pigeons and monkeys exposed to doses of approximately 10 mg/kg body weight per day for long periods . Chlorite can affect red blood cells resulting in methaemoglobin formation in cats and monkeys. Studies using chlorate have not identified any dose-related effects associated with long-term exposure.

Chlorine dioxide was not mutagenic in tests with different strains of bacteria. No data are available on the mutagenic activity of chlorite or chlorate. None of the compounds induced chromosomal aberrations in tests with mouse bone-marrow cells.

The International Agency for Research on Cancer has concluded that chlorite is not classifiable as to its carcinogenicity in humans (Group 3, no human data and inadequate evidence in animals) (IARC 1991).

DERIVATION OF GUIDELINES

The guideline values were determined as follows:

i) Chlorine dioxide:

$$1\ \text{mg/L} = \frac{3\ \text{mg/kg body weight per day} \times 70\ \text{kg}}{2\ \text{L/day} \times 100}$$

where:

- 3 mg/kg body weight per day is the no effect level from subchronic studies with rats, pigeons and monkeys (Bercz *et al* 1982, Taylor and Pfohl 1984, Orme *et al* 1985)
- 70 kg is the average weight of an adult
- 2 L/day is the average amount of water consumed by an adult
- 100 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations and 10 for intraspecies variations). A safety factor of 100 is adequate because of the availability of some human data.

It is assumed that all chlorine dioxide intake is from drinking water.

This health-based value exceeds the taste and odour threshold of 0.4 mg/L.

The 1993 WHO Guidelines do not have a guideline value for chlorine dioxide because of its rapid breakdown and because the chlorite guideline value is considered to be adequately protective for potential toxicity from chlorine dioxide.

ii) Chlorite:

$$0.3 \text{ mg/L} = \frac{1 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.8}{2 \text{ L/day} \times 100}$$

where:

- 1 mg/kg body weight per day is the no effect level from a 90-day study using rats (Heffernan *et al* 1979)
- 0.8 is the proportion of total daily intake attributable to the consumption of water, based on the occasional use of chlorite in the food industry
- other factors apply as above.

The WHO guideline value of 0.2 mg/L was determined using an adult body weight of 60 kg. The difference is not significant.

iii) Chlorate:

Data are insufficient to determine a guideline value for chlorate. Further research is needed to characterise the toxic effects.

REFERENCES

APHA Method 4500-ClO_2 Part D (1992). Chlorine dioxide: DPD method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Bercz JP, Jones L, Garner L, Murray D, Ludwig A and Boston J (1982). Subchronic toxicity of chlorine dioxide and related compounds in drinking water in the nonhuman primate. *Environmental Health Perspectives,* 46, 47–55.

Hefernan WP, Guion C and Bull RJ (1979). Oxidative damage to the erythrocyte induced by sodium chlorite, *in vivo*. *Journal of Environmental Pathology and Toxicology,* 2, 1487–1499.

IARC (International Agency for Research on Cancer) (1991). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: chlorinated drinking water, chlorination byproducts, some other halogenated compounds, cobalt and cobalt compounds. World Health Organization, International Agency for Research on Cancer, 52.

Orme J, Taylor DH, Laurie RD and Bull RJ (1985). Effects of chlorine dioxide on thyroid function in neonatal rats. *Journal of Toxicology and Environmental Health*, 15, 315–322.

Taylor DH and Pfohl RJ (1984). Effects of chlorine dioxide on the neurobehavioral development of rats. Water Chlorination: Chemistry, Environmental Impact and Health Effects, 5, 355–364. Proceedings of 5th Conference on Water Chlorination: Environmental Impact and Health Effects, Williamsburg, Virginia, June 3–8, Lewis Publ.

NOTE: Important general information is contained in PART II, Chapter 6

Chlorine

GUIDELINE

Based on health considerations, the guideline value for chlorine in drinking water is 5 mg/L.

GENERAL DESCRIPTION

Chlorine dissociates in water to form hypochlorous acid and hypochlorite ion. Chlorine and hypochlorites are toxic to microorganisms and are used extensively as disinfectants for drinking water supplies. Chlorine is also used to disinfect sewage and waste water, swimming pool water, in-plant supplies, and industrial cooling water.

Chlorine has an odour threshold in drinking water of about 0.6 mg/L, but some people are particularly sensitive and can detect amounts as low as 0.2 mg/L. Water authorities may need to exceed the odour threshold value of 0.6 mg/L in order to maintain an effective disinfectant residual.

In the food industry, chlorine and hypochlorites are used for general sanitation and for odour control. Large amounts of chlorine are used in the production of industrial and domestic disinfectants and bleaches, and it is used in the synthesis of a large range of chemical compounds.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

When used as a disinfectant, the free chlorine residual in major Australian reticulated supplies ranges from 0.1 mg/L to 4 mg/L, with typical concentrations of about 0.2 mg/L.

REMOVAL FROM DRINKING WATER

Chlorine can be removed from drinking water by aeration, by exposure to sunlight, or by the addition of reducing agents such as sodium bisulfite.

MEASUREMENT

The concentration of chlorine in drinking water can be determined by the DPD ferrous titrimetric method (APHA Method 4500-Cl Part F 1992). The limit of determination is 0.1 mg/L.

HEALTH CONSIDERATIONS

Chlorine, or hypochlorites, are strong oxidising agents that readily react with organic molecules to produce a wide variety of chlorinated compounds. This reactivity makes it difficult to separate the effects of chlorine from those of its metabolites. In animal studies using a naturally occurring nonradioactive chlorine isotope, chlorine was rapidly absorbed by the gastrointestinal tract, and highest concentrations of the isotope were found in blood plasma.

It is assumed that the toxicities of aqueous solutions containing chlorine, hypochlorous acid or hypochlorite are similar since they are in dynamic equilibrium. Chlorine concentrations therefore refer to free available chlorine.

Very few toxic effects have been associated with drinking water containing high chlorine concentrations. In one report, 150 people drank water with 50 mg/L during a period of mains disinfection, with no adverse effects. Several instances have been reported where military personnel drank water with chlorine concentrations up to 32 mg/L for several months with no ill effects.

NOTE: Important general information is contained in PART II, Chapter 6

Mouth irritation and momentary constriction of the throat were observed when the chlorine concentration exceeded 90 mg/L. Most people would refuse to drink water with a chlorine concentration over 25 mg/L.

A number of studies have suggested an association between water chlorination byproducts and various cancers. This association has been most consistent in relation to cancers of the bladder and rectum, but there are insufficient data to determine concentrations at which chlorination byproducts might cause increased risk to human health (see Section 6.3.2 for a discussion of disinfection byproducts, and Section V - Fact Sheets on specific disinfection byproducts).

Long-term animal toxicity studies have shown no specific effects from the ingestion of chlorine. Chlorine, hypochlorous acid and hypochlorite did not act as carcinogens or tumour initiators.

Assessment of the mutagenicity of chlorine is complicated by the reactivity of chlorine. Hypochlorite was found to be mutagenic in tests with one strain of bacteria but not with another. Chromosome aberrations were reported in tests with mammalian cells.

The International Agency for Research on Cancer has concluded that hypochlorites are not classifiable as to their carcinogenicity in humans (Group 3, no human data and inadequate evidence in animals) (IARC 1991).

DERIVATION OF GUIDELINE

The guideline value for chlorine in drinking water was determined as follows:

$$5 \text{ mg/L} = \frac{15 \text{ mg/kg body weight per day} \times 70 \text{ kg}}{2 \text{ L/day} \times 100}$$

where:

- 15 mg/kg body weight per day is the no effect level from a 2-year drinking water study using rodents (NTP 1992)
- 70 kg is the average weight of an adult
- 2 L/day is the average amount of water consumed by an adult
- 100 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations and 10 for intraspecies variations).

It is assumed that all chlorine intake is from drinking water.

REFERENCES

APHA Method 4500-Cl Part F (1992). Chlorine (residual): DPD Ferrous Titrimetric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (International Agency for Research on Cancer) (1991). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: chlorinated drinking water, chlorination byproducts, some other halogenated compounds, cobalt and cobalt compounds. World Health Organization, International Agency for Research on Cancer, 52.

NTP (National Toxicology Program) (1992). Toxicology and carcinogenesis studies of chlorinated water and chloraminated water in F344/N and B6C3F1 mice (drinking water studies). National Toxicology Program, Technical Report No. 392, Publication No. 92-2847. United States Department of Health and Human Services, National Institute of Health.

Chloroacetic acids

chloroacetic acid
dichloroacetic acid (DCA)
trichloroacetic acid (TCA)

GUIDELINE

Based on health considerations, the concentrations of chloroacetic acids in drinking water should not exceed the following values:

chloroacetic acid	***0.15 mg/L***
dichloroacetic acid	***0.1 mg/L***
trichloroacetic acid	***0.1 mg/L***

GENERAL DESCRIPTION

Chloroacetic acids are produced in drinking water as byproducts of the reaction between chlorine and naturally occurring humic and fulvic acids. Concentrations reported overseas range up to 0.16 mg/L, and are typically about half the chloroform concentration.

The chloroacetic acids are used commercially as reagents or intermediates in the preparation of a wide variety of chemicals. Monochloroacetic acid can be used as a pre-emergent herbicide, dichloroacetic acid as an ingredient in some pharmaceutical products, and trichloroacetic acid as a herbicide, soil sterilant and antiseptic.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Based on preliminary data, concentrations of chloroacetic acids in Australian drinking waters range from 0.01 mg/L to 0.1 mg/L for chloroacetic acid, from 0.003 mg/L to 0.05 mg/L for dichloroacetic acid, and from 0.001 mg/L to 0.1 mg/L for trichloroacetic acid.

LIMITING FORMATION IN DRINKING WATER

The formation of chloroacetic acids in drinking water can be minimised by removing naturally occurring organic matter from the source water, reducing the amount of chlorine added, or using alternative disinfectants.

MEASUREMENT

The chloroacetic acids can be analysed by a liquid-liquid extraction procedure (USEPA Draft Method 552 1990). In this method the sample is adjusted to pH 11.5 and extracted with methyl tert-butyl ether (MTBE) to remove neutral and basic compounds. The sample is then acidified to pH 0.5 and the chloroacetic acids extracted into MTBE. The dried extracts are methylated, and the esters analysed by gas chromatography using electron capture detection. Limits of determination are lower than 0.001 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Chloroacetic acids would be expected to be absorbed after ingestion in view of their water solubility, but there are no data to confirm this assumption. Dichloroacetate is rapidly metabolised to glyoxylate and oxalate by the liver, but no data are available on how the other chloroacetic acids are metabolised.

Dichloroacetic acid has been used in humans to control blood sugar and cholesterol levels. There are no studies on the short- or long-term exposure of humans to chloroacetic acid or trichloroacetic acid.

In rats and mice fed chloroacetic acid for two years, survival was decreased in rats at doses of 15-30 mg/kg body weight per day, whereas in mice, survival was affected at 100 mg/kg body weight per day (males) but not at 50 mg/kg body weight per day. There was no evidence of carcinogenic activity.

Rats given dicholoroacetic acid by gavage at 3 months developed brain lesions and increases in mean liver, kidney and adrenal weight at doses from 125 mg/kg body weight per day. Similar effects were observed at 3 months in dogs fed encapsulated dichloroacetate at 50 mg/kg body weight per day. Mice receiving dichloroacetate in their drinking water for a year had decreased body weight at doses from 410 mg/kg body weight per day, increased liver weight at doses from 77 mg/kg body weight per day, and an increase in the incidence of hepatocellular carcinomas and adenomas at doses from 295 mg/kg body weight per day.

Trichloroacetic acid administered in drinking water to rats for 90 days significantly increased liver peroxisomal activity at a dose of 355 mg/kg body weight per day. A 12-month drinking water study in mice reported increases in liver weight and hepatocellular carcinomas at doses from 178 mg/kg body weight per day.

No data are available on the genotoxicity of dichloroacetic acid. Trichloroacetic acid and chloroacetic acid are not mutagenic in tests using bacteria, but have shown some mutagenic activity in some mammalian cells.

DERIVATION OF GUIDELINES

The guideline values for the chloroacetic acids in drinking water were determined as follows:

i) Chloroacetic acid:

$$0.15\ \text{mg/L} = \frac{15\ \text{mg/kg body weight per day} \times 70\ \text{kg} \times 0.2}{2\ \text{L/day} \times 500} \times \frac{5}{7}$$

where:

- 15 mg/kg body weight per day is the lowest effect level based on a 2-year feeding study using rats (NTP 1992)
- 70 kg is the average weight of an adult
- 0.2 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 500 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 5 for use of the low effect level, which is close to the no effect level).
- 5/7 is used to convert data based on a 5-day week feeding study to a 7-day week equivalent.

The 1993 WHO Guidelines do not have a health-based guideline for chloroacetic acid.

ii) Dichloroacetic acid:

$$0.1 \text{ mg/L} = \frac{7.6 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.2}{2 \text{ L/day} \times 500}$$

where:

- 7.6 mg/kg body weight per day is the no effect level based on a 90-day drinking water study using mice (DeAngelo *et al* 1991)
- 500 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 5 for limited evidence of carcinogenicity)
- other factors are as above.

The 1993 WHO guideline value of 0.05 mg/L includes a factor of 10 for carcinogenicity. On review this was considered to be excessive and a lower factor was used.

iii) Trichloroacetic acid:

$$0.1 \text{ mg/L} = \frac{36 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.2}{2 \text{ L/day} \times 2000}$$

where:

- 36 mg/kg body weight per day is the no effect level based on a 90-day drinking water study using male rats (Mather *et al* 1990)
- 2000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations, 10 for evidence of carcinogenicity in animals and 2 because a less than lifetime study was used but chronic studies are available)
- other factors are as above.

REFERENCES

DeAngelo AB, Daniel FB, Stober JA and Olsen GR (1991). The carcinogenicity of dichloroacetic acid in the male B6C3F mouse. *Fundamental and Applied Toxicology,* 16, 337–347.

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USEPA Draft Method 552 (1990). Determination of haloacetic acids in drinking water by liquid-liquid extraction, derivatization, and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

NOTE: Important general information is contained in PART II, Chapter 6

Chlorobenzene

GUIDELINE

Based on aesthetic considerations (taste), the concentration of chlorobenzene in drinking water should not exceed 0.01 mg/L.

Chlorobenzene would not be a health concern unless the concentration exceeded 0.3 mg/L.

GENERAL DESCRIPTION

Chlorobenzene is used as a solvent and may be present in drinking water through contamination of water sources by spills or discharges. It has occasionally been detected in drinking water supplies in Canada and the United States at concentrations up to 0.005 mg/L. Inhalation from the atmosphere is believed to be the major route of environmental exposure.

Chlorobenzene has a low taste and odour threshold in water of about 0.01 mg/L.

It is used primarily as a solvent for pesticide formulations, in di-isocyanate manufacture, as a degreasing agent for mechanical parts, and in the production of nitrochlorobenzene. It is also used in the production of other halogenated organic compounds.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Chlorobenzene has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Aeration or adsorption onto granular activated carbon will remove chlorobenzene from water.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for analysis (USEPA Draft Method 502.1 1986). An inert gas is bubbled through the sample and chlorobenzene trapped on an adsorbent. The adsorbent is then heated and chlorobenzene analysed using gas chromatography with electron capture detection. The limit of determination is 0.0002 mg/L.

HEALTH CONSIDERATIONS

In humans, chlorobenzene is absorbed after ingestion or inhalation, and distributed primarily to adipose tissue and to the liver and kidney. It is metabolised into 4-chlorocatechol, which is excreted in urine.

An extensive review and summary of the human and animal toxicity data for chlorobenzenes is available (IPCS 1991).

There are few data on the effects of chlorobenzene on humans, and those that are available are of poor quality. They consist mainly of cases of poisoning and occupational exposure, with the principal effect being disturbances to the central nervous system.

NOTE: Important general information is contained in PART II, Chapter 6

Studies over 2 years using rats and mice reported adverse effects to the liver, kidneys, and blood-cell formation at high doses (250 mg/kg body weight per day). There is evidence of an increase of liver tumours in male rats fed doses of 120 mg/kg body weight per day of monchlorobenzene for 2 years. No increases were observed in female rats, or in male and female mice. Chlorobenzene was not mutagenic in tests with bacteria, but may bind to RNA and DNA.

DERIVATION OF GUIDELINE

The health-based guideline value for chlorobenzene in drinking water was determined as follows:

$$0.3 \text{ mg/L} = \frac{60 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 500} \times \frac{5}{7}$$

where:

- 60 mg/kg body weight per day is the no effect level from a 2-year gavage study using rats (NTP 1985)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 500 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 5 for limited evidence of carcinogenicity)
- 5/7 is used to convert data based on a 5 day per week feeding study to a 7-day week equivalent.

This health-based guideline value is greater than the taste and odour threshold of 0.01 mg/L.

REFERENCES

IPCS (1991). Chlorobenzenes other than hexachlorobenzene. Environmental Health Criteria, 128. World Health Organization, International Programme on Chemical Safety.

NTP (1985). Toxicology and carcinogenesis studies of chlorobenzene in F344/N rats and B6C3F1 mice (gavage studies). National Toxicology Program, NTR Report No. 261, Publication No. 86-2517. United States Department of Health and Human Services, National Institutes of Health.

USEPA Draft Method 502.1 (1986). Volatile halogenated organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (ESML), Cincinnati, Ohio.

Chloroketones

1,1-dichloropropanone (dichloroacetone)
1,3-dichloropropanone
1,1,1-trichloropropanone (trichloroacetone)
1,1,3-trichloropropanone

GUIDELINE

Data are inadequate to set guideline values for chloroketones in drinking water.

GENERAL DESCRIPTION

The chloroketones are produced in drinking water as byproducts of the reaction between naturally occurring organic matter and chlorine. No data are available on other sources or uses for these compounds.

Concentrations of chloroketones in drinking water reported overseas are very low and are estimated at less than 0.01 mg/L.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies 1,1,1-trichloropropanone has been recorded in concentrations up to 0.02 mg/L, but it is usually below the limit of determination of 0.0005 mg/L. No data are available for other chloroketones.

LIMITING FORMATION IN DRINKING WATER

The presence of chloroketones in drinking water can be minimised by removing naturally occurring organic matter from the source water, by reducing the amount of chlorine added, or by the use of alternative disinfectants.

MEASUREMENT

A solvent extraction procedure is suitable for the analysis of chloroketones (USEPA Draft Method 551 1990). Sodium chloride is added to the sample and the chloroketones extracted using methyl tert-butyl ether. The extracts are then analysed using gas chromatography with an electron capture detector. Limits of determination are less than 0.0005 mg/L.

HEALTH CONSIDERATIONS

No data are available on absorption from the gastrointestinal tract, metabolism or health effects in humans.

Acute oral toxicity studies in mice using 1,1-dichloropropanone and 1,3-dichloropropanone have found no toxic effects with single doses of 130 mg/kg and 20 mg/kg respectively. No long-term toxicity studies have been reported.

NOTE: Important general information is contained in PART II, Chapter 6

Both 1,1-dichloropropanone and 1,3-dichloropropanone were direct-acting mutagens in tests with bacteria. There was some evidence that 1,3-dichloropranone initiated skin tumours in mice when applied at 50 mg/kg body weight per day for two weeks. There was no evidence that either 1,1-dichloropropanone or 1,1,1-trichloropropanone acted in this way.

The NHMRC Standing Committee on Toxicity reviewed the available data for chloroketones in 1991. It was concluded that data were insufficient to set no effect levels for these compounds.

REFERENCE

USEPA Draft Method 551, (1990). Determination of chlorination disinfection byproducts and chlorinated solvents in drinking water by liquid-liquid extraction and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Chlorophenols

2-chlorophenol
2,4-dichlorophenol
2,4,6-trichlorophenol

GUIDELINE

Based on aesthetic considerations, the concentration of chlorophenols in drinking water should not exceed the following values.

Chlorophenols would not be a health concern unless concentrations exceeded the health values listed.

	Health value	*Aesthetic value (odour and taste)*
2-chlorophenol	***0.3 mg/L***	***0.0001 mg/L***
2,4-dichlorophenol	***0.2 mg/L***	***0.0003 mg/L***
2,4,6-trichlorophenol	***0.02 mg/L***	***0.002 mg/L***

GENERAL DESCRIPTION

Chlorophenols may be present in drinking water as a result of chlorination of water that contains phenol or lower chlorophenols, or from contamination of water sources. Chlorination of water containing natural organic compounds can produce very low concentrations of chlorophenols. Degradation of phenoxy herbicides such as 2,4,5-T and 2,4-D also generates chlorophenols. The limited data available from overseas studies indicate that concentrations in drinking water are very low.

Chlorophenols have taste and odour thresholds in the range 0.0001 mg/L to 0.002 mg/L, with a characteristic antiseptic smell.

Chlorophenols are used commercially as preservatives, moth-proofing agents, germicides and anti-mildew agents. Exposure to chlorophenols via tap water has been estimated to be less than 10% of total dietary exposure.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

No data are available on concentrations of chlorophenols in Australian drinking waters. If present at all, it is likely that concentrations would be extremely low.

TREATMENT OF DRINKING WATER

In pilot studies, granular activated carbon has successfully removed over 90% of 2-chlorophenol from water. It would probably be similarly effective in removing the other chlorophenols.

MEASUREMENT

Sensitive and isomer-specific procedures for the analysis of chlorophenols are available (USEPA Method 604 1986). The chlorophenols are derivatised with pentafluorobenzyl ether, and analysed using gas chromatography with electron capture detection. Limits of determination are 0.01 mg/L for monochlorophenol, 0.0005 mg/L for dichlorophenol and 0.00001 mg/L (10 ng/L) for trichlorophenol.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Chlorophenols are known to be efficiently absorbed and metabolised when administered orally to laboratory animals. Highest concentrations occur in the liver, brain and fat.

An extensive review and summary of the human and animal toxicity data for chlorophenols is available (IPCS 1989).

People occupationally exposed to chlorophenols often complain of irritation to the skin, mucous membranes and respiratory tract as a result of direct airborne contact. In addition, chronic ailments, skin lesions and ulcerations (particularly chloracne), and clinical indications of liver damage and neurological effects have also been reported, particularly in association with high exposures.

There have been a number of studies on the toxic effects of chlorophenols in rats and mice. Short-term exposure to high doses results in an increased respiration rate, motor weakness, tremors, convulsion, coma and death. Long-term studies over 2 years could not determine any specific dose-related effects using either 2-chlorophenol or 2,4-dichlorophenol, but 2,4,6-trichlorophenol induced leukaemia and lymphomas in male rats, and liver cancer in male and female mice.

No information is available on the mutagenic effects of 2-chlorophenol. Mutagenic tests on bacteria were negative for 2,4-dichlorophenol. Separate tests gave weakly positive and negative results for 2,4,6-trichlorophenol.

The International Agency for Research on Cancer has concluded that 2,4,6-trichlorophenol is possibly carcinogenic to humans (group 2B, sufficient evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The guideline values for the chlorophenols in drinking water, based on health considerations, were determined as follows:

i) 2-chlorophenol:

$$0.3 \text{ mg/L} = \frac{7.5 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 100}$$

where:

- 7.5 mg/kg body weight per day is the no effect level based on a 2-year drinking water study using rats (Exon and Koller 1985)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 100 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations and 10 for intraspecies variations). The use of this safety factor was recommended by the NHMRC Standing Committee on Toxicity.

The 1993 WHO Guidelines do not have a health-based guideline for 2-chlorophenol.

ii) 2,4-dichlorophenol:

$$0.2 \text{ mg/L} = \frac{4.5 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 100}$$

where:

- 4.5 mg/kg body weight per day is the no effect level based on a 2-year drinking water study using rats (Exon and Koller 1985). The use of this value was recommended by the NHMRC Standing Committee on Toxicity following a review of the available toxicity data for the chlorophenols
- other factors are as above.

The 1993 WHO Guidelines do not have a health-based guideline for 2,4-dichlorophenol.

iii) 2,4,6-trichlorophenol:

$$0.02 \text{ mg/L} = \frac{4.5 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 4.5 mg/kg body weight per day is the no effect level based on a 2-year drinking water study using rats (Exon and Koller 1985). The use of this value was recommended by the NHMRC Standing Committee on Toxicity following a review of the available toxicity data for the chlorophenols
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for carcinogenic effects)
- other factors are as above.

The WHO guideline value of 0.2 mg/L for 2,4,6-trichlorophenol was based on a calculation that estimated an additional lifetime risk of one fatal cancer per hundred thousand people.

As the guideline values based on health considerations are greater than the taste thresholds for these compounds, the taste thresholds should be used as the guideline values.

REFERENCES

Exon JH and Koller LD (1985). Toxicity of 2-chlorophenol, 2,4-dichlorophenol and 2,4,6-trichlorophenol. Water Chlorination: Chemistry, Environmental Impact and Health Effects. Proceedings of the 5th Conference on Water Chlorination: Environmental Impact and Health Effects, Williamsburg, Virginia, June 3-8, 1984. Jolly RL *et al* (editors), Chelsea, Michigan, Lewis Publisher Inc., 5, 307-330.

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1989). Chlorophenols other than Pentachlorophenol. Environmental Health Criteria, 93. World Health Organization, International Programme on Chemical Safety.

USEPA Method 604 (1986). Phenols. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

NOTE: Important general information is contained in PART II, Chapter 6

Chloropicrin

GUIDELINE

Data are inadequate to set a guideline value for chloropicrin in drinking water.

GENERAL DESCRIPTION

Chloropicrin is formed in water by the reaction of chlorine with humic acids, amino acids and nitrophenols. The presence of nitrate will assist in the formation of chloropicrin but reducing agents will convert it to chloroform (see Fact Sheet on Trihalomethanes). Chloropicrin has been detected in drinking water supplies overseas at concentrations of less than 0.005 mg/L.

Chloropicrin is used commercially in the manufacture of organic compounds including methyl violet. It may be used as a grain fumigant and soil sterilant.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

No data are available on the concentrations of chloropicrin in Australian drinking waters.

LIMITING FORMATION IN DRINKING WATER

The presence of chloropicrin in drinking water can be minimised by removing naturally occurring organic matter from the source water, by reducing the amount of chlorine added, or by using alternative disinfectants.

MEASUREMENT

A solvent extraction procedure is suitable for the analysis of chloropicrin (USEPA Draft Method 551 1990). Sodium chloride is added to the sample, and the chloropicrin extracted using methyl tert-butyl ether. The extract is then analysed using gas chromatography with an electron capture detector. The limit of determination is approximately 0.00002 mg/L (20 ng/L).

HEALTH CONSIDERATIONS

Chloropicrin is known to be highly irritant to skin and eyes. No long-term data are available on health effects in humans.

A study using rats and mice identified a short-term lethal dose of 23 mg/kg body weight per day for female rats; however, the high mortality rate in the study prevented the establishment of a no effect level.

Chloropicrin exhibited mutagenic activity in some tests with bacteria, and with human lymphocytes *in vitro*.

The NHMRC Standing Committee on Toxicity reviewed the available toxicity data for chloropicrin in 1991. Data were considered to be insufficient to set a no effect level.

NOTE: Important general information is contained in PART II, Chapter 6

REFERENCE

USEPA Draft Method 551, (1990). Determination of chlorination disinfection byproducts and chlorinated solvents in drinking water by liquid-liquid extraction and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Chromium

GUIDELINE

Based on health considerations, the concentration of hexavalent chromium (Cr(VI)) in drinking water should not exceed 0.05 mg/L. If the concentration of total chromium exceeds this value then a separate analysis for hexavalent chromium should be undertaken.

GENERAL DESCRIPTION

Chromium is present in the environment in the trivalent (Cr(III)) and hexavalent (Cr(VI)) states.

Trivalent chromium is the most common naturally occurring state. Most soils and rocks contain small amounts of chromium oxide, and weathering, oxidation and bacterial action convert this insoluble compound into soluble Cr(III) salts.

Trivalent chromium salts are used in leather tanning, manufacture of catalysts, paint pigments, fungicides, and ceramic and glass manufacture.

Trivalent chromium is an essential trace element for humans, with food being the major source of intake.

Hexavalent chromium occurs infrequently in nature. Its presence in water is generally the result of industrial and domestic chromium waste discharges. Hexavalent chromium compounds are used in the metallurgical industry for chrome alloy and chrome metal production, and in the chemical industry as oxidising agents.

Hexavalent chromium is not considered to be an essential nutrient and harmful effects due to chromium have been attributed to this form.

Total chromium concentrations in drinking water are usually less than 0.005 mg/L although concentrations between 0.06 mg/L to 0.12 mg/L have been reported overseas.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies concentrations of total chromium range up to 0.03 mg/L, with typical concentrations usually less than 0.005 mg/L.

TREATMENT OF DRINKING WATER

Chromium can be removed from drinking water sources by coagulation/filtration, ion exchange, reverse osmosis and lime softening. Trivalent chromium can be oxidised to hexavalent chromium with disinfectants, particularly chlorine, chlorine dioxide and ozone.

MEASUREMENT

The total chromium concentration in drinking water can be determined by inductively coupled plasma emission spectroscopy or graphite furnace atomic absorption spectroscopy (APHA Method 3500-Cr Parts B or C 1992). The limit of determination is approximately 0.01 mg/L.

Hexavalent chromium (Cr(VI)) can be determined with a colorimetric method using diphenylcarbizide (APHA Method 3500-Cr part D 1992). The limit of determination is 0.005 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

The absorption of chromium after ingestion is low and depends on the valence state. Hexavalent chromium is more readily absorbed from the gastrointestinal tract than trivalent compounds. It is able to penetrate cell membranes, and within cells it is reduced to Cr(III) and forms complexes with proteins and genetic material.

An extensive review and summary of the human and animal toxicity data for chromium is available (IPCS 1988).

Epidemiological studies have found an association between inhalation of hexavalent chromium compounds and lung cancer, especially in humans occupationally exposed during chromate production. There is no evidence that organs other than the lung are affected or that ingestion of hexavalent chromium compounds can cause cancer.

There are sufficient animal data to indicate that many hexavalent chromium compounds are carcinogenic. Hexavalent chromium compounds also cause mutations and chromosome aberrations in a variety of test systems. The mutagenic activity can be decreased or abolished by reducing agents, such as gastric juice.

In animal studies, orally administered trivalent chromium compounds have not been shown to induce cancer or to induce mutations in genetic material.

The International Agency for Research on Cancer has concluded that hexavalent chromium is carcinogenic to humans (Group 1, sufficient evidence of carcinogenicity in humans); and that trivalent chromium is not classifiable as to its carcinogenicity to humans (Group 3, inadequate evidence in humans and inadequate evidence in animals) (IARC 1990).

DERIVATION OF GUIDELINE

The guideline value for chromium in drinking water is based on a WHO assessment and should be reviewed when more toxicological data become available. It was adopted after consideration of the following points:

- The guideline value of 0.05 mg/L has been used in many countries for a number of years with no known cases of chromium toxicity.
- The value was originally set following a conservative assessment of studies on the toxicity of hexavalent chromium to rats (Mackenzie *et al* 1958).
- Trivalent chromium is essential for human health and has no known toxic effects.
- Data are insufficient to determine whether a higher value would be equally safe.

Analysis for the separate valence states of chromium is time consuming and hence the guideline value applies to total chromium. If concentrations of total chromium exceed the guideline value, it is recommended that separate analyses for Cr(VI) and Cr(III) be undertaken.

REFERENCES

APHA Method 3500-Cr Part B (1992). Chromium: Atomic Absorption method for total chromium. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Cr Part C (1992). Chromium: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Cr Part D (1992). Chromium: Colorimetric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (International Agency for Research on Cancer) (1990). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: chromium, nickel and welding. World Health Organization, International Agency for Research on Cancer, 49.

IPCS (International Programme on Chemical Safety) (1988). Chromium. Environmental Health Criteria, 61. World Health Organization, International Programme on Chemical Safety.

MacKenzie RD, Byerrum RU, Decker CF, Hoppert CA and Langham RF (1958). Chronic toxicity studies: II. Hexavalent and trivalent chromium administered in drinking water to rats. *American Medical Association Archives of Industrial Health,* 18, 232–234.

NOTE: Important general information is contained in PART II, Chapter 6

Colour (True)

GUIDELINE

Based on aesthetic considerations, true colour in drinking water should not exceed 15 HU.

GENERAL DESCRIPTION

Two terms are used to describe colour. 'True colour' is the colour after particulate matter has been removed (usually by filtration through a 0.45 micrometer pore size filter). 'Apparent colour' is what one actually sees; it is the colour resulting from the combined effect of true colour and any particulate matter, or turbidity. In turbid waters, the true colour is substantially less than the apparent colour.

In natural waters, colour is due mainly to the presence of dissolved organic matter including humic and fulvic acids, which originate from soil and decaying vegetable matter. Surface water can also be coloured by waste discharges, for example from dyeing operations in the textile industry, and paper manufacture.

The dissolution of metals in pipes and fittings can also discolour drinking water. Badly corroded iron pipes can produce a brownish colour whereas corrosion of copper pipes can produce a blue-green colouration on sanitary ware and a faint blue colour in water in extreme cases. The condition of household pipes can significantly influence water colour.

In bore water, 'red water' is a frequent problem, caused by the oxidation of iron. In addition, a black discolouration in reservoirs and distribution systems can result from the action of bacteria on dissolved manganese to produce insoluble oxides. Some of these compounds form fine suspensions, or are only partially dissolved, and so contribute to apparent rather than true colour.
(See Section 5.6)

As a guide, tea has a colour of about 2500 HU (Hazen units, see below). A true colour of 15 HU can be detected in a glass of water, and a true colour of 5 HU can be seen in larger volumes of water, for instance in a white bath. Few people can detect a true colour level of 3 HU, and a true colour of up to 25 HU would probably be accepted by most people provided the turbidity was low. Some examples of drinking water with differing turbidity and colour are shown in Plate 1.

True colour is preferred analytically, as the measurement is more precise than for apparent colour, and not as dependent on site or time. If both true colour and turbidity are at the guideline values (i.e. true colour of 15 HU and turbidity of 5 NTU), the apparent colour could be 20 HU. This is considered to be acceptable.

Variations in colour are likely to lead to more complaints than a high but consistent colour.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies true colour ranges from 1 HU to 25 HU for filtered or fully treated supplies, and from 1 HU to 85 HU for unfiltered supplies.

MEASUREMENT

Colour can be measured spectrophotometrically or using a visual comparator. In both cases, the standard unit of measurement is the hazen unit (HU). (True colour is often quoted as True Colour Units, or TCU; however, the numerical values are identical.) Hazen units are defined in terms of a platinum-cobalt standard (APHA Method 2120B 1992). This standard was developed for the analysis of colour in natural waters with a yellow-brown appearance, and is not applicable to waters with different colours.

NOTE: Important general information is contained in PART II, Chapter 6

It is advisable to record the pH with the colour measurement, as the colour of natural surface waters increases with pH.

Colour values obtained using a spectrophotometer are dependent on the wavelength used for the measurement. There is no standard wavelength used in Australia, but values ranging from 395 nm to 465 nm are generally used. In the absence of a suitable Australian Standard, the British Standard, which uses 436 nm (BSI Method BS6068 1986), is suitable. An Australian Standard should be developed as a priority.

TREATMENT OF DRINKING WATER

Constituents of natural colour derived from humic and fulvic acids can be reduced by coagulation followed by filtration (AWWA 1990). Oxidation by chlorine or ozone will also reduce colour but may produce undesirable byproducts.

HEALTH CONSIDERATIONS

Colour is generally related to organic content, and while colour derived from natural sources such as humic and fulvic acids is not a health consideration, chlorination of such water can produce a variety of chlorinated organic compounds as byproducts (see Section 6.3.2). If the colour is high at the time of disinfection, then the water should be checked for disinfection byproducts.
It should be noted, however, that low colour at the time of disinfection does not necessarily mean that the concentration of disinfection byproducts will be low.

Reactions between naturally occurring humic and fulvic material and water disinfectants (such as chlorine, ozone, chloramines and chlorine dioxide) can also cause difficulties in maintaining an adequate level of disinfectant, thus creating the opportunity for bacterial reinfection or regrowth.

The solubility of some organic pollutants can also be increased through complex formation with humic material.

Coloured water may prompt people to seek other, perhaps less safe, sources of drinking water.

DERIVATION OF GUIDELINE

The guideline value is based on the colour that is just noticeable in a glass of water. This is generally accepted as being 15 HU.

GUIDELINES IN OTHER COUNTRIES

The Canadian Guidelines and the 1984 WHO Guidelines both recommend a value of 15 HU. The 1993 WHO Guidelines indicate that a colour above 15 TCU may give rise to consumer complaints.

The United States EPA Secondary Drinking water Regulations have a maximum concentration for colour of 15 HU.

The European Economic Community Standards for colour are a maximum admissible value of 20 HU and a guideline value of 1 HU.

REFERENCES

APHA Method 2120B (1992). Colour: Visual comparison method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

AWWA (1990). Water Quality and Treatment: A handbook of community water supplies. American Water Works Association, 4th edition, McGraw-Hill Inc.

BSI Method BS6068 (1986). Examination and determination of colour. British Standards Institution, British Standard for Water Quality, Section 2.22.

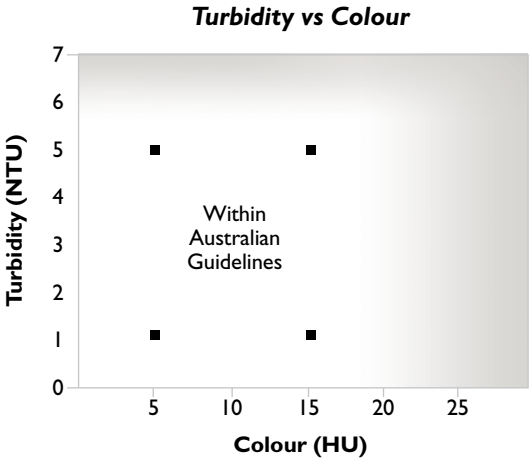
COLOUR AND TURBIDITY

1. Colour = 5 HU
   Turbidity = 1 NTU

2. Colour = 5 HU
   Turbidity = 5 NTU

3. Colour = 15 HU
   Turbidity = 5 NTU

4. Colour = 15 HU
   Turbidity = 1 NTU



NOTE: Important general information is contained in PART II, Chapter 6

Copper

(Revised and endorsed 2001)

GUIDELINE

Based on health considerations, the concentration of copper in drinking water should not exceed 2 mg/L.

Based on aesthetic considerations, the concentration of copper in drinking water should not exceed 1 mg/L.

GENERAL DESCRIPTION

Copper is widely distributed in rocks and soils as carbonate and sulfide minerals.

Copper is relatively resistant to corrosion and is used in domestic water supply pipes and fittings. It is also used in the electroplating and chemical industries, and in many household goods. Copper sulfate is used extensively to control the growth of algae in water storages.

Copper is present in uncontaminated surface waters at very low concentrations, usually less than 0.01 mg/L. The concentration can rise substantially when water with a low pH and hardness remains in stagnant contact with copper pipes and fittings. Under these conditions, the concentration of copper can reach 5 mg/L or higher. In one extreme case overseas, a concentration of 22 mg/L was reported.

The taste threshold for copper is in the range 1-5 mg/L, depending on the water purity. Concentrations above 1 mg/L may cause blue or green stains on sanitary ware. Such stains may also be due to slowly leaking taps, where copper corrosion occurs over a long time, and are not necessarily due to high concentrations of copper in drinking water.

Food is the main source of copper intake. Intake from water would normally be less than 10% of total intake.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, total copper concentrations range up to 0.8 mg/L, with typical concentrations of about 0.05 mg/L.

TREATMENT OF DRINKING WATER

Copper can be removed from drinking water by increasing the pH, and then using the water treatment processes of coagulation followed by filtration. Aggressive water, which is likely to induce corrosion of copper pipes, should be stabilised with respect to pH and hardness as part of the treatment process prior to distribution in order to minimise copper leaching.

MEASUREMENT

The copper concentration can be determined by inductively coupled plasma emission spectroscopy (APHA Method 3500-Cu Part C 1992) with an estimated limit of determination of 0.01 mg/L. Alternatively, flame or graphite furnace atomic absorption spectroscopy can be used (APHA 3500-Cu Part B 1992) with limits of determination of 0.05 mg/L and 0.005 mg/L respectively.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Copper is an essential trace element for humans. It is estimated that adult requirements are about 2-3 mg per person per day. High doses of copper (above 50 mg/kg bodyweight) can be lethal.

The absorption of copper by the gastrointestinal tract is in the range of 25–60%, depending on a number of factors, including copper speciation and copper dietary status (Olivares *et al* 1998). Copper is stored in the liver, brain and muscle tissue. High concentrations can also be found in the kidneys, heart and hair. Copper is eliminated from the body mainly in the bile.

Many cases of copper poisoning have been reported, including cases involving the poisoning of children who had their food prepared in copper or brass pots (Tanner 1998). Copper poisoning has resulted in cirrhosis of the liver and, in extreme cases, death. Other less severe symptoms associated with the consumption of water containing 3-5 mg/L copper (but not 1 mg/L) are gastrointestinal symptoms such as nausea, abdominal pain and vomiting (Pizarro *et al* 1999). Infants are thought to be most susceptible, though in one study of 3-month-old infants given water containing 2 mg/L copper over 9 months there were no acute or chronic adverse consequences (Olivares *et al* 1998). In the genetic disorders Wilson's disease and idiopathic copper toxicosis, sufferers are particularly susceptible to copper (Lönnerdal and Uauy 1998).

Apart from humans, sheep are the most susceptible animals to the toxic effects of copper, with a daily intake of 1-2 mg/kg body weight resulting in serious illness and death.

Copper was not found to be carcinogenic in tests with mice and dogs. The results of mutagenicity tests with different strains of bacteria were generally negative. Tests for mutagenicity using mammalian cells, both in vitro and *in vivo*, gave predominantly positive results.

DERIVATION OF GUIDELINE

The health-based guideline value of 2 mg/L (rounded up) for copper in drinking water was derived as follows:

$$2\ \text{mg/L} = \frac{0.5\ \text{mg/kg bodyweight per day} \times 70\ \text{kg} \times 0.1}{2\ \text{L/day}}$$

where:

- 0.5 mg/kg body weight per day is the provisional maximum tolerable daily intake for humans (WHO 1982)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult.

It should be emphasised that in this derivation, which others have also used and which is still endorsed by the WHO (1998), there is considerable uncertainty (Fitzgerald 1998). Nevertheless, on the basis of recent copper investigation studies, the derived guideline value appears to be a safe level for infants and is just below a level where minor symptoms were observed in adults.

In premises with a history of copper corrosion, water that has been in stagnant contact (6 hours or more) with copper pipes and fittings should not be used in the preparation of food or drink. Copper levels can be effectively reduced by flushing the taps for 1 minute.

REFERENCES

APHA Method 3500-Cu Part B (1992). Copper: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Cu Part C (1992). Copper: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

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Tanner MS (1998). Role of copper in Indian childhood cirrhosis. *American Journal of Clinical Nutrition,* 67(suppl), 1074–1081S.

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WHO (World Health Organization) (1998). Guidelines for drinking-water quality, 2nd edition; Addendum to Volume 1, Recommendations.World Health Organization, Geneva, Switzerland.

NOTE: Important general information is contained in PART II, Chapter 6

Cyanide

GUIDELINE

Based on health considerations, the concentration of cyanide in drinking water should not exceed 0.08 mg/L.

GENERAL DESCRIPTION

Cyanide can be present in drinking water through the contamination of source water, or through the natural decomposition of some plants that synthesise cyanoglycosides. Some microorganisms, such as the cyanobacterium *Anacystis nidulans* and the bacterium *Chromobacterium violaceum,* produce free cyanide. In uncontaminated water sources, free cyanide concentrations are usually less than 0.01 mg/L.

Sodium cyanide is used in the extraction of gold and silver from low-grade ores. It is also used in the electroplating, steel and chemical industries.

Some foods can contain quite high concentrations of cyanide. Green almonds and improperly treated cassava are of particular concern.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies cyanide concentrations range up to 0.05 mg/L, with typical concentrations usually less than 0.02 mg/L.

TREATMENT OF DRINKING WATER

There are no published reports on methods for the removal of cyanide from drinking water. Chlorine gas or hypochlorite will react with cyanide to form cyanate. Ozone is also an effective oxidant.

MEASUREMENT

The cyanide concentration in drinking water can be determined with a colorimetric method using chloramine-T (APHA Method 4500-CN Part E 1992). The limit of determination is 0.02 mg/L.

HEALTH CONSIDERATIONS

Cyanide is highly toxic. It is rapidly absorbed by the gastrointestinal tract and metabolised to thiocyanate.

In humans, long-term consumption of improperly prepared cassava in the tropics has been linked with effects on the thyroid gland and particularly the nervous system. Cyanide may deplete vitamin B12 and result in a deficiency that can cause goitre and cretinism. People most at risk are those with a nutritionally inadequate diet.

Animal studies indicate that pigs may be more sensitive than rats to the effects of long-term exposure to cyanide. In a six-month study using pigs, exposure to cyanide was reported to increase ambivalence (sic) and result in slower response times to stimuli. Behaviour demanding high energy appeared to be more readily affected by cyanide exposure than low-energy behaviour.

No data are available on the carcinogenic properties of cyanide. Tests for mutagenicity with different strains of bacteria have been mostly negative.

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The guideline value for cyanide in drinking water was derived as follows:

$$0.08 \text{ mg/L} = \frac{1.2 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.2}{2 \text{ L/day} \times 100}$$

where:

- 1.2 mg/kg body weight per day is the no effect level from 6-month feeding studies using pigs Jackson *et al* 1986, (Jackson 1988)
- 70 kg is the average weight of an adult
- 0.2 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 100 is the safety factor in applying the results of animal studies to humans (10 for interspecies variations and 10 for intraspecies variations).

The WHO guideline of 0.07 mg/L was based on an adult weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

APHA Method 4500-CN Part E (1992). Cyanide: Colorimetric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

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Jackson LC (1988). Behavioural effects of chronic sub-lethal dietary cyanide in an animal model: Implications for humans consuming cassava (Manihot esculenta). *Human Biology*, 60, 597–614.

Cyanogen chloride

GUIDELINE

Based on health considerations, the concentration of total cyanogenic compounds in drinking water should not exceed 0.08 mg/L.

GENERAL DESCRIPTION

Cyanogen chloride is a byproduct of chloramination. It can be formed as a byproduct of the reaction between organic precursors with hypochlorous acid in the presence of the ammonium ion. Concentrations reported overseas in chloraminated supplies are typically 0.004 mg/L.

Cyanogen chloride may be used commercially in chemical synthesis, and for fumigation.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

No data are available on concentrations of cyanogen chloride in Australian drinking waters.

LIMITING FORMATION IN DRINKING WATER

The presence of cyanogen chloride in drinking water can be minimised by removing naturally occurring organic matter from the source water, by reducing the amount of chloramine added, or by the use of alternative disinfectants.

MEASUREMENT

A suitable method for analysis involves extraction from water using the purge and trap technique followed by gas chromatography/mass spectrometry (USEPA Draft Method 524.2 1986). The limit of determination is 0.0003 mg/L.

HEALTH CONSIDERATIONS

Cyanogen chloride is highly irritant and very poisonous, as it is rapidly metabolised to cyanide in the body and has similar toxicity.

Effects of ingested cyanogen chloride in humans have not been reported. A concentration of 1 ppm in air causes irritation on inhalation.

Only acute toxicity data are available on the health effects of cyanogen chloride in animals.

No data are available on the carcinogenicity or mutagenicity of cyanogen chloride.

The NHMRC Standing Committee on Toxicity reviewed available toxicity data for cyanogen chloride in 1991. It was considered that data were insufficient to set a no effect level.

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

As cyanogen chloride is rapidly converted to cyanide by the body, the guideline value is based on the cyanide value of 0.08 mg/L (see also Fact Sheet on *Cyanide*).

REFERENCE

USEPA Draft Method 524.2 (1986). Volatile organic compounds in water by purge and trap capillary column gas chromatography/mass spectrometry. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

2,4-D (2,4-dichlorophenoxyacetic acid)

GUIDELINE

2,4-D should not be detected in drinking water. If present in drinking water, 2,4-D would not be a health concern unless the concentration exceeded 0.03 mg/L.

If it is detected, remedial action should be taken to stop contamination. The limit of determination is 0.0001 mg/L.

GENERAL DESCRIPTION

2,4-D is a systemic herbicide used for the control of broadleaf and aquatic weeds.

2,4-D is removed from the environment principally by biodegradation to 2,4-dichlorophenol, and has a half-life in soil of about 4-7 days. It is rapidly biodegraded in water and does not accumulate in bottom sediments or aquatic organisms.

2,4-D has been detected in a number of drinking water supplies in a variety of countries. The maximum concentration reported was 0.03 mg/L, with a mean of 0.0003 mg/L.

No data are available on Australian dietary intake of 2,4-D; however, in 1987 the adult average dietary intake in the United States was reported to be about 0.000007 mg/day (7 ng/day).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

2,4-D has not been detected in major Australian drinking water supplies.

TREATMENT OF DRINKING WATER

Powdered activated carbon has been found to be effective in decreasing the concentration of the sodium salt and ester formulations of 2,4-D.

MEASUREMENT

Residues of 2,4-D in water can be measured by extraction, chemical derivatisation and analysis using gas chromatography with electron capture detection (APHA Method 6640 Part B 1992). The limit of determination is 0.0001 mg/L.

HEALTH CONSIDERATIONS

2,4-D administered orally as the free acid or the salt is absorbed rapidly and almost completely in humans and excreted in urine. Absorption of the esters is slower. In rats, 2,4-D is distributed widely throughout the body.

An extensive review and summary of the human and animal toxicity data for 2,4-D is available (IPCS 1984).

A range of case-control epidemiological studies have dealt with exposure to 2,4-D and other herbicides. Some have reported an association between herbicides, including 2,4-D, and non-Hodgkins lymphoma.

NOTE: Important general information is contained in PART II, Chapter 6

In a 2-year feeding study using rats, kidney and thyroid weights were increased and some changes observed in kidney function at doses of about 45 mg/kg body weight per day. Some kidney changes were also observed at doses of 5mg/kg body weight per day in a 2-year study using mice.

2,4-D did not exhibit any carcinogenic effects in three long-term studies in rats or mice; however, these studies were considered inadequate for evaluation of carcinogenicity.

2,4-D has been tested for mutagenicity in a variety of systems including mammalian cells. Results have mostly been negative.

The International Agency for Research on Cancer has concluded that 2,4-D is possibly carcinogenic to humans (Group 2B, limited evidence in humans, inadequate evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The health-based guideline value of 0.03 mg/L for 2,4-D was determined as follows:

$$0.03 \text{ mg/L} = \frac{0.01 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day}}$$

where:

- 0.01 mg/kg body weight per day is the ADI determined by the NHMRC Pesticide and Agricultural Chemicals Standing Committee
- 70 kg is the average weight of an adult
- 0.1 gives a guideline value based on 10% of the ADI
- 2 L/day is the average amount of water consumed by an adult.

The ADI includes a safety factor of 100 (10 for interspecies variations 10 for intraspecies variations). No additional safety factor is necessary.

REFERENCES

APHA Method 6640 Part B (1992). Chlorinated phenoxy acid herbicides: Liquid-liquid extraction, gas chromatographic method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1984). 2,4-Dichlorophenoxyacetic acid (2,4-D). Environmental Health Criteria, 29. World Health Organization, International Programme on Chemical Safety.

DDT (1,1,1-trichloro-di-(4-chlorophenyl) ethane) and its derivatives

GUIDELINE

DDT should not be detected in drinking water. If present in drinking water, DDT would not be a health concern unless the concentration exceeded 0.02 mg/L.

If it is detected, remedial action should be taken to stop contamination. The practical limit of determination is 0.00006 mg/L (60 ng/L).

GENERAL DESCRIPTION

DDT is a nonsystemic contact insecticide with a wide activity. It has been progressively banned in many countries since the early 1970s, because of ecological considerations. DDT is not registered for use in Australia. However, it may be detected occasionally because of its persistence in the environment and, possibly, because of illegal use.

DDT and its metabolites (including DDE) are resistant to degradation by microorganisms. DDT is readily adsorbed by soils and sediments, which can act as sinks and long-term sources of exposure. Most DDT present in water supplies is attached to soil or clay particles.

In a study of surface water supplies in the United States between 1964 and 1968, the highest concentration of DDT recorded was 0.0008 mg/L. In Germany, concentrations were even lower, averaging 0.00001 mg/L (10 ng/L).

Food is probably the major source of intake of DDT. In 1965, it was estimated that in the United States intake of DDT from food was approximately 0.04 mg/day compared with 0.00004 mg/day (40 ng/L) from water.

Since the early 1970s, there has been a progressive decline in dietary exposure to DDT in Australia. The 1990 Australian Market Basket Survey found that, if detected at all, DDT and metabolite residues had decreased in all foods tested compared with the 1987 survey (NHMRC and NFA 1991). A similar situation occurred for DDE contamination of human milk. This indicates that DDT and its metabolites are gradually disappearing from the Australian environment.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

DDT has not been found in major Australian reticulated supplies, but has occasionally been detected in streams flowing into water storages. The maximum value detected is 0.004 mg/L but, if detected at all, values are typically 0.0002 mg/L or less.

TREATMENT OF DRINKING WATER

As DDT is readily adsorbed onto soil or clay surfaces, coagulation with alum or ferric salts followed by filtration has been reported to achieve DDT removal of between 30% and 98%. Granular activated carbon is also effective.

MEASUREMENT

DDT and its metabolites can be extracted from water using nonpolar solvents (such as pentane, hexane or iso-octane) and analysed using gas chromatography with electron capture detection (APHA Method 6630 Part B 1992). The limit of determination for p,p'-DDT is approximately 0.00006 mg/L (60 ng/L).

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

The absorption of DDT from the gastrointestinal tract is facilitated by the presence of fat in food, and is virtually complete. The compound is stored preferentially in body fat, but uptake into fat is slow. In humans and most other animals, some DDT is converted to DDE, which is stored even more readily than DDT.

Extensive reviews and summaries of the human and animal toxicology of DDT are available (IPCS 1979, JMPR 1984, IARC 1991).

The principal public health concern regarding DDT arises from its ability to bioaccumulate. There is no evidence that DDT has any reproductive, teratogenic or carcinogenic effects in humans. An epidemiological study where workers were exposed to an average dose of 0.25 mg/kg body weight per day of DDT for 25 years reported no adverse effects.

Long-term oral studies have been carried out using rats, mice, hamsters, dogs, and monkeys. DDT produces an increase in liver tumours in some strains of mice at a dose of 0.3 mg/kg body weight per day and above, and in some strains of rats at 7.5 mg/kg per body weight and above.

In most studies DDT did not induce genotoxic effects in rodents or human cell systems; nor was it mutagenic to bacteria.

The International Agency for Research on Cancer has concluded that DDT is a possible human carcinogen (Group 2B, inadequate evidence in humans and sufficient evidence in animals) (IARC 1991).

DERIVATION OF GUIDELINE

The health-based guideline value of 0.02 mg/L for DDT was determined as follows:

$$0.02\ \text{mg/L} = \frac{0.02\ \text{mg/kg body weight per day} \times 13\ \text{kg} \times 0.1}{1\ \text{L/day}}$$

where:

- 0.02 mg/kg body weight per day is the maximum ADI based on no effect levels in humans, rats and monkeys (JMPR 1984)
- 13 kg is the weight of a young child (the child weight was used because DDT bioaccumulates and children may be exposed to a greater amount in relation to their body weight than adults
- 0.1 gives a guideline value based on 10% of the ADI
- 1 L/day is the amount of water consumed by a young child.

The ADI includes a safety factor of 500. No additional safety factors are necessary.

The guideline value exceeds the solubility of DDT in water, but is still appropriate because DDT may be adsorbed on particulate matter present in drinking water.

The WHO guideline value of 0.002 mg/L was based on a child weight of 10 kg, and used 1% of the ADI to allow for increased exposure from other sources. Such a low percentage of the ADI was considered inappropriate for Australia, where usage of DDT has declined markedly.

REFERENCES

APHA Method 6630 Part B (1992). Organochlorine pesticides: Liquid-liquid extraction, gas chromatographic method I. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1991). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Occupational Exposures in Insecticide Application, and Some Pesticides. World Health Organization, International Agency for Research on Cancer, 53.

IPCS (1979). DDT and its derivatives. Environmental Health Criteria, 9. World Health Organization, International Programme on Chemical Safety.

JMPR (1984). Pesticide Residues in Food. Report on the Joint Meeting on Pesticide Residues. Food and Agriculture Organization, Plant Production and Protection Paper 62, Rome.

NHMRC and NFA (1991). The 1990 Australian Market Basket Survey. National Health and Medical Research Council and National Food Authority, AGPS, Canberra.

NOTE: Important general information is contained in PART II, Chapter 6

Dichlorobenzenes

1,2-dichlorobenzene (1,2-DCB)
1,3-dichlorobenzene (1,3-DCB)
1,4-dichlorobenzene (1,4-DCB)

GUIDELINE

Based on aesthetic considerations, the concentrations of dichlorobenzenes in drinking water should not exceed the values shown below.

Dichlorobenzenes would not be a health concern unless concentrations exceeded the health values shown below:

	Health value	*Aesthetic value*
1,2-dichlorobenzene	***1.5 mg/L***	***0.001 mg/L***
1,3-dichlorobenzene	***inadequate data***	***0.02 mg/L***
1,4-dichlorobenzene	***0.04 mg/L***	***0.0003 mg/L (300 ng/L)***

GENERAL DESCRIPTION

Dichlorobenzenes are widespread in the environment and may be present in drinking water though spills and discharges, from atmospheric deposition, or by contact with contaminated soils. Studies in Japan, England, Canada and the United States have reported concentrations in the range 0.0000005 mg/L (0.5 ng/L) to 0.013 mg/L. Most supplies tested are below 0.00001 mg/L (10 ng/L), with 1,2-DCB and 1,4-DCB the most widely detected isomers. Sources of human exposure to DCBs are mainly food and air.

The dichlorobenzenes impart an offensive taste and odour to water, with thresholds between 0.0003 mg/L and 0.02 mg/L.

1,4-DCB is used in toilet blocks to deodorise air, and as a moth repellent, and is widely diffused in the environment. 1,3-DCB is a minor fumigant and insecticide and can be formed from incomplete combustion of waste. 1,2-DCB is used primarily as a chemical intermediate for dyestuffs and pesticides.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

DCBs have not been found in Australian drinking waters. They are included here to provide guidance in the unlikely event of contamination, and because they have been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

It is unlikely that DCB concentrations are reduced significantly during conventional water treatment processes. Removal using packed tower aeration or by the use of granular activated carbon is more than 90% effective and it is likely that concentrations below 0.001 mg/L can be achieved using these methods.

NOTE: Important general information is contained in PART II, Chapter 6

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for analysis (USEPA Draft Method 502.1 1986). An inert gas is bubbled through the sample and the dichlorobenzenes trapped on an adsorbent. The adsorbent is then heated and the dichlorobenzenes analysed using gas chromatography with electron capture detection. The limit of determination is approximately 0.0002 mg/L.

HEALTH CONSIDERATIONS

DCBs are absorbed rapidly through the lungs and from the gastrointestinal tract, and then distributed to tissues, primarily to fat or fatty tissue, and the lungs and kidneys. They are metabolised by the liver to the respective chlorophenols and eliminated in urine.

An extensive review and summary of the human and animal toxicity data for chlorobenzenes is available (IPCS 1986).

In the various reported cases of human exposure to DCBs, inhalation is the primary route. Toxic effects include liver damage, blood disorders, and disturbances to the immune system, the central nervous system or the respiratory tract. Skin pigmentation and allergic dermatitis have followed skin contact.

In rodents, long-term gavage (measured force-feeding) studies showed high doses of 1,2-DCB (120 mg/kg body weight per day) to affect mainly the liver and kidney, but found no adverse effects at lower doses. On balance, the available evidence suggests that 1,2-DCB is neither mutagenic in tests with bacteria nor carcinogenic in rodents.

No data are available on chronic toxicity for 1,3-DCB. No mutagenic activity was seen in tests with bacteria.

Long-term gavage studies involving 1,4-DCB produced similar results to the 1,2-DCB studies. In addition, there is evidence that 1,4-DCB increases the incidence of kidney tumours in male rats and liver tumours in mice after long-term exposure. It did not exhibit mutagenic activity in tests with bacteria or mammalian cells.

The International Agency for Research on Cancer has concluded that 1,4-DCB is possibly carcinogenic to humans (Group 2B, inadequate evidence in humans but sufficient evidence in animals), but that 1,2-DCB is unclassifiable as to its carcinogenicity (Group 3, inadequate evidence in humans and animals) (IARC 1987).

DERIVATION OF GUIDELINE

The guideline values for dichlorobenzenes in drinking water were determined as follows:

i) 1,2-dichlorobenzene:

The health-based guideline value of 1.5 mg/L was determined as follows:

$$1.5 \text{ mg/L} = \frac{60 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 100} \times \frac{5}{7}$$

where:

- 60 mg/kg body weight per day is the no effect level from a 2-year gavage study using mice (NTP 1985)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 100 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations and 10 for intraspecies variations)
- 5/7 is used to convert data based on a 5 day per week gavage study to a 7-day week equivalent.

This health-based guideline value exceeds the taste and odour threshold of 0.001 mg/L. The WHO guideline value of 1 mg/L was based on an adult body weight of 60 kg. The difference in the guideline values is not significant.

ii) 1,3-dichlorobenzene

There are insufficient long-term data to set a guideline value for 1,3-DCB in drinking water based on health considerations. The maximum concentration guideline of 0.02 mg/L is based on the aesthetic considerations of taste and odour.

iii) 1,4-dichlorobenzene

The health-based guideline value of 0.04 mg/L was determined as follows:

$$0.04 \text{ mg/L} = \frac{150 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 10\,000} \times \frac{5}{7}$$

where:

- 150 mg/kg body weight per day is the lowest effect level based on the appearance of kidney tumours in a 2-year gavage study using rats (NTP 1987)
- 10 000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations, 10 because a lowest effect level was used instead of a no effect level, and 10 because carcinogenic effects were observed at the lowest doses used)
- other factors are as above.

This health-based value exceeds the taste and odour threshold of 0.0003 mg/L. The WHO guideline value of 0.3 mg/L did not include the additional factor of 10 for possible carcinogenic effects.

NOTE: Important general information is contained in PART II, Chapter 6

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1991). Chlorobenzenes other than hexachlorobenzene. Environmental Health Criteria, 128. World Health Organization, International Programme on Chemical Safety.

NTP (1985). Toxicology and carcinogenesis studies of 1,2-dichlorobenzene (o-dichlorobenzene) in F344/N rats and B6C3F1 mice (gavage studies). National Toxicology Program, Technical Report No. 255, Publication No. 86-2511. United States Department of Health and Human Services, National Institute of Health.

NTP (1987). Toxicology and carcinogenesis gavage studies of 1,4-dichlorobenzene in F344/N rats and B6C3F1 mice. National Toxicology Program, Technical Report Series No. 319, Publication No. 87-2575, National Institute of Health, Bethesda, United States.

USEPA Draft Method 502.1 (1986). Volatile halogenated organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (ESML), Cincinnati, Ohio.

Dichloroethanes

1,1-dichloroethane
1,2-dichloroethane

GUIDELINE

1,1-dichloroethane: data are inadequate to set a drinking water guideline value.

1,2-dichloroethane: based on health considerations, the concentration in drinking water should not exceed 0.003 mg/L.

GENERAL DESCRIPTION

Dichloroethanes are present in some industrial effluent and have occasionally been found in drinking water supplies in the United States at concentrations below 0.006 mg/L.

The major use for 1,2-dichloroethane is in the production of vinyl chloride. It is also used in the production of other solvents, and can be used as a lead scavenger in petrol. 1,1-dichloroethane is used in the commercial production of 1,1,1-trichloroethane, as a solvent in paints, and as a varnish and finish remover.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Dichloroethanes have not been found in Australian drinking waters. They are included here to provide guidance in the unlikely event of contamination, and because they have been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

The dichloroethanes can be removed from drinking water using packed tower aeration, or by adsorption onto granular activated carbon.

MEASUREMENT

The dichloroethanes can be analysed by the purge and trap method (USEPA Method 502.1 1986). In this method an inert gas is bubbled through the sample and the dichloroethanes trapped on an adsorbent. The adsorbent is then heated and the dichloroethanes analysed using gas chromatography with electron capture detection. The limit of determination is approximately 0.0002 mg/L.

HEALTH CONSIDERATIONS

1,2-dichloroethane is absorbed through the lungs and gastrointestinal tract. Highest concentrations occur in the kidney and liver where it is metabolised to 2-chloroethanol. There are few data for 1,1-dichloroethane but it could be absorbed faster as it is more lipophilic (fat soluble).

An extensive review and summary of the human and animal toxicity data for 1,2-dichloroethane is available (IPCS 1987). A number of cases of poisoning following consumption of high doses of 1,2-dichloroethane have been reported. While not all cases have been fatal, death is attributed to circulatory and respiratory failure.

1,1-dichloroethane has been used as an anaesthetic. Its use was discontinued because of problems associated with heart rhythm.

NOTE: Important general information is contained in PART II, Chapter 6

A 13-week inhalation study with 1,1-dichloroethane reported elevated blood-urea nitrogen concentrations in cats but not in rats, rabbits or guinea pigs. No other adverse effects were observed. A 78-week feeding study reported a marginally significant increase in the incidence of tumours of the mammary glands of female rats. No statistically significant increase in tumours was observed in male rats, or male and female mice. 1,1-dichloroethane has exhibited mutagenic activity in tests with bacteria and mammalian cells.

A 13-week feeding and drinking water study with 1,2-dichloroethane using rats and mice reported increased kidney and liver weights at high doses (4000 mg/L). No increase in the incidence of tumours or lesions was observed in mice or male rats, but female rats exhibited an increase in the incidence of kidney lesions.

A significant increase in tumours of the fore-stomach and circulatory system was reported in male rats fed 1,2-dichloroethane five times per week for 78 weeks. The same study reported tumours of the mammary glands in female rats. 1,2-dichloroethane has exhibited mutagenic activity in tests with different strains of bacteria, and metabolites are known to be strongly mutagenic.

The International Agency for Research on Cancer has concluded that 1,2-dichloroethane is possibly carcinogenic to humans (Group 2B, no data in humans but sufficient evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The assessment of the toxicological data of these compounds by the WHO has been used without review; however, the guideline value has been adjusted to a risk level of one in one million.

i) 1,1-dichloroethane

There are insufficient long-term data to set a health-based guideline value for 1,1-dichloroethane in drinking water.

ii) 1,2-dichloroethane

The guideline value for 1,2-dichloroethane in drinking water has been set at 0.003 mg/L. The WHO has conservatively calculated, using an extrapolation model based on a 78 week study in rats (NCI 1978), that consumption of water containing 0.003 mg/L of 1,2-dichloroethane would pose a lifetime risk of one additional cancer per million people.

The guideline value should be reviewed when more data are available.

The WHO guideline value of 0.03 mg/L was based on a calculation that estimated an additional lifetime risk of one fatal cancer per 100 000 people.

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1987). 1,2-Dichloroethane. Environmental Health Criteria, 62. World Health Organization, International Programme on Chemical Safety.

NCI (1978). Bioassay of 1,2-dichloroethane for possible carcinogenicity. National Cancer Institute, Department Health Education and Welfare, Washington DC, Report NCI-CG-TR-55.

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Dichloroethenes

1,1-dichloroethene (1,1-DCE)
1,2-dichloroethene (1,2-DCE)

GUIDELINE

Based on health considerations, the concentrations of dichloroethenes in drinking water should not exceed the following values:

1,1-dichloroethene 0.03 mg/L

1,2-dichloroethene 0.06 mg/L

GENERAL DESCRIPTION

Available data indicate that the dichloroethenes are rarely found in drinking water. Studies in the United States have very occasionally reported DCEs in groundwater, usually from wells heavily contaminated with other chlorinated solvents.

1,1-DCE is used as a chemical intermediate in the manufacture of chloroform and polyvinylidene (PVDE) polymers. 1,2-DCE is also used as an intermediate in the manufacture of chlorinated solvents, and as a solvent. It can occur as two isomers, the cis and trans forms.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

DCEs have not been found in Australian drinking waters. They are included here to provide guidance in the unlikely event of contamination, and because they have been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

The DCEs can be removed from drinking water by aeration, or by adsorption onto granular activated carbon.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for analysis (USEPA Draft Method 502.1 1986). An inert gas is bubbled through the sample and the dichloroethenes trapped on an adsorbent. The adsorbent is then heated and the dichloroethenes analysed using gas chromatography with electron capture detection. The limit of determination is approximately 0.0002 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

The DCEs can be readily absorbed through the lungs and the gastrointestinal tract. They are distributed primarily to the liver and kidneys, and are metabolised to chloroacetic acid, chloroacetyl chloride, dichloroacetaldehyde and reactive epoxides.

In humans, exposure to high concentrations in air can lead to central nervous system depression. The DCEs have been used as anaesthetics.

A long-term study where rats were exposed to 1,1-DCE in their drinking water for 2 years reported minimal swelling to liver cells but no other adverse effects. No changes were observed in tissues taken from dogs after 97 days of exposure. 1,1-DCE induced tumours in mice in one inhalation study, but was not carcinogenic in other studies, including one drinking water study. It has exhibited some mutagenic activity in tests with bacteria but not with cultured mammalian cells.

The International Agency for Research on Cancer has concluded that 1,1-DCE is not classifiable as to its carcinogenicity (Group 3, evidence inadequate in humans and limited in animals) (IARC 1987).

No long-term data are available for 1,2-DCE; however, a 90-day immunotoxicity study with mice using the trans isomer reported increases in glutathione levels and aniline hydroxylase activity. No data are available on carcinogenicity bioassays with animals. The cis isomer, but not the trans isomer, has exhibited some mutagenic activity *in vivo* in tests with bacteria. Neither isomer induced chromosomal aberrations in hamster lung cells *in vitro*.

DERIVATION OF GUIDELINE

The assessment of the toxicological data of these compounds by the WHO has been used without review. The guideline values were determined as follows:

i) 1,1-dichloroethene

$$0.03 \text{ mg/L} = \frac{9 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 9 mg/kg body weight per day is the lowest effect level based on a 2-year drinking water study using rats (Quast *et al* 1983)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 because a lowest effect level was used instead of a no effect level).

ii) 1,2-dichloroethene

$$0.06 \text{ mg/L} = \frac{17 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 17 mg/kg body weight per day is the no effect level based on a 90-day drinking water study using mice (Barnes *et al* 1985)
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for the less than lifetime study)
- other factors apply as above.

The WHO guideline value of 0.05 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

Barnes DW, Sanders VM, White KL, Shopp GM and Munson AE (1985). Toxicology of trans-1,2-dichloroethylene in the mouse. *Drug and Chemical Toxicology*, 8, 373–392.

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

Quast JF, Humiston CG, Wade CE, Ballard J, Beyer JE, Schwetz RW and Norris JM (1983). A chronic toxicity and oncogenicity study in rats and subchronic toxicity study in dogs on ingested vinylidene chloride. *Fundamental and Applied Toxicology,* 3, 55–62.

USEPA Draft Method 502.1 (1986). Volatile halogenated organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (ESML), Cincinnati, Ohio.

Dichloromethane (methylene chloride)

GUIDELINE

Based on health considerations, the concentration of dichloromethane in drinking water should not exceed 0.004 mg/L.

GENERAL DESCRIPTION

Dichloromethane releases into the environment are substantial and widely dispersed. In overseas studies it has been found in the parts-per-trillion range in air and is a common contaminant of ground and surface waters, with higher concentrations found in groundwater. In surface waters it can volatilise into air and will degrade in the atmosphere.

Dichloromethane is a widely used organic solvent. It can be found in paints, insecticides, degreasing agents, cleaning fluids and paint strippers.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Dichloromethane has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Dichloromethane concentrations in drinking water can be reduced using aeration, or by adsorption onto granular activated carbon.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for analysis (USEPA Draft Method 502.1 1986). An inert gas is bubbled through the sample and dichloromethane trapped on an adsorbent. The adsorbent is then heated and dichloromethane analysed using gas chromatography with electron capture detection. The limit of determination is approximately 0.0003 mg/L.

HEALTH CONSIDERATIONS

Studies indicate that dichloromethane is completely absorbed after ingestion and distributed primarily to the liver. It is metabolised to carbon monoxide, carbon dioxide and formic acid.

An extensive review and summary of the human and animal toxicity data for dichloromethane is available (IPCS 1984).

Inhalation of high doses has induced narcosis in humans, and acute exposure has caused impairment of sensory and motor functions.

In animals, a 2-year drinking water study on rats reported some changes to the liver at doses from 52 mg/kg body weight per day. Studies have shown mice to be less sensitive than rats to the toxic effects of dichloromethane.

NOTE: Important general information is contained in PART II, Chapter 6

Epidemiological investigations have failed to demonstrate a correlation between dichloromethane exposure and increased cancer incidence.

Overall, carcinogenicity of dichloromethane given in water to rodents is borderline and not conclusive. By inhalation there is clear evidence of carcinogenicity in rodents (IARC 1987).

The International Agency for Research on Cancer has concluded that dichloromethane is possibly carcinogenic to humans (Group 2B, inadequate evidence in humans but sufficient evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The guideline value for dichloromethane in drinking water of 0.004 mg/L was determined as follows:

$$0.004 \text{ mg/L} = \frac{6 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 5000}$$

where:

- 6 mg/kg body weight per day is the lowest effect level based on a 2-year drinking water study using rats (Serota *et al* 1986)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 5000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations, 10 for genotoxicity and 5 for lowest effect level).

The WHO guideline of 0.02 mg/L did not include a safety factor for the use of a lowest effect level. The need to use this additional factor arose after a statistical evaluation of the data in the referenced study indicating that the end point was a lowest effect level, not a no effect level.

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1984). Methylene chloride. Environmental Health Criteria, 32. World Health Organization, International Programme on Chemical Safety.

Serota DG, Thakur AK, Ulland BM, Kirschman JC, Brown NM, Coots RH and Morgareidge K (1986). A two-year drinking water study of dichloromethane in rodents: I. Rats. *Food and Chemical Toxicology,* 24, 951–958.

USEPA Draft Method 502.1 (1986). Volatile halogenated organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (ESML), Cincinnati, Ohio.

Dissolved oxygen

GUIDELINE

Based on aesthetic considerations, it is desirable that the dissolved oxygen concentration in drinking water be greater than 85% saturation.

No health-based guideline value has been set for dissolved oxygen.

GENERAL DESCRIPTION

Drinking water will generally contain an adequate concentration of dissolved oxygen; however, under some circumstances the oxygen concentration may be reduced. This may occur, for instance, where water has been drawn from deep storages, where there is considerable growth of microorganisms in a distribution system, or following prolonged periods of high water temperature.

Low oxygen concentrations or anoxic conditions enable nuisance anaerobic microorganisms to grow, producing byproducts that affect the aesthetic quality of the water and increase corrosion of pipes and fittings.

There are a number of such nuisance microorganisms. Manganese-reducing bacteria produce black manganese deposits which can slough off pipes and soil laundry. Sulfate-reducing bacteria can produce hydrogen sulfide, giving drinking water a 'rotten egg' smell. Nitrate-reducing bacteria can produce nitrite. Iron-reducing bacteria can increase the concentration of ferrous ion in solution which will lead to the deposition of insoluble ferric salts when aeration is increased.

Localised pH changes associated with the growth of nuisance microorganisms can cause rapid corrosion in metal pipes.

Water from groundwater sources will generally have low oxygen concentrations and while this may cause no difficulties for most supplies, some supplies may need aeration to improve water quality (e.g. taste and odour).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies the dissolved oxygen concentration is generally greater than 85% saturation. Ground water supplies may have less dissolved oxygen.

TREATMENT OF DRINKING WATER

The dissolved oxygen concentration in drinking water can be increased by aeration or ozonation.

MEASUREMENT

The dissolved oxygen content of drinking water can be determined on site using an oxygen-sensitive membrane electrode (APHA Method 4500-O Part G 1992). Alternatively, the iodometric method (azide modification) can be used (APHA Method 4500-O Part C 1992).

HEALTH CONSIDERATIONS

There have been no direct health effects caused by low oxygen concentrations in drinking water. Indirect effects may result from the corrosion of fittings, which can give rise to higher concentrations of heavy metals such as lead, copper and cadmium, and by the anaerobic generation of hydrogen sulfide and nitrite.

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The guideline value of more than 85% saturation is based on aesthetic considerations for taste, odour and prevention of corrosion of pipes and fittings. If the concentration is lower than 85%, an investigation should be carried out to determine the cause.

REFERENCES

APHA Method 4500-O Part C (1992). Oxygen: Azide modification. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 4500-O Part G (1992). Oxygen: Membrane electrode method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Epichlorohydrin

GUIDELINE

Based on health considerations, the concentration of epichlorohydrin in drinking water should not exceed 0.0005 mg/L.

GENERAL DESCRIPTION

Epichlorohydrin is used in the manufacture of glycerine and unmodified epoxy resins, including resins used in water treatment (polyelectrolytes). The USEPA has proposed that the maximum residual epichlorohydrin content in flocculating agent shall not exceed 0.01% which, at maximum resin usage rates of 20 mg/L, would lead to an epichlorohydrin concentration in drinking water of less than 0.002 mg/L. No monitoring of epichlorohydrin concentrations in drinking water has been reported. Epichlorohydrin hydrolyses in water and this can cause difficulties in detection.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Epichlorohydrin has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

No published reports are available on water treatment procedures for the removal of epichlorohydrin. Aeration is unlikely to be successful.

MEASUREMENT

Epichlorohydrin can be determined using gas chromatography with electron capture detection (Pesselman and Feit 1988). The limit of determination is approximately 0.05 mg/L.

HEALTH CONSIDERATIONS

In laboratory animals epichlorohydrin is rapidly absorbed after ingestion, inhalation and skin contact, and is distributed to the liver, kidneys and pancreas.

An extensive review and summary of the human and animal toxicity data for epichlorohydrin is available (IPCS 1984).

In humans, skin contact with high concentrations can cause initial redness, itching, or a burning sensation. The initial effects of inhalation are similar, and can be followed by vomiting and severe headache. Long-term exposure can cause kidney and liver damage. Epichlorohydrin has been reported to increase chromosome damage in lymphocytes, and decrease blood cell counts in occupationally exposed workers.

A long-term study where male rats were given epichlorohydrin in their drinking water for 81 weeks reported a decrease in leucocytes and an increase in the incidence of fore-stomach tumours from a dose of 39 mg/kg body weight per day and fore-stomach hyperplasia from 18 mg/kg body weight per day. A 2-year gavage study in rats, using doses of 2 and 10 mg/kg body weight per day, also reported induction of fore-stomach carcinomas. Inhalation studies in rats have reported the appearance of nasal cavity carcinomas.

NOTE: Important general information is contained in PART II, Chapter 6

Epichlorohydrin has been shown to be genotoxic both *in vitro* and *in vivo*. It is an alkylating agent and a direct-acting mutagen.

The International Agency for Research on Cancer has concluded that epichlorohydrin is probably carcinogenic to humans (Group 2A, insufficient evidence in humans, sufficient evidence in animals, and other supportive data) (IARC 1987).

DERIVATION OF GUIDELINE

The assessment of the toxicological data for epichlorohydrin by the WHO has been used without review. The guideline value of 0.0005 mg/L was determined as follows:

$$0.0005 \text{ mg/L} = \frac{2 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 10\,000} \times \frac{5}{7}$$

where:

- 2 mg/kg body weight per day is the lowest effect level based on a 2-year gavage study using rats (Wester *et al* 1985)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 10 000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations, 10 because a lowest effect level was used instead of a no effect level, and 10 for carcinogenic effects)
- 5/7 is used to convert data based on a 5 day per week feeding study to a 7-day week equivalent.

Although epichlorohydrin is a genotoxic carcinogen, the use of a linear multistage model for estimating cancer risk was considered inappropriate because tumours are seen only at the site of administration where epichlorohydrin is highly irritating.

The limit of determination is approximately 0.05 mg/L; however, concentrations in drinking water can be controlled by product specification.

The WHO guideline value of 0.0004 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1984). Epichlorohydrin. Environmental Health Criteria, 33. World Health Organization, International Programme on Chemical Safety.

Pesselman RL and Feit MJ (1988). Determination of residual epichlorohydrin and 3-chloropropanediol in water by gas chromatography with electron capture detection. Journal of Chromatography, 439, 488-542.

Wester PW, Van Der Heijden CA, Bisschop A and Van Esch GJ (1985). Carcinogenicity study with epichlorohydrin (CEP) by gavage in rats. Toxicology, 36, 325-339.

Ethylbenzene

GUIDELINE

Based on aesthetic considerations (taste and odour), the concentration of ethylbenzene in drinking water should not exceed 0.003 mg/L.

Ethylbenzene would not be a health concern unless the concentration exceeded 0.3 mg/L.

GENERAL DESCRIPTION

Ethylbenzene occurs naturally as a component of crude oil and is present in petrol, but in small quantities. It may be present in drinking water following pollution of source water. Overseas studies have reported concentrations in drinking water ranging from 0.00001 mg/L to 0.0004 mg/L (10 ng/L to 400 ng/L).

Ethylbenzene is produced commercially by the alkylation of benzene with ethylene, and by fractionation of petroleum. It is a major component of commercial xylene and is used commercially in paints, insecticides and blends of petrol. It can also be found as a constituent of asphalt and naphtha.

The taste and odour threshold in water varies from 0.002 mg/L to 0.2 mg/L, depending on individual sensitivities and water temperature.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Ethylbenzene has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Ethylbenzene can be removed from drinking water by aeration or by adsorption onto granular activated carbon.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for the analysis of ethylbenzene (USEPA Draft Method 503.1 1986). An inert gas is bubbled through the sample and ethylbenzene trapped on an adsorbent. The adsorbent is then heated and ethylbenzene analysed using gas chromatography with photoionization detection. The limit of determination is less than 0.001 mg/L.

HEALTH CONSIDERATIONS

Ethylbenzene is readily absorbed from the human gastrointestinal tract. It can be stored in fat and is metabolised to mandelic and phenylglyoxalic acids and excreted in the urine. It can cross the placenta.

No data are available on the health effects in humans after oral exposure, and inhalation data are limited to short-term studies.

A 6-month gavage study using rats reported enlargement of the liver and kidney at high doses (400 mg/kg body weight per day). Liver effects were also observed in a number of inhalation studies. No longer-term studies are available.

Studies on the mutagenic activity of ethylbenzene to bacteria, insects and mammalian cells have reported negative results.

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The health-based guideline value for ethylbenzene in drinking water was determined as follows:

$$0.3 \text{ mg/L} = \frac{136 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000} \times \frac{5}{7}$$

where:

- 136 mg/kg body weight per day is the no effect level based on a 6-month gavage study using rats (Wolf *et al* 1956)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for the limited data and short duration of the study)
- 5/7 is used to convert data based on a 5 day per week gavage study to a 7-day week equivalent.

This health-based value exceeds the taste threshold of 0.003 mg/L for ethylbenzene in water.

REFERENCES

USEPA Draft Method 503.1 (1986). Volatile organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Wolf MA, Rowe VK, McCollister DD, Hollingsworth RL and Oyen F (1956). Toxicology studies of certain alkylated benzenes and benzene: experiments on laboratory animals. *AMA Archives of Industrial Health,* 14, 387–398.

Ethylenediamine tetraacetic acid (EDTA)

GUIDELINE

Based on health considerations, the concentration of ethylenediamine tetraacetic acid in drinking water (as the free acid) should not exceed 0.25 mg/L.

GENERAL DESCRIPTION

EDTA is a metal-complexing agent and may act to mobilise some heavy metals in the environment. It has occasionally been detected in drinking water supplies overseas at concentrations of up to 0.9 mg/L, but usually less than 0.1 mg/L.

EDTA is used widely in industry and agriculture. It is used in laundry detergents, water softening, electroplating, textile and paper production, as a food additive, and in cosmetics. Most of these uses will result in the release of EDTA to the aquatic environment. It is also used as a drug in chelation therapy, particularly in cases involving lead poisoning.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

EDTA has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

There are no published reports on methods for the removal of EDTA from drinking water, although it may be oxidised by ozone.

MEASUREMENT

EDTA can be analysed by potentiometric stripping analysis (Fayyad *et al* 1988). The limit of determination is 0.001 mg/L.

HEALTH CONSIDERATIONS

EDTA is poorly absorbed in the gut and does not form any significant metabolites. It does not accumulate in the body.

There is considerable clinical experience in the use of EDTA for the treatment of heavy metal poisoning.

Long-term feeding studies with rats and dogs reported no interference to mineral metabolism. Results from other studies have been affected by the formation of zinc complexes in the gastrointestinal tract, which prevents the zinc from being absorbed.

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The guideline value for EDTA (as the free acid) in drinking water was determined as follows:

$$0.25 \text{ mg/L} = \frac{1.9 \text{ mg/kg body weight per day} \times 13 \text{ kg} \times 0.1}{1 \text{ L/day} \times 10}$$

where:

- 1.9 mg/kg body weight per day is the amount of EDTA that can be consumed from all sources per day without adverse effects (WHO 1974)
- 13 kg is the average weight of a child at 2 years of age (this value was used because of the possibility of complexation of zinc, an essential element for humans, and the need to protect the most sensitive group)
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 1 L/day is the average amount of water consumed by a 2-year-old child
- 10 is a safety factor to reflect the fact that the data for EDTA are relatively old (the WHO assessment was dated 1974), and concern over zinc complexation.

The WHO guideline value of 0.2 mg/L was based on a child body weight of 10 kg. The difference in guideline values is not significant.

REFERENCES

Fayyad M, Tutunji M and Taha Z (1988). Indirect trace determination of EDTA in waters by potentiometric stripping analysis. *Analytical Letters,* 21, 1425–1432.

WHO (1974). Toxicological evaluation of some food additives including anti-caking agents, anti-microbials, anti-oxidants, emulsifiers and thickening agents. World Health Organization Food Additive Series No 5, WHO, Geneva.

Fluoride

GUIDELINE

Based on health considerations, the concentration of fluoride in drinking water should not exceed 1.5 mg/L.

GENERAL DESCRIPTION

Fluoride occurs naturally in seawater (1.4 mg/L), soil (up to 300 parts per million) and air (from volcanic gases and industrial pollution). Naturally occurring fluoride concentrations in drinking water depend on the type of soil and rock through which the water drains. Generally, concentrations in surface water are relatively low (<0.1-0.5 mg/L), while water from deeper wells may have quite high concentrations (1-10 mg/L) if the rock formations are fluoride-rich.

Inorganic fluorine compounds are used in aluminium production, as a flux in the steel and glass fibre industries, and in phosphate fertilisers, bricks, tiles and ceramics.

Virtually all foodstuffs contain traces of fluoride. In particular, high amounts can be found in dried tea leaves because of natural concentration by the tea plant. Total daily intake from all sources varies considerably, but has been estimated at 0.46 mg to 5.4 mg, with about 10% coming from unfluoridated drinking water.

Fluoride is used to protect teeth against dental caries. It is present in most brands of toothpaste, and it is often added to drinking water supplies.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In unfluoridated supplies, fluoride concentrations are typically less than 0.1 mg/L, but can range from less than 0.05 mg/L up to 1.5 mg/L, with the higher values reported from groundwater sources.

In fluoridated supplies, the target fluoride concentration is between 0.7 and 1 mg/L, with the lower concentrations applying where the climate is hot, to allow for a higher average consumption of water.

TREATMENT OF DRINKING WATER

Fluoride concentrations in drinking water can be reduced by dilution with other sources, or by using activated alumina or bone char. Conventional coagulation with alum is much less effective.

MEASUREMENT

The fluoride concentration in drinking water can be determined using an ion-specific electrode (APHA Method 4500-F^- Part C 1992). The limit of determination is 0.1 mg/L.

HEALTH CONSIDERATIONS

Because fluoride is widely dispersed in the environment, all living organisms are exposed to it and all tolerate modest amounts. It has been claimed that fluoride is an essential trace element for humans, but this is difficult to establish conclusively, and no data are available on the minimum amount needed. Fluoride is absorbed quickly following ingestion. It is not metabolised, but diffuses passively into all body compartments. About 40% is excreted in urine within 9 hours, and about 50% over 24 hours. Fluoride has an affinity for mineralising tissues of the body: in young people, bone and teeth; in older people, bone. Thus excretion is somewhat greater in adults because they have proportionately less mineralising tissue than children.

NOTE: Important general information is contained in PART II, Chapter 6

Fluoride has been shown to prevent dental caries very effectively, and knowledge of its anti-caries effect came from the observed association of low caries prevalences with naturally occurring fluoride in drinking water (at about 1 mg/L). The NHMRC has extensively reviewed health aspects of fluoride and its prevention of dental disease. Many health authorities around the world recommend fluoridation of public water supplies as an important public health measure.

Concentrations above 1.5 mg/L may disturb tooth mineralisation in children up to about 6 to 8 years, leading to dental fluorosis, a mottling of the teeth which can occasionally occur to an unsightly degree.

Skeletal fluorosis, characterised by hypermineralisation and thus brittle bones, has occurred in association with high fluoride concentrations in drinking water, and also with occupational exposure to fluoride-containing dust. It generally occurs after prolonged exposure (several years) and is reversible: if the exposure is removed, the fluoride levels in bones gradually decline.

Regular consumption of water with fluoride concentrations above about 4 mg/L involves progressively increasing risks of skeletal fluorosis. The USEPA has set this level as the maximum acceptable for drinking water: above it, communities are required to lower the fluoride concentration by treatment to remove it, or by dilution.

People with kidney impairment have a lower margin of safety for fluoride intake. Limited data indicate that their fluoride retention may be up to three times normal.

There is no substantiated epidemiological evidence that fluoride or fluoridation causes cancer. One animal study showed an increased incidence of bone tumours in some male rats that were exposed to very high concentrations of fluoride in water, but female rats and mice were not affected.

Tests for mutagenicity with strains of bacteria have been negative. Chromosome aberrations have been reported in tests with mammalian cells but only at extremely high fluoride concentrations.

The International Agency for Research on Cancer has concluded that fluoride is not classifiable as to its carcinogenicity in humans (Group 3, inadequate evidence in humans and in animals) (IARC 1987).

DERIVATION OF GUIDELINE

It was recognised in setting the guideline value of 1.5 mg/L that there is a narrow margin between concentrations producing beneficial effects to teeth and those producing objectionable fluorosis.

The minimum concentration required for a protective effect against dental caries is about 0.5 mg/L, and concentrations around 1 mg/L in temperate climates are optimal for caries prevention. At concentrations between 1.5 and 2 mg/L, mottling of teeth due to dental fluorosis may occur, sometimes to an objectionable degree.

The guideline value of 1.5 mg/L has been set to protect children from the risk of dental fluorosis. If this value is exceeded in circumstances where it is not practical to defluoridate, then parents should be advised to use rainwater or bottled water for children up to about 6 years to limit or prevent dental fluorosis.

The guideline value should not be regarded as a recommended value for fluoridation of water supplies.

REFERENCES

APHA Method 4500-F^- Part C (1992). Fluoride: Ion-selective electrode method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

NHMRC (1991). The effectiveness of water fluoridation. National Health and Medical Research Council, and Department of Health, Housing and Community Services, Canberra.

NOTE: Important general information is contained in PART II, Chapter 6

Formaldehyde

GUIDELINE

Based on health considerations, the concentration of formaldehyde in drinking water should not exceed 0.5 mg/L.

GENERAL DESCRIPTION

Formaldehyde may be present in drinking water through ozonation of naturally occurring humic material, contamination by accidental spills, or deposition from the atmosphere. Typical concentrations in air are probably in the low parts-per-billion range. Overseas, formaldehyde has been detected in ozonated drinking water at concentrations up to 0.03 mg/L.

Formaldehyde is used industrially in the wood, paper and textile industries. It is also used in the production of a number of chemicals and for the preservation of biological material. It is occasionally used as a disinfectant, sometimes to disinfect water filters. Other sources of exposure include cigarette smoke and food. Formaldehyde is present in almost all common foods, and adult dietary intake is estimated at 11 mg/day. Drinking water would contribute less than 10% of total intake.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

No data are available on the concentrations of formaldehyde in Australian drinking waters.

TREATMENT OF DRINKING WATER

There are no published reports on methods for the removal of formaldehyde from drinking water.

MEASUREMENT

Formaldehyde can be determined by formation of the 2,4-dinitro-phenylhydrazone derivative followed by analysis with high performance liquid chromatography (HPLC) with UV detection (Whittle and Rennie 1988). The limit of determination is 0.006 mg/L.

HEALTH CONSIDERATIONS

Formaldehyde is readily absorbed from the gastrointestinal tract and is rapidly metabolised to formic acid and subsequently to carbon dioxide and water.

An extensive review and summary of the human and animal toxicity data for formaldehyde is available (IPCS 1989).

Most human health data are from inhalation studies, where formaldehyde causes irritation of the respiratory tract, and dermal studies, where it causes skin irritation. Formaldehyde has been linked to outbreaks of haemolytic anaemia in patients using improperly serviced dialysis units, where formaldehyde was used to disinfect the units and residual amounts remained in the water filter.

A number of epidemiological studies have looked at the effects of inhalation of formaldehyde. No effects could be directly attributed to long-term occupational exposure, but studies among exposed workers have reported elevated incidences of a number of cancers including nasal, buccal, nasopharyngeal, skin, prostate and colon cancers. The available human evidence indicates that formaldehyde does not have a high carcinogenic potential (IPCS 1989).

NOTE: Important general information is contained in PART II, Chapter 6

In a 2-year drinking water study using rats, severe damage to gastric mucosa was reported only at the highest doses (over 80 mg/kg body weight per day), but no tumours were observed, either in the stomach or at other sites. Other studies have shown similar pathological changes to the stomach, but again only at the highest doses.

There was no evidence of tumour-promoting activity when formaldehyde was applied to mouse skin, but rats inhaling formaldehyde exhibited a markedly increased incidence of cancer of the nasal cavity. Formaldehyde has demonstrated mutagenic activity when applied to cells *in vitro* but not when applied *in vivo*.

The International Agency for Research on Cancer has concluded that formaldehyde is probably carcinogenic to humans (Group 2A, limited human evidence, sufficient animal evidence, based on inhalation studies) (IARC 1987). The weight of evidence indicates that formaldehyde is not carcinogenic by the oral route.

DERIVATION OF GUIDELINE

The guideline value for formaldehyde in drinking water was determined as follows:

$$0.5 \text{ mg/L} = \frac{15 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 100}$$

where:

- 15 mg/kg body weight per day is the no effect level based on a 2-year drinking water study in rats (Til *et al* 1989)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 100 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations and 10 for intraspecies variations). The use of this safety factor was recommended by the NHMRC Standing Committee on Toxicity.

The WHO derived a guideline value of 0.9 mg/L based on a 20% allocation of total daily intake to drinking water. In determining the Australian guideline value, it was felt that sufficient data were available to indicate that 10% was a more realistic figure.

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1989). Formaldehyde. Environmental Health Criteria, 89. World Health Organization, International Programme on Chemical Safety.

Til HP, Woutersen RA, Feron VJ, Hollanders VHM, Falke HE and Clary JJ (1989). Two-year drinking water study of formaldehyde in rats. *Food and Chemical Toxicology,* 27, 77–87.

Whittle PJ and Rennie PJ (1988). Determination of formaldehyde in river water by high-performance liquid chromatography. Analyst, 113, 665–666.

Haloacetonitriles

dichloroacetonitrile
trichloroacetonitrile
dibromoacetonitrile
bromochloroacetonitrile

GUIDELINE

Data are inadequate to set guideline values for haloacetonitriles in drinking water.

GENERAL DESCRIPTION

Haloacetonitriles are formed from organic precursors during chlorination of drinking water. Concentrations of dihaloacetonitriles reported overseas range up to 0.04 mg/L but are typically less than 0.001 mg/L. Concentrations of trichloroacetonitrile are less than 0.001 mg/L.

Trichloroacetonitrile has been used as an insecticide. No data are available on uses for the other haloacetonitriles.

TYPICAL CONCENTRATIONS IN AUSTRALIAN DRINKING WATER

No data are available on concentrations of haloacetonitriles in Australian drinking waters.

LIMITING FORMATION IN DRINKING WATER

The presence of haloacetonitriles in drinking water can be minimised by removing naturally occurring organic matter from the source water, by reducing the amount of chlorine added, or by the use of alternative disinfectants.

MEASUREMENT

A solvent extraction procedure is suitable for the analysis of haloacetonitriles (USEPA Draft Method 551 1990). Sodium chloride is added to the sample and the haloacetonitriles extracted using methyl tert-butyl ether. The extracts are then analysed using gas chromatography with an electron capture detector. Limits of determination are less than 0.0001 mg/L.

HEALTH CONSIDERATIONS

Haloacetonitriles are rapidly absorbed from the gastrointestinal tract and metabolised to single carbon compounds, including cyanide. Insufficient data are available to indicate whether haloacetonitriles can accumulate in specific organs.

No data are available on the health effects of haloacetonitriles in humans.

Dichloroacetonitrile and dibromoacetonitrile caused decreased body weights in 90-day feeding studies with rats, but specific target organs were not identified. Dibromoacetonitrile and bromochloroacetonitrile caused an increase in the incidence of squamous cell carcinomas when applied to the skin of mice in the presence of agents which promote tumour growth. No significant increase was observed for dichloroacetonitrile or trichloroacetonitrile.

NOTE: Important general information is contained in PART II, Chapter 6

Dichloroacetonitrile and bromochloroacetonitrile were direct-acting mutagens in tests on bacteria, whereas tests with dibromoacetonitrile and trichloroacetonitrile were negative. All four compounds induced DNA damage (sister chromatid exchange and DNA strand breaks) in mammalian cells.

Studies with rats indicate that dichloroacetonitrile and trichloroacetonitrile can cause fetal deformities. No data are available for other haloacetonitriles.

The NHMRC Standing Committee on Toxicity reviewed the available data for haloacetonitriles in 1991, and concluded that data were insufficient to set no effect levels for these compounds.

DERIVATION OF GUIDELINE

The WHO has set guideline values for dichloroacetonitrile (0.09 mg/L) and trichloroacetonitrile (0.001 mg/L) based on developmental effects in rats following short-term exposure during gestation. The WHO guideline value for dibromoacetonitrile (0.1 mg/L) was from a 90-day study using rats in which there were a large number of accidental animal deaths. The guidelines should be reviewed as soon as long-term toxicological data are available.

These studies were not considered to be sufficient to set Australian guideline values.

REFERENCE

USEPA Draft Method 551 (1990). Determination of chlorination disinfection byproducts and chlorinated solvents in drinking water by liquid-liquid extraction and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Hardness (as Calcium carbonate)

GUIDELINE

To minimise undesirable build-up of scale in hot water systems, total hardness (as calcium carbonate) in drinking water should not exceed 200 mg/L.

GENERAL DESCRIPTION

Hard water requires more soap than soft water to obtain a lather. It can also cause scale to form on hot water pipes and fittings. Hardness is caused primarily by the presence of calcium and magnesium ions, although other cations such as strontium, iron, manganese and barium can also contribute.

Total hardness is the sum of the concentrations of calcium and magnesium ions expressed as a calcium carbonate equivalent. Hardness may also be classified as carbonate (temporary) or noncarbonate (permanent) hardness. Carbonate hardness is the total alkalinity expressed as calcium carbonate, where alkalinity is the sum of the carbonate, bicarbonate and hydroxide content. Noncarbonate hardness is the difference between the total and carbonate hardness.

Degrees of hardness can be described as follows:

<60 mg/L $CaCO_3$	soft but possibly corrosive
60-200 mg/L $CaCO_3$	good quality
200-500 mg/L $CaCO_3$	increasing scaling problems
>500 mg/L $CaCO_3$	severe scaling

Public acceptance of hardness can vary considerably among communities and is generally related to the hardness that the consumer has come to expect, which in turn is due to the source of the water.

Soft water may lead to greater corrosion of pipes, although this will depend on other factors such as pH, alkalinity and dissolved oxygen concentration. Total hardness above 200 mg/L may lead to excessive scaling of pipes and fittings, and cause blockage of safety relief valves in hot water systems.

High total hardness may be a problem for supplies reliant on groundwater. Surface waters can generally be expected to have acceptable values.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Total hardness in major Australian reticulated supplies ranges between about 5 mg/L and about 380 mg/L.

MEASUREMENT

Hardness can be determined by titration of calcium and magnesium with EDTA (APHA Method 2340C 1992).

TREATMENT OF DRINKING WATER

Carbonate (temporary) hardness can be readily reduced by treatment, for example using lime softening; however, this is rarely practised for Australian drinking water. Sodium hexametaphosphate has been used to reduce scale build-up, but does not affect hardness.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Some epidemiological studies have found that hard water may have a beneficial effect on health, particularly on some types of cardiovascular disease (NAS 1977), but the data are inadequate to conclude that the association is causal.

There is some indication that soft water, with a hardness of less than about 75 mg/L, may adversely affect mineral balance.

DERIVATION OF GUIDELINE

The guideline value is based on two considerations:

- difficulty in obtaining a lather with soap
- water with a total hardness (as calcium carbonate) above 200 mg/L can cause a rapid build-up of undesirable deposits, or scale, in hot water pipes and fittings. Removal of these deposits can be costly.

GUIDELINES IN OTHER COUNTRIES

The 1984 WHO Guideline value for total hardness is 500 mg/L. The 1993 WHO Guidelines do not provide a specific value for hardness.

The Canadian Guidelines rate over 500 mg/L as unacceptable, over 200 mg/L as poor, and 80-100 mg/L as acceptable.

The EEC standards do not include a maximum concentration for hardness, but consider a minimum concentration of at least 60 mg/L to be desirable.

REFERENCES

APHA Method 2340C (1992). Hardness: EDTA titrimetric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

NAS (1977). Drinking water and health. National Academy of Sciences, Washington DC.

Heptachlor and heptachlor epoxide

GUIDELINE

Heptachlor should not be detected in drinking water. If present in drinking water, heptachlor would not be a health concern unless the concentration exceeded 0.0003 mg/L.

If it is detected, remedial action should be taken to stop contamination. The limit of determination is 0.00005 mg/L (50 ng/L).

GENERAL DESCRIPTION

Heptachlor is a broad spectrum insecticide used in Australia until September 1994 to protect wooden structures against termites. Its other former uses were withdrawn in the late 1970s and early 1980s. Heptachlor epoxide, an oxidation product of heptachlor, is not commercially available.

Heptachlor is moderately persistent in soil. It is transformed slowly to the epoxide, which is very resistant to further chemical or biological degradation.

Heptachlor has been detected at low nanogram per litre concentrations in water supplies in Europe and the United States. It has been found in a number of foods including human milk. The daily adult intake for heptachlor and the epoxide in the United States has been estimated at about 0.000007 mg/day (7 ng/day) and 0.0002 mg/day respectively. The 1990 Australian Market Basket Survey did not find heptachlor or the epoxide in any of the foods tested (NHMRC and NFA 1991).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Heptachlor has not been detected in major Australian drinking water supplies.

TREATMENT OF DRINKING WATER

No published reports are available on methods for the removal of heptachlor from drinking water supplies. Granular activated carbon would probably be effective.

MEASUREMENT

Heptachlor can be extracted from water using a nonpolar solvent such as pentane, and analysed using gas chromatography with electron capture detection (APHA Method 6630 Part B 1992). The limit of determination is 0.00005 mg/L (50 ng/L).

HEALTH CONSIDERATIONS

Heptachlor is absorbed rapidly from the gastrointestinal tract of rats and distributed throughout the body. It is metabolised to the epoxide and excreted in faeces.

Extensive reviews and summaries of the human and animal toxicology of heptachlor are available (IPCS 1984, JMPR 1991, IARC 1991, NHMRC 1992).

Heptachlor is acutely neurotoxic in animals and humans at high doses, and is hepatotoxic in animals. It caused liver tumours in mice, and in one study, thyroid follicular cell carcinoma in rats. At high exposure levels, heptachlor can affect the viability of the offspring of rodents and dogs.

Heptachlor has not been reported to be genotoxic or teratogenic in animals.

NOTE: Important general information is contained in PART II, Chapter 6

The International Agency for Research on Cancer has concluded that heptachlor is possibly carcinogenic to humans (Group 2B, inadequate evidence in humans, sufficient evidence in experimental animals) (IARC 1991).

DERIVATION OF GUIDELINE

The health-based guideline value of 0.0003 mg/L for heptachlor and heptachlor epoxide was determined as follows:

$$0.0003 \text{ mg/L} = \frac{0.0001 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day}}$$

where:

- 0.0001 mg/kg body weight per day is the maximum ADI based on a no effect level of 0.025 mg/kg body weight per day from two studies using dogs (JMPR 1991)
- 70 kg is the average weight of an adult
- 0.1 gives a guideline value based on 10% of the ADI
- 2 L/day is the average amount of water consumed by an adult.

The maximum ADI value includes a safety factor of 200 (10 for interspecies variations, 10 for intraspecies variations and 2 for the inadequacy of the data base). No additional safety factors are necessary.

The WHO guideline value of 0.00003 mg/L (30 ng/L) was determined using 1% of the ADI to allow for increased exposure from other sources. Such a low percentage of the ADI was considered inappropriate for Australia.

REFERENCES

APHA Method 6630 Part B (1992). Organochlorine pesticides: Liquid-liquid extraction, gas chromatographic method I. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1991). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Occupational Exposures in Insecticide Application, and Some Pesticides. World Health Organization, International Agency for Research on Cancer, 53.

IPCS (1984). Heptachlor. Environmental Health Criteria, 38. World Health Organization, International Programme on Chemical Safety.

JMPR (1991). *Pesticide Residues in Food* - 1991. Report of the Joint Meeting of the FAO Panel of Experts on Pesticide Residues in Food and the Environment and the WHO Expert Group on Pesticide Residues. Food and Agricultural Organization of the United Nations, FAO Plant Production and Protection Paper III, Rome.

NHMRC (1992). Cyclodiene Insecticide Use in Australia. National Health and Medical Research Council, AGPS, Canberra.

NHMRC and NFA (1991). The 1990 Australian Market Basket Survey. National Health and Medical Research Council and National Food Authority, AGPS, Canberra.

Hexachlorobutadiene

GUIDELINE

Based on health considerations, the concentration of hexachlorobutadiene in drinking water should not exceed 0.0007 mg/L.

GENERAL DESCRIPTION

Hexachlorobutadiene has occasionally been detected in drinking water supplies in the United States and some European countries at concentrations less than 0.005 mg/L.

Hexachlorobutadiene is used as a solvent in chlorine gas production, an intermediate in the manufacture of rubber compounds, a lubricant, a pesticide and a fumigant.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Hexachlorobutadiene has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Granular activated carbon has proved effective in trials for the removal of hexachlorobutadiene from drinking water.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for analysis (USEPA Draft Method 502.1 1986). An inert gas is bubbled through the sample and hexachlorobutadiene trapped on an adsorbent. The adsorbent is then heated and hexachlorobutadiene analysed using gas chromatography with electron capture detection. The limit of determination is approximately 0.0004 mg/L.

HEALTH CONSIDERATIONS

Experiments in laboratory animals have revealed that approximately 95% of the ingested dose of hexachlorobutadiene is absorbed. It has been found in the blood, liver, brain, spleen, kidney and mesentery. Hexachlorobutadiene is metabolised in the gastrointestinal tract and kidney to a number of water soluble metabolites, and excreted in the urine.

Long-term intermittent human exposure has been reported to cause higher incidences of hypotension, myocardial dystrophy, nervous system and liver disorders, and respiratory tract lesions.

In studies using rats, hexachlorobutadiene caused multiple toxicologic effects, with the kidney being the organ most affected. Kidney tumours have been induced at doses of 20 mg/kg body weight per day.

Tests for mutagenicity with different strains of bacteria have reported both positive and negative results. Some metabolites have given positive results.

The International Agency for Research on Cancer has concluded that hexachlorobutadiene is not classifiable as to its carcinogenicity to humans (Group 3, no adequate evidence in humans and limited evidence in animals) (IARC 1987).

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The assessment of the toxicological data for hexachlorobutadiene by the WHO has been used without review. The guideline value of 0.0007 mg/L was determined as follows:

$$0.0007 \text{ mg/L} = \frac{0.2 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 0.2 mg/kg body weight per day is the no effect level based on a 2-year feeding study using rats (Kociba 1977)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for possible carcinogenic effects and genotoxicity of some metabolites).

The WHO guideline value of 0.0006 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

Kociba RJ, Keyes DG, Jersey GC, Ballard JJ, Dittenber DA, Quast JF, Wade CE, Humiston CG and Schwetz BA (1977). Results of a two-year toxicity study with hexachlorobutadiene in rats. *American Industrial Hygiene Association Journal,* 38, 589–602.

USEPA Draft Method 502.1 (1986). Volatile halogenated organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Hydrogen sulfide
Sulfide

GUIDELINE

Based on aesthetic considerations, the concentration of hydrogen sulfide in drinking water should not exceed 0.05 mg/L.

No health-based guideline value has been set for hydrogen sulfide, or sulfide, as the aesthetic guideline is considerably below the concentration that would cause health problems.

GENERAL DESCRIPTION

Hydrogen sulfide is formed in drinking water by the hydrolysis of soluble sulfides, or through the reduction of sulfate by the action of microorganisms. Both processes require anoxic conditions. In well-oxygenated water, sulfide will be chemically or biologically oxidised to sulfate or elemental sulfur, and concentrations are extremely low. Higher concentrations can occur in anoxic water drawn from deep storages.

In water, hydrogen sulfide will be in equilibrium with the sulfide and hydrosulfide ions. The ratio will depend on pH, temperature and salinity. At pH 7.4, about a third will be present in undissociated form, with the remainder present as hydrosulfide. Above pH 10, the sulfide ion will be the dominant form; below pH 5, undissociated hydrogen sulfide will predominate.

Hydrogen sulfide has an obnoxious 'rotten egg' gas odour, with a taste and odour threshold of 0.05 mg/L. High concentrations in air can have a deceptively sweet smell and cause 'olfactory fatigue' (a deadening of the sense of smell).

Hydrogen sulfide is used industrially in the production of sulfur, sulfuric acid, inorganic sulfides, thiophenes and other organic compounds. It occurs as a byproduct in a number of processes including petrol refining, coke ovens, paper mills, iron smelters, food processing and tanneries. It is present in sewers and is a major component of sewage odour.

Data on the concentration of hydrogen sulfide in food are scarce, although a number of foods and drinks are known to contain sulfides.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Australian drinking water supplies have not been routinely monitored for hydrogen sulfide, or sulfide.

TREATMENT OF DRINKING WATER

Hydrogen sulfide can be removed from drinking water by keeping the water well oxygenated.

MEASUREMENT

The sulfide concentration of drinking water can be determined using the methylene blue colorimetric method (APHA Method 4500-S^{2-} Part D 1992). The limit of determination is 0.02 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Soluble sulfides are absorbed rapidly from the gastrointestinal tract, although hydrogen sulfide is absorbed principally by the lung. Animal studies have indicated that after absorption, hydrogen sulfide is distributed to the brain, liver, kidneys, pancreas and small intestine.

An extensive review and summary of the human and animal toxicity data for hydrogen sulfide is available (IPCS 1981).

There are no data on the human health effects of ingesting water that contains hydrogen sulfide. Ingestion of sulfides has been known to cause nausea, vomiting and irritation of the mucous membranes. Inhalation of hydrogen sulfide is known to be extremely toxic to humans, with exposure to amounts as low as 5 ppm for 30 minutes or more producing headaches, dizziness, nausea, gastrointestinal disorders and breathing problems. Inhalation of concentrations above 500 ppm can cause cardiac failure and death.

Animal data are mainly from short-term inhalation studies. Effects include neurotoxic activity and distortions in cardiac rhythm.

No long-term carcinogenicity bioassays have been undertaken on hydrogen sulfide. Sodium sulfide did not induce cancers in experimental animals. Hydrogen sulfide was not found to be mutagenic in tests with different strains of bacteria.

DERIVATION OF GUIDELINE

The guideline value of 0.05 mg/L is based on the aesthetic considerations of taste and odour. Insufficient data are available to determine a guideline value based on health considerations. The guideline value is, however, considerably lower than the concentration likely to have a harmful effect and it is therefore unlikely that a person would consume a harmful dose.

REFERENCE

APHA Method 4500-S^{2-} Part D (1992). Sulphide: Methylene blue method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IPCS (1981). Hydrogen Sulfide. Environmental Health Criteria, 19. World Health Organization, International Programme on Chemical Safety.

Iodine
Iodide

GUIDELINE

Iodide: Based on health considerations, the concentration of iodide in drinking water should not exceed 0.1 mg/L.

Iodine: No guideline value has been set for molecular iodine.

GENERAL DESCRIPTION

The element iodine is present naturally in seawater, nitrate minerals and seaweed, mostly in the form of iodide salts. It may be present in water due to leaching from salt and mineral deposits. Iodide can be oxidised to molecular iodine with strong disinfectants such as chlorine.

Molecular iodine solutions are used as antiseptics and as sanitising agents in hospitals and laboratories. Iodine is occasionally used for the emergency disinfection of water for field use but is not used for disinfecting larger drinking water supplies. Iodide is used in pharmaceutical and photographic materials.

Iodide has been detected in drinking water in the United States at a mean concentration of 0.004 mg/L, with a maximum of 0.018 mg/L.

Iodine has a taste threshold in water of about 0.15 mg/L.

Iodide occurs in cows' milk and seafood. Some countries add iodide to table salt to compensate for iodide-deficient diets.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Australian drinking water supplies have not been routinely monitored for iodine or iodide; however, it is likely that concentrations are extremely low. Significant amounts would result in the formation of iodoform byproducts upon chlorination, and these have generally not been detected.

TREATMENT OF DRINKING WATER

It is unlikely that the concentration of iodine or iodide in drinking water would ever be high enough to justify water treatment.

MEASUREMENT

The iodine or iodide concentration in drinking water can be determined using the Leuco crystal violet method (APHA 4500-I^-, Part B 1992). The limit of determination is approximately 0.01 mg/L.

HEALTH CONSIDERATIONS

Iodine is an essential trace element for humans and is used in the synthesis of thyroid hormones. The recommended dietary intake for adults ranges from 0.03 mg/day to 0.15 mg/day.

Iodine is efficiently absorbed by the gastrointestinal tract and deposited in the thyroid gland, the eye, and muscle tissue. More than 70% is found in the thyroid gland.

High oral doses (more than 30 mg/kg body weight) of iodine can be lethal. Lower doses (3.3 mg/kg body weight) have been used to treat asthmatic patients without adverse effects.

NOTE: Important general information is contained in PART II, Chapter 6

Chronic exposure to high amounts of iodide in the diet (over 2 mg/day) can result in a condition known as iodism. Symptoms resemble those of a sinus cold. Long-term consumption of iodinated drinking water has not been associated with adverse health effects in humans. Prisoners drinking water containing up to 1 mg/L iodine for five years showed no signs of iodism or hypothyroidism, but some changes in uptake of iodine by the thyroid gland were observed.

Animal studies using chickens susceptible to autoimmune thyroiditis reported an increase in the incidence of the disease when they were given high doses of iodide in their drinking water (200 mg/L). Excessive iodide consumption may increase the incidence of this disease in humans.

Iodide has not been shown to increase the incidence of cancer of the thyroid in laboratory animals. No data are available on the mutagenic activity of iodine.

DERIVATION OF GUIDELINE

The guideline value for iodide in drinking water was derived as follows:

$$0.1 \text{ mg/L} = \frac{1 \text{ mg/day} \times 0.2}{2 \text{ L/day}}$$

where:

- 1 mg/day is the maximum tolerable daily intake for humans (WHO 1989) based on the effects of iodide
- 0.2 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult.

The maximum tolerable daily intake value includes adequate safety factors. No additional safety factors are necessary.

Recent data from studies on rats indicate that the effects of molecular iodine in drinking water on thyroid hormone concentrations in the blood differ from those of iodide. The guideline value therefore applies only to iodide. No guideline value can be established for molecular iodine.

REFERENCES

APHA Method 4500-I^- Part B (1992). Iodide: Leuco crystal violet method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

WHO (1989). Toxicological evaluation of certain food additives and contaminants: Iodine. World Health Organization Food Additive Series, 24, 267-294. The 33rd meeting of the Joint FAO/WHO Expert Committee on Food Additives, Geneva.

Iron

GUIDELINE

Based on aesthetic considerations (precipitation of iron from solution and taste), the concentration of iron in drinking water should not exceed 0.3 mg/L.

No health-based guideline value has been set for iron.

GENERAL DESCRIPTION

Iron occurs commonly in soil and rocks as the oxide, sulfide and carbonate minerals. In water, it is present in oxidised forms as ferric (Fe(III)) or ferrous (Fe(II)) compounds.

Iron has many domestic and industrial applications, ranging from iron and steel products and pigments in paints to food colours and preparations for preventing iron deficiency in humans. Iron sulfate (hydroxylated ferrous sulfate) is used as a flocculant in water treatment.

In aerated surface waters, iron is often complexed with organic matter such as humic material, or adsorbed onto suspended matter. Iron concentrations in uncontaminated surface waters are usually less than 1 mg/L; however, water supplied through rusting iron pipes can have concentrations of 5 mg/L or higher.

In oxygen-depleted ground water, iron concentrations of up to 100 mg/L have been recorded.

Iron has a taste threshold of about 0.3 mg/L in water, and becomes objectionable above 3 mg/L. High iron concentrations give water an undesirable rust-brown appearance and can cause staining of laundry and plumbing fittings, fouling of ion-exchange softeners, and blockages in irrigation systems. Growths of iron bacteria, which concentrate iron, may cause taste and odour problems and lead to pipe restrictions, blockages and corrosion.

Food is the major source of iron intake, and iron is a natural constituent in plants and animals. Fish, green vegetables and tomatoes have high iron content.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, total iron concentrations range up to 4 mg/L, with typical concentrations around 0.1 mg/L.

TREATMENT OF DRINKING WATER

Iron salts can be effectively removed by the standard water treatment processes of coagulation followed by filtration. Groundwater supplies with a high iron content can be treated to form iron precipitates using aeration, oxidation with chlorine, pH adjustment or lime softening.

MEASUREMENT

The iron concentration in drinking water can be determined using inductively coupled plasma emission spectroscopy or graphite furnace atomic absorption spectroscopy (APHA Method 3500-Fe Parts B or C 1992). The limits of determination are 0.01 mg/L and 0.005 mg/L respectively. Alternatively the phenanthroline colorimetric method (APHA 3500-Fe Part D 1992), which has a limit of determination of 0.01 mg/L, can be used. Flame atomic absorption spectroscopy is not sufficiently sensitive.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Iron is an essential trace element for humans. Minimum daily requirement varies with age and sex. For example, women aged 11-50 years need about 14 mg per day but this requirement doubles for pregnant women, while men require about 7 mg per day. Iron deficiency is common and affects people throughout the world.

The amount of iron absorbed from food by the gastrointestinal tract varies from 1% to 20%, according to individual requirements and the source of iron. It is used in the production of haemoglobin, myoglobin and a number of enzymes, and is stored in the spleen, liver, bone marrow and muscle.

Numerous cases of iron poisoning have been reported, mainly among young children who ingest medicinal iron supplements formulated for adults. Physiological regulation of iron absorption confers a high degree of protection against iron toxicity and there are a number of reports of people, particularly adults, taking high doses of iron with no adverse effects.

Studies with animals over long periods have reported only very mild adverse effects associated with a high iron intake.

There is no evidence that iron induces cancer in laboratory animals. Most iron salts have been inactive in tests for mutagenicity and do not induce chromosome aberrations in human cells.

DERIVATION OF GUIDELINE

Insufficient data are available to determine a health-based guideline value for iron in drinking water. The guideline value is based on the taste threshold of 0.3 mg/L, which is similar to the concentration that would result in iron precipitating out of solution. Sufficient human data exist to indicate that iron in drinking water would not become a health concern unless the concentration was above 3 mg/L, well in excess of the concentration that would cause water to taste objectionable, and it is unlikely that such water would be consumed.

REFERENCES

APHA Method 34500-Fe Part B (1992). Iron: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Fe Part C (1992). Iron: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Fe Part D (1992). Iron: Phenanthroline method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Lead

GUIDELINE

Based on health considerations, the concentration of lead in drinking water should not exceed 0.01 mg/L.

GENERAL DESCRIPTION

Lead can be present in drinking water as a result of dissolution from natural sources, or from household plumbing systems containing lead. These may include lead in pipes, or in solder used to seal joints. The amount of lead dissolved will depend on a number of factors including pH, water hardness and the standing time of the water.

Lead is the most common of the heavy metals and is mined widely throughout the world. It is used in the production of lead acid batteries, solder, alloys, cable sheathing, paint pigments, rust inhibitors, ammunition, glazes and plastic stabilisers. The organo-lead compounds tetramethyl and tetraethyl lead are used extensively as anti-knock and lubricating compounds in gasoline.

Drinking water concentrations of lead reported overseas are usually less than 0.002 mg/L, but concentrations of 0.1 mg/L have been reported in Scotland where lead pipes and soft, acidic water are contributing factors.

Approximately 80% of the daily intake of lead is from the ingestion of food, dirt and dust. Food contains small but significant quantities of lead, which can increase when acidic food is stored in lead-glazed ceramic pottery or lead-soldered cans. The use of lead-free solders is becoming more widespread in the food processing industry. The average Australian adult dietary intake of lead is approximately 0.1 mg per day.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, total lead concentrations range up to 0.01 mg/L, with typical concentrations less than 0.005 mg/L.

TREATMENT OF DRINKING WATER

Lead concentrations in drinking water can be reduced by conventional methods of water treatment using coagulants or lime softening.

MEASUREMENT

The concentration of lead in drinking water can be determined by graphite furnace atomic absorption spectroscopy (APHA Method 3500-Pb Part B 1992). The limit of determination is 0.005 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Lead can be absorbed by the body through inhalation, ingestion or placental transfer. In adults, approximately 10% of ingested lead is absorbed but in children this figure can be 4 to 5 times higher. After absorption, the lead is distributed in soft tissue such as the kidney, liver, and bone marrow where it has a biological half-life in adults of less than 40 days, and in skeletal bone where it can persist for 20 to 30 years.

In humans, lead is a cumulative poison that can severely affect the central nervous system. Infants, fetuses and pregnant women are most susceptible. Placental transfer of lead occurs in humans as early as the 12th week of gestation and continues throughout development.

Many epidemiological studies have been carried out on the effects of lead exposure on the intellectual development of children. Although there are some conflicting results, on balance the studies demonstrate that exposure to lead can adversely affect intelligence.

These results are supported by experiments using young primates, where exposure to lead causes significant behavioural and learning difficulties of the same type as those observed in children.

Other adverse effects associated with exposure to high amounts of lead include kidney damage, interference with the production of red blood cells, and interference with the metabolism of calcium needed for bone formation.

Epidemiological studies have found no association between lead and tumour incidence. Kidney tumours, however, have been reported in rats, mice and hamsters fed lead salts in their diet, but only at doses above 27 mg/kg body weight per day. Gliomas (brain tumours) have also been reported in rats. In addition, lead salts given orally to rats have increased the carcinogenic activity of known carcinogens.

Tests for mutagenicity using strains of bacteria have largely been negative. Tests using mammalian cells have been inconclusive, with some studies reporting negative results and some reporting chromosome damage.

The International Agency for Research on Cancer has concluded that lead is possibly carcinogenic to humans (Group 2B, inadequate human data but sufficient evidence in animals for inorganic lead compounds) (IARC 1987).

DERIVATION OF GUIDELINE

The guideline value for lead in drinking water is based on a WHO assessment and was determined by the need to protect young children, infants and pregnant women, the groups most at risk. The value was determined as follows:

$$0.01 \text{ mg/L} = \frac{0.0035 \text{ mg/kg body weight per day} \times 13 \text{ kg} \times 0.2}{1 \text{ L/day}}$$

where:

- 0.0035 mg/kg body weight per day is the lead intake which, based on metabolic studies with infants, does not result in an increase in lead retention (Ziegler *et al* 1978, Ryu *et al* 1983)
- 13 kg is the average weight of a child at 2 years of age
- 0.2 is the proportion of total lead intake attributable to water consumption. Sufficient data are available to indicate that 80% of intake is from food, dirt and dust
- 1 L/day is the average amount of water consumed by a young child.

The NHMRC in 1993 established guidelines for lead in Australians, which provide the basis for establishing acceptable levels of lead in air, food, soil and water. Pending an assessment of the impact of this review on the guideline value for lead, the guideline should be regarded as an interim value.

REFERENCES

APHA Method 3500-Pb Part B (1992). Lead: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

NHMRC (1993) Revision of Australian Guidelines for Lead in Blood and Lead in Ambient Air, 115th Session, NHMRC, www.nhmrc.gov.au/publications/reports/eh8.pdf

Ryu JE, Ziegler EE, Nelson SE and Fomon SJ (1983). Dietary intake of lead and blood lead concentration in early infancy. *American Journal of Disease of Children*, 137, 886–891.

Zeigler EE, Edwards BB, Jensen RL, Mahaffey KR and Fomon SJ (1978). Absorption and retention of lead by infants. *Pediatric Research*, 12, 29–34.

NOTE: Important general information is contained in PART II, Chapter 6

Lindane

GUIDELINE

Lindane should not be detected in drinking water. If present in drinking water, lindane would not be a health concern unless the concentration exceeded 0.02 mg/L.

If it is detected, remedial action should be taken to stop contamination. The limit of determination is 0.00005 mg/L (50 ng/L).

GENERAL DESCRIPTION

Lindane is the gamma isomer of hexachlorocyclohexane. It is registered for use in Australia as an insecticide for seed treatment only, and as a therapeutic substance for the treatment of head lice on humans.

In soil, lindane can be degraded under aerobic conditions, with a half-life from 88 to 1146 days. The main degradation products are chlorobenzenes, and penta- and tetra-chlorophenols. Anaerobic degradation is more rapid than aerobic degradation.

Lindane can enter water supplies from direct application for the control of mosquitoes, from use in agriculture and forestry, and other sources. Overseas, lindane has occasionally been detected in surface and groundwater supplies.

Daily adult dietary intake of lindane has been estimated in some countries at approximately 0.001 mg/day. No data are available on Australian dietary intakes.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Lindane has been detected on a number of occasions in major Australian storage reservoirs and source waters. Usually concentrations are very low (less than 0.0002 mg/L).

TREATMENT OF DRINKING WATER

No published reports are available on methods for the removal of lindane from drinking water. Granular activated carbon would probably be effective.

MEASUREMENT

Lindane residues can be extracted from water using nonpolar solvents such as pentane, and analysed using gas chromatography with electron capture detection (APHA Method 6630 Part B 1992). The limit of determination is 0.00005 mg/L (50 ng/L).

HEALTH CONSIDERATIONS

Lindane is efficiently absorbed by the gastrointestinal tract and stored in fatty tissue. It can cross the placenta and can also be present in human milk. Lindane is metabolised to chlorocyclohexenes and hexachlorocyclohexanol.

Extensive reviews and summaries of the human and animal toxicology of lindane are available (IARC 1987, JMPR 1989, IPCS 1991).

Lindane is neurotoxic in humans. Oral administration of 30 mg per person for up to 3 days produced only nausea in 6 of 15 patients; however, severe toxic symptoms were described in healthy volunteers after oral intake of 15-17 mg/kg body weight of lindane in a liquid carrier.

NOTE: Important general information is contained in PART II, Chapter 6

Occupational poisoning has also been reported. Blood dyscrasias have been reported in people exposed to lindane or lindane and other chemicals; however, studies conducted over periods of several weeks to several years have given no indication of a cause-effect relationship.

In some studies, but not in others, lindane produced hyperplastic nodules and/or hepatocellular adenomas in mice at doses from 24 mg/kg body weight per day. A study in rats using dose levels up to about 32 mg/kg body weight per day was negative.

Lindane appears not to have mutagenic potential.

The International Agency for Research on Cancer has concluded that lindane is possibly carcinogenic to humans (Group 2B, inadequate human data, limited evidence in experimental animals) (IARC 1987).

DERIVATION OF GUIDELINE

The health-based guideline value of 0.02 mg/L for lindane was determined as follows:

$$0.02 \text{ mg/L} = \frac{0.008 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day}}$$

where:

- 0.008 mg/kg body weight per day is the maximum ADI derived from a short-term study using rats (JMPR 1989)
- 70 kg is the average weight of an adult
- 0.1 gives a guideline value based on 10% of the ADI
- 2 L/day is the average amount of water consumed by an adult.

The maximum ADI value includes a safety factor of 100 (10 for interspecies variations and 10 for intraspecies variations). No additional safety factor to account for the tumour-promoting potential of lindane was included in the calculation of the ADI because effects were seen only at high doses and the compound has had extensive international review. No additional safety factors are necessary.

The WHO guideline value of 0.002 mg/L was determined using 1% of the ADI to allow for increased exposure from other sources. Such a low percentage of the ADI was considered inappropriate for Australia, where lindane has only rarely been detected in food and drinking water supplies.

REFERENCES

APHA Method 6630 Part B (1992). Organochlorine pesticides: Liquid-liquid extraction, gas chromatographic method I. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1991). Lindane. Environmental Health Criteria, 124. World Health Organization, International Programme on Chemical Safety.

JMPR (1989). Pesticide Residues in Food - 1989. Report of the Joint FAO/WHO Meeting on Pesticide Residues in Food. Food and Agriculture Organization of the United Nations, FAO Plant Production and Protection Paper 99.

Manganese

GUIDELINE

Based on aesthetic considerations, the concentration of manganese in drinking water should not exceed 0.1 mg/L.

Manganese would not be a health consideration unless the concentration exceeded 0.5 mg/L.

GENERAL DESCRIPTION

Manganese is present in the environment in the divalent (Mn(II)), tetravalent (Mn(IV)), and heptavalent (Mn(VII)) states. Most of the divalent compounds are soluble in water. The most common tetravalent compound, manganese dioxide, is insoluble; however, the heptavalent permanganate is soluble.

Manganese is principally used in the manufacture of iron, steel and alloys.

Uncontaminated rivers and streams generally have low concentrations of manganese, ranging from 0.001 mg/L to 0.6 mg/L. High concentrations may occur in polluted rivers or under anoxic conditions such as at the bottom of deep reservoirs or lakes, or in groundwater.

At concentrations exceeding 0.1 mg/L, manganese imparts an undesirable taste to water and stains plumbing fixtures and laundry. Even at concentrations of 0.02 mg/L, manganese will form a coating on pipes that can slough off as a black ooze. Some nuisance microorganisms can concentrate manganese and give rise to taste, odour and turbidity problems in distribution systems.

Manganese interferes with the commonly used DPD method for determining chlorine residual, resulting in an overestimation of the residual so that chlorine appears to be present when it may not be.

Concentrations of manganese in food can vary considerably. Highest concentrations have been reported in grains, nuts and vegetables, while tea leaves can have extremely high concentrations of manganese. It has been estimated that the average dietary intake of manganese is 2-4 mg per day.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, manganese concentrations can range up to 0.25 mg/L, with typical concentrations usually less than 0.01 mg/L.

TREATMENT OF DRINKING WATER

Manganese concentrations in drinking water can be reduced by converting soluble forms to insoluble precipitates, followed by filtration. Chlorine can be used to oxidise some forms of manganese. Lime softening at high pH may also be effective in removing some forms.

MEASUREMENT

The manganese concentration in drinking water can be determined using inductively coupled plasma emission spectroscopy or graphite furnace atomic absorption spectroscopy (APHA Method 3500-Mn Parts B or C 1992). The limits of determination are 0.005 mg/L and 0.001 mg/L respectively.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Manganese is an essential element and is required by mammals and birds for normal growth. Manganese deficiency affects bone, the brain and reproduction in a number of animal species. Although no specific symptoms have been described in humans, it has been suggested that manganese deficiency may be associated with anaemia, and in children, with bone disorders.

Owing to the low solubility of manganese in gastric juices, only 3–8% of ingested manganese is absorbed by the gastrointestinal tract. After absorption, it is concentrated in the liver and eventually excreted in faeces. In humans it has a relatively short biological half-life of 13 to 37 days.

An extensive review and summary of the human and animal toxicity data for manganese is available (IPCS 1981).

In humans, manganese toxicity has occurred mainly as a result of inhalation of manganese dust over long periods. By the oral route, manganese is regarded as one of the least toxic elements.

In one case involving the heavy consumption of highly contaminated well water, symptoms included lethargy, increased muscle tone, tremor and mental disturbances. Concentrations of manganese were over 14 mg/L; however, concentrations of other metals were also high and the reported effects may not be due solely to manganese.

Experiments with laboratory animals have shown no adverse effects other than a change in appetite and a reduction in the metabolism of iron in haemoglobin synthesis.

There is no firm evidence that manganese is carcinogenic. Some studies indicate that it may, in fact, have an anticarcinogenic effect. Some *in vitro* studies using mammalian and bacterial cells have reported that manganese acts as a mutagen.

DERIVATION OF GUIDELINE

The health-based guideline value for manganese in drinking water can be derived as follows:

$$0.5 \text{ mg/L} = \frac{10 \text{ mg/day} \times 0.1}{2 \text{ L/day}}$$

where:

- 10 mg/day is the amount of manganese that can be safely consumed from all sources (WHO 1973)
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult.

The maximum tolerable daily intake value includes adequate safety factors. No additional safety factors are necessary.

This value exceeds the concentration at which manganese can cause taste and other problems. Based on these considerations, the aesthetic guideline value has been set at 0.1 mg/L.

REFERENCES

APHA Method 3500-Mn Part B (1992). Manganese: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Mn Part C (1992). Manganese: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IPCS (1981). Manganese. Environmental Health Criteria, 17. World Health Organization, International Programme on Chemical Safety.

WHO (1973). Trace elements in human nutrition: Manganese. Report of the World Health Organization Expert Committee, Technical Report Service, 532, 34-36, Geneva.

NOTE: Important general information is contained in PART II, Chapter 6

Mercury

GUIDELINE

Based on health considerations, the concentration of total mercury in drinking water should not exceed 0.001 mg/L.

GENERAL DESCRIPTION

Natural release of mercury into drinking water is extremely low, but contamination can result from industrial emission or spills. Mercury compounds fall into two categories: inorganic mercury salts, many of which are very insoluble in water; and organic mercury compounds, the most notable being methyl mercury. Inorganic mercury can be converted into methyl mercury, possibly by the action of bacteria in sediments, and can then readily enter the food chain.

Mercury is used widely in electrical components including cells, lamps, arc rectifiers and switches. It is also used in dental amalgams, fungicides, antiseptics, preservatives and pharmaceuticals.

Concentrations of total mercury in natural water are generally so low that accurate analysis is difficult. Studies overseas have reported concentrations of less than 0.0005 mg/L, with some sources less than 0.00003 mg/L (30 ng/L). The highest value was 0.0055 mg/L from some wells in Japan.

Food is the main route of exposure, with highest concentrations found in fish and fish products. The average Australian adult dietary intake of mercury is approximately 0.004 mg per day. Drinking water is likely to constitute only a small fraction of total intake.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, the concentrations of total mercury range up to 0.001 mg/L, with typical concentrations usually less than 0.0001 mg/L.

TREATMENT OF DRINKING WATER

Coagulation is moderately effective in reducing the concentration of inorganic mercury in drinking water. Granular activated carbon is effective in removing both inorganic and organic mercury from water.

MEASUREMENT

The concentration of total mercury in drinking water can be determined by the cold vapour atomic absorption method (APHA 3500-Hg Part B 1992). The limit of determination is 0.0001 mg/L.

HEALTH CONSIDERATIONS

a) Inorganic mercury

Less than 15% of inorganic mercury in drinking water is absorbed by the gastrointestinal tract. Inorganic mercury compounds accumulate in the kidney and have a long biological half-life, probably many years.

An extensive review and summary of the human and animal toxicity data for inorganic mercury is available (IPCS 1991).

NOTE: Important general information is contained in PART II, Chapter 6

Many studies have looked at groups of workers occupationally exposed to mercury, and have reported health effects including tremors, mental disturbances and gingivitis (inflammation of the mucous membrane surrounding the teeth). The main toxic effects are to the kidney, leading to kidney failure.

In animal studies, the principal target organs of mercury toxicity are the kidney and the central nervous system. Some disruption to ovulation in female rats has also been reported.

Various reports indicate that inorganic mercury binds to, and damages, mammalian DNA. Some evidence of carcinogenicity in rats has been reported.

b) Organic mercury

Organic mercury compounds are unlikely to be found in uncontaminated drinking water; however, the toxic effects are more severe than those of inorganic mercury.

An extensive review and summary of the human and animal toxicity data for methyl mercury is available (IPCS 1990).

Methyl mercury compounds are almost completely absorbed by the gastrointestinal tract. Methyl mercury has greater lipid solubility than inorganic mercury and can cross biological membranes, especially in the brain, spinal cord, peripheral nerves and placenta.

The main effects of methyl mercury poisoning are severe irreversible neurological disorder and mental disability.

In Japan, two major epidemics of methyl mercury poisoning, known as Minamata disease, were caused by the industrial release into Minamata Bay of methyl mercury and other mercury compounds. The compounds accumulated in fish, which were subsequently eaten by humans. Other countries have reported cases of poisoning caused by mercury contamination of bread and cereal.

Animal studies with rats, cats, monkeys and squirrels have shown similar results, with the main effects of long-term exposure being behavioural changes, neurological disturbances and disturbances to the movement of legs and tails.

Data are insufficient to determine the carcinogenic effects of methyl mercury; however, it is active in inducing chromosomal aberrations *in vivo*.

DERIVATION OF GUIDELINE

The guideline value for mercury in drinking water was derived as follows:

$$0.001 \text{ mg/L} = \frac{0.00047 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day}}$$

where:

- 0.00047 mg/kg body weight per day is the maximum tolerable daily intake to ensure that adverse effects will not occur (WHO 1988)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult.

The maximum tolerable daily intake value includes adequate safety factors. No additional safety factors are necessary.

The guideline value was set on the basis of the toxicity of methyl mercury, as this is the most toxic form. It is likely that methyl mercury would be less than 10% of the total mercury concentration.

The guideline value should be sufficient to protect pregnant women and nursing mothers, who are at greatest risk from the adverse effects of methyl mercury. Data are insufficient to determine a separate value for this group.

REFERENCES

APHA Method 3500-Hg Part B (1992). Mercury: Cold vapor Atomic Absorption method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IPCS (1990). Methyl Mercury. Environmental Health Criteria, 101. World Health Organization, International Programme on Chemical Safety.

IPCS (1991). Inorganic Mercury. Environmental Health Criteria, 118. World Health Organization, International Programme on Chemical Safety.

WHO (1988). Toxicological evaluation of certain food additives and contaminants: Methylmercury. 33rd meeting of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization Food Additive Series, 24, 296-328.

NOTE: Important general information is contained in PART II, Chapter 6

Molybdenum

GUIDELINE

Based on health considerations, the concentration of molybdenum in drinking water should not exceed 0.05 mg/L.

GENERAL DISCUSSION

Molybdenum is present in ground and surface waters at very low concentrations, generally below 0.01 mg/L. Higher concentrations have been reported in the vicinity of molybdenum mining operations. Fly ash deposited onto soils from coal-fired power stations can be a significant source of molybdenum. Application of fertilisers may also increase the concentration of molybdenum in ground and surface water.

Molybdenum is used in the production of steel, electrical components such as spark plugs, and nonferrous metal alloys. Molybdenum compounds are used as lubricants in oils and greases, and in fertilisers to overcome molybdenum deficiency in soils.

Many foods contain significant amounts of molybdenum. Legumes, grains and liver have the highest concentrations and food is a significant source of intake.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Australian drinking water supplies have not been routinely monitored for molybdenum.

TREATMENT OF DRINKING WATER

There are no published methods for the removal molybdenum from drinking water.

MEASUREMENT

The concentration of molybdenum in drinking water can be determined by inductively coupled plasma emission spectroscopy or graphite furnace atomic absorption spectroscopy (APHA Method 3500-Mo Parts B or C 1992). Limits of determination are 0.04 mg/L and 0.005 mg/L respectively.

HEALTH CONSIDERATIONS

Molybdenum is an essential trace element for humans and other animals. The estimated requirement is between 0.15 mg/day and 0.5 mg/day for adults.

Approximately 30–70% of dietary molybdenum is absorbed in the gastrointestinal tract. Highest concentrations of molybdenum are found in the liver, kidney and bones. There does not appear to be any significant bioaccumulation of molybdenum in the body. Approximately 90% of ingested molybdenum is excreted in the urine.

Data are scarce on the long- and short-term toxicity of molybdenum in humans. One study of people consuming up to 0.2 mg/L of molybdenum in drinking water for 2 years reported no adverse effects. Another study has linked high intake of molybdenum in food with gout-like symptoms, joint pains of the legs and hands, and enlargement of the liver.

NOTE: Important general information is contained in PART II, Chapter 6

A number of long- and short-term animal studies have been undertaken, with considerable variability in the results depending on the chemical nature of the compound and the animal species. Effects included changes in skin and fur pigment, enlargement of joints, weight loss, diarrhoea and emaciation. Not all these effects were observed in each study and effects usually occurred only at high doses.

No relevant data are available on the carcinogenicity of molybdenum. Tests for mutagenicity with bacteria have been inconclusive.

DERIVATION OF GUIDELINE

The guideline value for molybdenum in drinking water was determined as follows:

$$0.05 \text{ mg/L} = \frac{0.5 \text{ mg/day} \times 0.2}{2 \text{ L/day}}$$

where:

- 0.5 mg/day is the upper range of the estimated adult requirement for molybdenum
- 0.2 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult.

Studies with animals and humans, while unable to establish a no effect level, reported no adverse effects due to molybdenum in drinking water at concentrations of 0.05 mg/L (Chappell *et al* 1979).

Adverse human health effects have been reported with molybdenum intakes of 10 mg/day (Chappell *et al* 1979). This is a hundred times higher than the guideline value, assuming that water consumption is 2 litres per day.

The WHO guideline value of 0.07 mg/L was determined using a different approach which, upon review, was considered to be questionable. The difference between the two values is not significant.

REFERENCES

APHA Method 3500-Mo Part B (1992). Molybdenum: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Mo Part C (1992). Molybdenum: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Chappell WR, Meglen RR, Moure-Eraso R, Solomons CC, Tsangas TS, Walravens PA and Wilson PW (1979). Human health effects of molybdenum in drinking water. United States Environmental Protection Agency, EPA-600/1-79-006, Cincinnati, Ohio, 100 pages, NTIS PB-292755.

Monochloramine

(Revised and endorsed 2001)

GUIDELINE

Based on health considerations, the concentration of monochloramine in drinking water should not exceed 3 mg/L (equivalent to 4.1 mg Cl as Cl_2/L).

GENERAL DESCRIPTION

Monochloramine is used as a disinfectant for drinking water supplies. Its use as an alternative to chlorine is becoming more widespread. Although it is less effective than chlorine as an oxidising agent, it persists for a longer time in lengthy pipelines; contact times with microorganisms are consequently longer and concentrations of byproducts such as trihalomethanes are reduced. Where monochloramine is used overseas as a primary disinfectant, concentrations range from 1.5 to 2.5 mg/L.

Monochloramine, dichloramine and trichloramine can be formed when water containing ammonia is chlorinated. At neutral pH, monochloramine is the main product and is more persistent. Conditions that favour the formation of dichloramine and trichloramine should be avoided because these compounds have lower taste and odour thresholds than monochloramine.

Monochloramine has an odour threshold of 0.5 mg/L.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Monochloramine is used as a disinfectant in some Australian reticulated supplies, and concentrations up to 8 mg/L have been applied (but only in highly turbid supplies where it is difficult to maintain a residual without using a high initial dose). However, typical residual concentrations are about 0.5 mg/L.

REMOVAL FROM DRINKING WATER

Monochloramine can be removed from drinking water by the use of granular activated carbon, or by reducing agents such as sodium sulfite or sodium bisulfite.

MEASUREMENT

The concentration of monochloramine in drinking water can be determined by the DPD ferrous titrimetric method (APHA Method 4500-Cl Part F 1992). The limit of determination is 0.1 mg/L.

This method measures monochloramine in terms of mg Cl as Cl_2/L. The guideline value of 3mg/L monochloramine can be converted to mg Cl as Cl_2/L based on molecular weights as follows:

$$3 \text{ mg/L monochloramine} = \frac{71 \times 3}{51.5} = 4.1 \text{ mg CL as } Cl_2/L$$

where:

- 71 is the molecular weight of chlorine (Cl_2)
- 51.5 is the molecular weight of monochloramine (NH_2Cl).

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

In studies with rats it has been shown that monochloramine is readily absorbed and does not accumulate in tissues. It is metabolised rapidly to the chloride ion and excreted in urine In mammals, no specific toxic effects have been reported for monochloramine from either short or long-term studies. However monochloramine is toxic to fish.

Carcinogenicity studies have reported a slight increase in the incidence of mononuclear cell leukaemia in female rats exposed to monochloramine for 2 years, at doses of approximately 10 mg/kg bodyweight per day. There was no evidence of carcinogenic activity in male rats, or male and female mice.

In humans, short-term exposure to concentrations of up to 24 mg/L of monochloramine in drinking water did not produce adverse effects. Similarly, volunteers given water containing up to 5 mg/L of monochloramine for 12 weeks did not exhibit adverse effects.

Acute haemolytic anaemia has been reported in haemodialysis patients when tap water containing chloramines was used for dialysis.

Monochloramine exhibited weak mutagenic activity in one test using bacteria but was negative in another test. It did not induce chromosome aberrations in mammalian cells.

No data are available on the health effects of dichloramine or trichloramine in drinking water.

DERIVATION OF GUIDELINE

The guideline value for monochloramine in drinking water was derived as follows:

$$3 \text{ mg/L} = \frac{9.4 \text{ mg/kg bodyweight per day} \times 70 \text{ kg}}{2 \text{ L/day} \times 100}$$

where:

- 9.4 mg/kg body weight per day is the no observable adverse effect level (NOAEL) based on 2-year drinking water study using rats (NTP 1992) - a similar value was obtained from a human study but this was of a limited duration
- 70 kg is the average weight of an adult
- 2 L/day is the average amount of water consumed by an adult
- 100 is the safety factor from using the results of an animal study as a basis for human exposure (10 for interspecies variations, and 10 for intraspecies variations).

It should be noted that the guideline value is 3 mg/L of monochloramine and as described under 'Measurement' this is equivalent to 4.1 mg Cl as Cl_2/L as measured by standard DPD ferrous titrimetric methods.

It is assumed that all monochloramine intake is from drinking-water.

REFERENCES

APHA Method 4500-Cl Part F (1992). Chlorine (residual): DPD Ferrous Titrimetric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

NTP (1992). Toxicology and carcinogenesis studies of chlorinated water and chloraminated water in F344/N rats and B6C3F1 mice (drinking water studies). National Toxicology Program, Technical Report No. 392, Publication No. 92-2847. United States Department of Health and Human Services, National Institute of Health.

Nickel

GUIDELINE

Based on health considerations, the concentration of nickel in drinking water should not exceed 0.02 mg/L.

GENERAL DESCRIPTION

Drinking water generally contains very low concentrations of nickel. Concentrations reported overseas are usually less than 0.01 mg/L. Higher concentrations, up to 0.5 mg/L, have been reported where water has been in prolonged contact with nickel-plated tap and plumbing fittings; however, these higher concentrations are unusual.

Nickel is used in the electroplating industry and in alloys used in the chemical, marine, nuclear and aerospace industries. It is used as a catalyst in industrial processes, and in oil refining. Main releases to the environment are from the burning of fossil fuels and in waste discharges from electroplating industries.

Nickel is present in many foods. Highest concentrations occur in cocoa, soy beans and some cereals. It has been estimated that the average daily dietary intake is between 0.1 mg/day and 0.3 mg/day.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, concentrations of nickel range up to 0.03 mg/L, with typical concentrations less than 0.01 mg/L.

TREATMENT OF DRINKING WATER

Nickel can be co-precipitated with iron and manganese oxides.

MEASUREMENT

The nickel concentration in drinking water can be determined using inductively coupled plasma emission spectroscopy or graphite furnace atomic absorption spectroscopy (APHA Method 3500-Ni Parts B and C 1992). The limits of determination are approximately 0.02 mg/L and 0.005 mg/L respectively. Lower concentrations can be determined with pre-concentration using chelation or solvent extraction techniques.

HEALTH CONSIDERATIONS

Intestinal absorption of soluble nickel in drinking water can be as high as 27%, compared with only 0.7% from food. After absorption, nickel appears to be distributed to most organs, with higher amounts in the kidneys, lung and liver. It can cross the human placenta.

An extensive review and summary of the human and animal toxicity data for nickel is available (IPCS 1991).

In humans, long-term exposure may result in toxic effects to the kidney. Increased beta-microglobulin concentrations were reported among electroplating workers exposed to high amounts of nickel.

Nickel is known to be a common skin allergen and can cause dermatitis, particularly in younger women. While skin is sensitised, oral intake of low doses (0.0083 mg/kg body weight per day) may provoke contact dermatitis in sensitised individuals.

NOTE: Important general information is contained in PART II, Chapter 6

Several epidemiological studies have demonstrated that inhalation of nickel can cause lung, sinus and nasal cancer. There is no evidence that other organs are affected, or that nickel is carcinogenic when ingested.

Animal studies have reported altered body weights, some evidence of liver toxicity and mild kidney toxicity with high nickel doses (over 100 mg/kg body weight per day). Nickel has also affected the immune system in laboratory mice.

Some nickel compounds are carcinogenic when injected into laboratory animals but not when administered orally. Tests for mutagenicity with strains of bacteria have mostly been negative but gene mutations and chromosome aberrations have been reported in mammalian cells.

The International Agency for Research on Cancer has concluded that nickel compounds are carcinogenic to humans (Group 1, sufficient evidence of carcinogenicity in humans) (IARC 1990).

DERIVATION OF GUIDELINE

The guideline value for nickel in drinking water was derived as follows:

$$0.02 \text{ mg/L} = \frac{5 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 5 mg per kg body weight per day is the no effect level for altered organ-to-body-weight ratios in a 2-year study with rats (Ambrose 1976)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in applying the results of animal studies to humans (10 for interspecies variations, 10 for intraspecies variations and 10 to compensate for the lack of adequate studies on chronic effects and for increased intestinal absorption when taken on an empty stomach). An additional factor for carcinogenicity was not included as effects only occurred on inhalation (no effects were observed on ingestion) and were localised to the lung and nasal passages.

REFERENCES

Ambrose AM, Larson PS, Borzelleca JG and Hannigar GR Jr (1976). Long term toxicologic assessment of nickel in rats and dogs. *Journal of Food Science and Technology*, 13, 181–187.

APHA Method 3500-Ni Part B (1992). Nickel: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Ni Part C (1992). Nickel: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1990). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: chromium, nickel and welding. World Health Organization, International Agency for Research on Cancer, 49.

IPCS (1991). Nickel. Environmental Health Criteria, 108. World Health Organization, International Programme on Chemical Safety.

Nitrate and nitrite

GUIDELINE

Nitrate: Based on health considerations, the guideline value of 50 mg-NO_3/L (as nitrate) has been set to protect bottle-fed infants under 3 months of age. Up to 100 mg-NO_3/L can be safely consumed by adults and children over 3 months of age.

Where a water supply has between 50 and 100 mg-NO_3/L nitrate, active measures are required to ensure that those caring for infants are aware of the need to use alternative water sources in making up bottle feeds for babies under 3 months of age.

Nitrite: Based on health considerations, the concentration of nitrite in drinking water should not exceed 3 mg-NO_2/L (as nitrite).

GENERAL DESCRIPTION

Nitrate and nitrite ions are naturally occurring oxides of nitrogen that make up part of the nitrogen cycle.

Nitrate is formed from the oxidation of organic wastes such as manure, by the action of nitrogen-fixing bacteria in soils, or from lightning strikes through air. Nitrates are also manufactured for use in explosives and inorganic fertilisers.

Intensification of farming practices and sewage effluent disposal to streams have led to increasing amounts of nitrate in some waters, particularly groundwater.

The nitrite ion is relatively unstable and can be formed by the reduction of nitrate in poorly oxygenated waters. It is rapidly oxidised to nitrate and is seldom present in well oxygenated or chlorinated supplies. Chemical and biological processes can result in further reduction to various compounds, including ammonia, or oxidation back to nitrate.

Food, particularly vegetables and cured meat, is the major source of nitrate intake for humans.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies nitrate concentrations range up to 18 mg-NO_3/L, with typical concentrations usually less than 0.15 mg-NO_3/L. Nitrite is generally not present in significant concentrations, although operational difficulties in chloramination can lead to nitrite formation due to the action of nitrifying bacteria.

Very high nitrate concentrations (200-300 mg-NO_3/L) have been recorded in some groundwater supplies in rural areas.

TREATMENT OF DRINKING WATER

Conventional water treatment is not effective for nitrate removal. Nitrate reduction facilities are expensive to operate and involve the use of anion exchange resins.

NOTE: Important general information is contained in PART II, Chapter 6

MEASUREMENT

The nitrate concentration in drinking water can be determined by a colorimetric procedure following reduction of nitrate to nitrite using a cadmium column (APHA Method 4500-NO_3 Part E 1992). The limit of determination is 0.01 mg/L. Nitrite can be determined separately using the same procedure but without the reduction column (APHA Method 4500-NO_2 Part B 1992). Alternatively, nitrate and nitrite can be determined using ion chromatography (APHA Method 4110 Part B 1992).

HEALTH CONSIDERATIONS

The toxicity of nitrate to humans is thought to be solely due to its reduction to nitrite. The major biological effect of nitrite in humans is its involvement in the oxidation of normal haemoglobin to methaemoglobin, which is unable to transport oxygen to the tissues. This condition is called methaemoglobinaemia. Young infants are more susceptible to methaemoglobin formation than older children and adults. Other susceptible groups include pregnant women and people with a deficiency of glucose-6-phosphate dehydrogenase or methaemoglobin reductase.

In animals, laboratory experiments suggest that neither nitrite nor nitrate acts directly as a carcinogen. There is concern that nitrite may react with foods rich with secondary amines to form N-nitroso compounds in the stomach: many of these compounds are known to be carcinogenic in animals. Some epidemiological evidence suggests a relationship between nitrate and gastric cancer in humans, but this has not been confirmed in more definitive analytical studies.

Nitrate is not mutagenic in tests with bacteria and mammalian cells *in vitro*. Chromosome aberrations have been observed in the bone marrow of rats but may be due to the formation of N-nitroso compounds. Nitrite is mutagenic in both *in vivo* and *in vitro* experiments using mammalian cells.

DERIVATION OF GUIDELINE

The guideline value of 50 mg-NO_3/L for nitrate is set to protect young infants, the most sensitive group (USEPA 1990). Up to 100 mg-NO_3/L can be used by adults and children over 3 months of age without significant health effects. The guideline level for nitrite of 3 mg-NO_2/L is based on a relative potency for nitrite and nitrate with respect to methaemoglobin formation.

If the value of 50 mg-NO_3/L is exceeded, the local health authority should be informed so that parents can be advised to use rainwater or bottled water in making up feeds for babies under 3 months of age in order to prevent methaemoglobinaemia.

REFERENCES

APHA Method 4110 Part B (1992). Determination of ions by ion chromatography: ion chromatography with chemical suppression of eluant conductivity. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 4500-NO_3 Part E (1992). Nitrogen (nitrate): Cadmium reduction method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 4500-NO_2 Part B (1992). Nitrogen (nitrite): Colorimetric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

USEPA (1990). Drinking water criteria document on Nitrate/Nitrite. Report TR-1242-608 from ICAIR Life Systems Inc., Cleveland, Ohio. Prepared for Criteria and Standards Division Office of Drinking Water, United States Environmental Protection Agency, Washington DC.

Nitrilotriacetic acid (NTA)

GUIDELINE

Based on health considerations, the concentration of nitrilotriacetic acid in drinking water should not exceed 0.2 mg/L.

GENERAL DESCRIPTION

NTA may be present in drinking water that has been contaminated with sewage, for example by sewage discharge into a river or stream that is then used for drinking water. It is likely to be present in the form of metal complexes rather than the free acid. NTA has been detected in water supplies of municipalities in Canada and the United States at a mean concentration of less than 0.004 mg/L, with a small number of supplies exceeding 0.01 mg/L.

NTA is a chelating agent and forms soluble metal complexes with a number of metal ions including calcium and magnesium. It is used in laundry detergents as a replacement for phosphate, particularly in countries where legislation restricts the use of phosphate-based detergents. It is also used in the treatment of boiler water to prevent scale formation, and in the photographic, metal plating, textile manufacturing, and paper and cellulose industries. It is not widely used in Australia.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

NTA has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

No published reports are available on water treatment procedures to remove NTA from drinking water.

MEASUREMENT

Analysis can be undertaken using gas chromatography with a nitrogen-specific detector after converting NTA to the tri-n-butyl ester (Aue *et al* 1972, Malaiyandi *et al* 1979). The limit of determination is 0.0002 mg/L.

HEALTH CONSIDERATIONS

NTA is poorly absorbed by humans compared to experimental animals. It is rapidly excreted unchanged, but may be briefly retained in bone, probably due to the formation of complexes with calcium ions.

Data on the health effects in humans are scarce.

A number of long-term toxicity studies with animals have all shown similar results. No adverse effects are observed with low doses, but higher doses (30 mg/kg body weight per day) can cause some adverse effects to the kidney and urinary tract. The formation of kidney, urinary tract and bladder tumours has been reported in rats after prolonged exposure to high doses, but the tumours are believed to be the result of chelation of metal ions in the urinary tract.

Tests for mutagenic activity using bacteria have been negative; however, the NTA-iron complex is mutagenic in mammalian cells *in vitro*.

NOTE: Important general information is contained in PART II, Chapter 6

The International Agency for Research on Cancer has concluded that NTA is possibly carcinogenic to humans (Group 2B, no data in humans but sufficient evidence in animals) (IARC 1990).

DERIVATION OF GUIDELINE

The assessment of the toxicological data for NTA by the WHO has been used without review. The guideline value was determined as follows:

$$0.2 \text{ mg/L} = \frac{10 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.5}{2 \text{ L/day} \times 1000}$$

where:

- 10 mg/kg body weight per day is the no effect level from a 2-year feeding study using rats (Nixon *et al* 1972)
- 70 kg is the average weight of an adult
- 0.5 is the proportion of total daily intake attributable to the consumption of water, based on a WHO assessment of distribution
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for potential carcinogenic effects).

REFERENCES

Aue WA, Hastings CR, Gerhardt KO, Pierce JO, Hill HH and Mosman RF (1972). The determination of part-per-billion levels of citric and nitrilotriacetic acids in tap water and sewage effluents. *Journal of Chromatography,* 72, 259–267.

IARC (1990). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Some flame retardants and textile chemicals, and exposures in the textile manufacturing industry. World Health Organization, International Agency for Research on Cancer, 48.

Malaiyandi M, Williams DT and O'Grady R (1979). A national survey of nitrilotriacetic acid in Canadian drinking water. *Environmental Science and Technology*, 13, 59–62.

Nixon GA, Buehler EV and Niewenhuis RJ (1972). Two-year rat feeding study with trisodium nitrilotriacetate and its calcium chelate. *Toxicology and Applied Pharmacology*, 21, 244–252.

Organotins
dialkyltins
tributyltin oxide

GUIDELINE

Dialkyltins: Data are inadequate to set a guideline value for drinking water.

Tributyltin oxide: Based on health considerations, the concentration in drinking water should not exceed 0.001 mg/L.

GENERAL DESCRIPTION

The group of compounds known as the organotins comprises a large number of compounds with different properties and applications. Of these the dialkyl and tributyltin compounds have some application in the water industry and are the ones most likely to be found in drinking water supplies.

The dialkyltins are widely used as stabilisers in plastic, and may leach out of PVC water pipes for a short time after installation. In one study, dibutyltin sulfide was detected at a concentration of 0.01 mg/L in water that was in static contact with PVC pipes.

Tributyltins are used as biocides and have occasionally been detected in raw water in Canada, the United States, the United Kingdom and Switzerland, probably because of their use as antifouling agents on boats. The use of tributyl-organotin compounds, particularly tributyltin oxide, in antifouling paints has now been banned in a number of countries because it is extremely toxic to aquatic life. Tributyltin is also used as a biocide in boiler waters. Other organotins are unlikely to be found in water.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Organotins have not been found in Australian drinking waters. They are included here to provide guidance in the unlikely event of contamination, and because they have been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

No published reports are available on water treatment procedures that can be used to remove organotins from drinking water.

MEASUREMENT

The organotins can be analysed using a solvent extraction procedure (Greaves and Unger 1988). They are extracted using a hexane-tropolone mixture and derivatised to form hexylbutyltins. Analysis is by gas chromatography with flame photometric detection. Limits of determination are less than 0.000002 mg/L (2 ng/L).

HEALTH CONSIDERATIONS

Few data are available on the absorption and distribution of organotins in the body, but animal studies have reported that some of the compounds are poorly absorbed, and distributed primarily to the liver and kidney.

An extensive review and summary of the human and animal toxicity data for tributyltin compounds is available (IPCS 1990).

NOTE: Important general information is contained in PART II, Chapter 6

The dialkyltins have low general toxicity. A study using rats fed dialkyltin for 3 months reported depressed growth and mild anaemia only at the highest dose used (4mg/kg body weight per day). No toxic effects were observed at lower doses. Other studies with rats and dogs reported similar results. Carcinogenicity bioassays with animals have been inconclusive.

No data are available on the ingestion of tributyltin oxide in humans, although occupational information and dermal exposure are known to cause irritation. A number of long-term animal studies have been undertaken using tributyltin oxide. A 2-year chronic toxicity study using rats concluded that doses of 50 mg/kg body weight per day can induce toxicity to some organs including the thyroid and pituitary glands. A no effect level of 0.5 mg/kg body weight per day was established from this study (Wester *et al* 1990). An immunotoxicity study on the suppression of resistance to nematodes in rats identified a no effect level of 0.025 mg/kg body weight per day (Vos *et al* 1990). The latter immunotoxicity study is considered more sensitive but the significance to humans is questionable. The no effect levels agree to about an order of magnitude.

Tributyltin oxide was not mutagenic with bacteria and yeast but caused a significant increase in the number of benign tumours of the pituitary gland when fed to rats for 2 years.

DERIVATION OF GUIDELINE

The guideline value of 0.001 mg/L for tributyltin oxide in drinking water was determined as follows:

$$0.001 \text{ mg/L} = \frac{0.025 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 100}$$

where:

- 0.025 mg/kg body weight per day is the no effect level from a 18-month immunotoxicity study using rats (Vos *et al* 1990)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 100 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations and 10 for intraspecies variations).

The WHO guideline value of 0.002 mg/L was based on 20% of total daily intake coming from drinking water. The proportion contributed by drinking water to the total Australian intake is probably less.

REFERENCES

Greaves J and Unger MA (1988). A selected ion monitoring assay for tributyltin and its degradation products. *Biomedical and Environmental Mass Spectrometry,* 15, 565–569.

IPCS (1990). Tributyltin compounds. Environmental Health Criteria, 116. World Health Organization, International Programme on Chemical Safety.

Vos JG, DeKlerk A, Krajnc EI, VanLoveren H and Rozing J (1990). Immunotoxicity of bis(tri-n-butyltin)oxide in the rat: Effects of thymus dependent immunity and on nonspecific resistance following long-term exposure in young versus aged rats. *Toxicology and Applied Pharmacology*, 105, 144–155.

Wester PW, Krajnc EI, van Leeuwen FXR, Loeber JG, van der Heijden CA, Vaessen HAMG and Helleman PW (1990). Chronic toxicity and carcinogenicity of bis(tri-n-butyltin)oxide (TBTO) in the rat. *Food and Chemical Toxicology*, 28, 179–196.

pH

GUIDELINE

Based on the need to reduce corrosion and encrustation in pipes and fittings, the pH of drinking water should be between 6.5 and 8.5.

New concrete tanks and cement-mortar lined pipes can significantly increase pH and a value up to 9.2 may be tolerated, provided monitoring indicates no deterioration in microbiological quality.

GENERAL DESCRIPTION

pH is a measure of the hydrogen ion concentration of water. It is measured on a logarithmic scale from 0 to 14. A pH of 7 is neutral, greater than 7 is alkaline, and less than 7 is acidic.

One of the major objectives in controlling pH is to minimise corrosion and encrustation in pipes and fittings. Corrosion can be reduced by the formation of a protective layer of calcium carbonate on the inside of the pipe or fitting, and the formation of this layer is affected by pH, temperature, the availability of calcium (hardness) and carbon dioxide. If the water is too alkaline (above pH 8.5), the rapid deposition and build-up of calcium carbonate that can result may eventually block the pipe.

When pH is below 6.5 or above 11, the water may corrode plumbing fittings and pipes. This, however, will depend on other factors such as the material used, the concentration and type of ions in solution, the availability of oxygen, and the water temperature. Under some conditions, particularly in the presence of strong oxidising agents such as chlorine, water with a pH between 6.5 and 7 can be quite corrosive.

Chlorine disinfection efficiency is impaired above pH 8.0, although the optimum pH for monochloramine disinfectant formation is between 8.0 and 8.4. In chloraminated supplies chlorine can react with ammonia to form odorous nitrogen trichloride below pH 7.

Chlorination of water supplies can decrease the pH, while it can be significantly raised by lime leached from new concrete tanks or from pipes lined with asbestos cement or cement mortar. Values of pH above 9.5 can cause a bitter taste in drinking water, and can irritate skin if the water is used for ablutions.

MEASUREMENT

pH can be determined potentiometrically using a standard glass electrode and reference (APHA Method 4500-H^+ 1992).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies pH ranges between 6 and 10.8.

CONTROL IN DRINKING WATER SUPPLIES

The pH of water can be adjusted by the addition of acid or alkali. Usually lime, soda ash, sodium hydroxide, or a combination of lime and carbon dioxide are used (AWWA 1990).

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

A direct relationship between pH and human health is difficult to determine, as pH is closely associated with other aspects of water quality. Consumption of food and beverages with quite low or high pH is common and does not result in adverse health effects. Some carbonated soft drinks, for instance, have a pH of 2.5, orange fruit juice has a pH of about 3.8, and the pH of milk is 6.7.

In humans, extreme values of pH result in irritation of the eyes, skin and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH values above 11. Gastrointestinal irritation may occur in sensitive individuals at pH values above 10. Below pH 4, redness and irritation of the eyes have been reported, with the severity increasing with decreasing pH. Below pH 2.5, damage to the epithelium is irreversible and extensive.

pH may have an indirect effect on bacteriological quality through its effects on disinfection processes. It can affect the solubility of heavy metals, particularly lead and copper from pipes, and the formation of trihalomethanes (see Section 6.3.2) (USEPA 1989).

In studies using animals, solutions of differing pH have been injected into the abdominal skin of mice, resulting in irritation at pH 10 after 6 hours. In rabbits, eye irritation was reported at pH 10 but not at pH 4.5.

Chromosome aberrations and gene mutations have been reported in cultured mammalian and invertebrate cells using different acids between pH 4 and 6.5.

The effect of pH on health will depend on the buffering capacity of the water used. This is related to the nature and amount of dissolved inorganic and organic material. Water with a low buffering capacity can change pH rapidly, but water with a high buffering capacity is resistant to pH change. Extreme values of pH in association with highly buffered water are of greater concern than when the water has a low buffering capacity.

DERIVATION OF GUIDELINE

The guideline value is based on minimising corrosion and encrustation of plumbing fittings and pipes. Water with a pH between 6.5 and 8.5 should deposit a protective coating of calcium carbonate and prevent corrosion. High pH can cause scaling and encrustation problems, while lower pH can result in corrosion.

New concrete tanks and cement-mortar lined pipes can significantly increase pH and a value up to 9.2 may be tolerated, provided microbiological monitoring indicates no deterioration in bacteriological quality.

Insufficient data are available to set a health-based guideline value for pH.

GUIDELINES IN OTHER COUNTRIES

The Canadian Guidelines, United States Regulations, European Economic Community Standards, and 1984 WHO Guidelines all recommend a pH range of 6.5 to 8.5. The 1993 WHO Guidelines do not provide a specific range of pH values.

REFERENCES

APHA Method 4500-H^+ (1992). pH value: B. Electrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

AWWA (1990). *Water Quality and Treatment: A handbook of community water supplies.* American Water Works Association, 4th edition, McGraw-Hill Inc.

USEPA (1989). Health effects of drinking water treatment technologies. United States Environmental Protection Agency, Lewis Publ. Inc.

NOTE: Important general information is contained in PART II, Chapter 6

Plasticisers

Di(2-ethylhexyl) phthalate (DEHP)
Di(2-ethylhexyl) adipate (DEHA)

GUIDELINE

Di(2-ethylhexyl) phthalate: Based on health considerations, concentrations in drinking water should not exceed 0.01 mg/L.

Di(2-ethylhexyl) adipate: The data are inadequate to determine a guideline value.

GENERAL DESCRIPTION

DEHP and DEHA are commonly used plasticisers in flexible polyvinyl chloride products. They may be present in drinking water that has been in contact with these products for long periods of time, or as the result of industrial spills. Overseas studies have detected DEHP in drinking water on a few occasions at concentrations from 0.00005 mg/L (50 ng/L) to 0.01 mg/L. DEHA has been detected at concentrations between 0.000001 mg/L (1 ng/L) to 0.0001 mg/L (100 ng/L) in treated drinking water.

DEHP is the most widely used plasticiser. It is also used as a replacement for polychlorinated biphenyls (PCBs) in electrical capacitors. DEHA is used as a lubricant and in hydraulic fluids. Exposure to DEHP and DEHA is widespread because of the broad range of products using these plasticisers. Food is the major source of exposure, and it has been estimated that adult daily intake of DEHP and DEHA, as a result of consumption of food in contact with plastic products, is 0.2 mg to 16 mg.

People receiving kidney dialysis treatment may be exposed to much higher amounts of these plasticisers. In the United States it has been estimated that each dialysis patient could be receiving up to 90 mg of DEHP per treatment.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

No data are available on DEHP or DEHA concentrations in Australian drinking waters. It is unlikely that concentrations would exceed those reported overseas.

TREATMENT OF DRINKING WATER

There are no published reports on methods for the removal of DEHP or DEHA from drinking water.

MEASUREMENT

Measurement can be undertaken using a liquid extraction procedure (USEPA Draft Method 506 1990). The water sample is extracted with a ternary solvent consisting of methylene chloride, hexane and ethyl acetate. The extract is concentrated and analysed by gas chromatography with photoionization detection. The limit of determination is lower than 0.01 mg/L.

HEALTH CONSIDERATIONS

In animals, DEHP and DEHA are efficiently absorbed from the gastrointestinal tract, although marked differences in absorption are seen between species. Metabolism also differs markedly between species. Highest concentrations of metabolites are seen in the liver and adipose tissue.

NOTE: Important general information is contained in PART II, Chapter 6

An extensive review and summary of the human and animal toxicity data for DEHP is available (IPCS 1992).

Human volunteers fed up to 10 g of DEHP have experienced mild gastric disturbances, which occurred only at the highest dose. Dialysis patients receiving 150 mg per week intravenously showed no liver changes after one month, but had higher peroxisome numbers after a year. No data exist on the effects of ingested DEHA in humans.

Exposure to DEHP and DEHA can result in a significant increase in peroxisome proliferation in the liver cells of rats. An increase in peroxisome proliferation has been linked to the development of liver tumours in rodents. Humans are regarded as being less sensitive to chemically induced peroxisomal proliferation than rodents.

Long-term gavage (measured force-feeding) studies in rats using DEHP have reported that doses of 100 mg/kg body weight increased the activity of peroxisomal-associated enzymes, with higher doses resulting in depression of growth and enlargement of the liver and kidneys. Very high doses resulted in increased incidence of liver tumours. Short-term studies have reported increases in liver peroxisomal activity at lower doses (from 25 mg/kg body weight per day).

DEHP adversely affects reproduction in mice at 140 mg/kg body weight per day, and it is teratogenic and fetotoxic in mice with a no effect level of 35 mg/kg body weight per day.

A short-term study using DEHA in rats and mice reported peroxisomal proliferation with a no effect level of 100 mg/kg body weight per day. Longer-term studies are available, but have used much higher doses. DEHA adversely affects reproduction in rats at doses from 128 mg/kg body weight per day.

Neither DEHP nor DEHA exhibited mutagenic activity when applied to bacteria or to mammalian cells.

The International Agency for Research on Cancer has concluded that DEHA is not classifiable as to its carcinogenicity to humans (Group 3, no adequate evidence in humans and limited evidence in animals) and that DEHP is possibly carcinogenic to humans (Group 2B, no adequate evidence in humans but sufficient evidence in animals) (IARC 1982).

DERIVATION OF GUIDELINE

The guideline values were determined as follows:

i) DEHP

$$0.01\ \text{mg/L} = \frac{25\ \text{mg/kg body weight per day} \times 70\ \text{kg} \times 0.01}{2\ \text{L/day} \times 1000}$$

where:

- 25 mg/kg body weight per day is the lowest effect level based on a 14-day study using rats and hamsters (IPCS 1992). Although longer-term studies are available, they report no effect levels at higher doses.
- 70 kg is the average weight of an adult.
- 0.01 is the proportion of total daily intake attributable to the consumption of water. Sufficient data are available to indicate that food is by far the major source of exposure, and that drinking water contributes approximately 1% of total daily intake.
- 2 L/day is the average amount of water consumed by an adult.
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 because effects were observed at the lowest dose).

An additional safety factor for carcinogenic effects was not applied, as rats are by far the most sensitive species with respect to the sensitive end-point of peroxisomal proliferation.

The WHO guideline value of 0.008 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

ii) DEHA

The WHO has calculated a guideline value of 0.08 mg/L for DEHA based on a short-term developmental toxicity study (ICI 1988). The data are not considered to be adequate to determine an Australian guideline value.

REFERENCES

IARC (1982). IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans: Some industrial chemicals and dyestuffs. World Health Organization, International Agency for Research on Cancer, 29.

ICI (1988). Di(2-ethylhexyl)adipate: teratogenicity study in the rat. ICI Report No. CTL/P/2119.

IPCS (1992). Diethylhexyl phthalate. Environmental Health Criteria, 131. World Health Organization, International Programme on Chemical Safety.

USEPA Draft Method 506 (1990). Determination of phthalate and adipate esters in drinking water by liquid-liquid extraction or liquid-solid extraction and gas chromatography with photoionization detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Polycyclic aromatic hydrocarbons (PAHs)

GUIDELINE

Based on health considerations, the concentration of benzo(a)pyrene in drinking water should not exceed 0.00001 mg/L (10 ng/L). Data are inadequate to set guideline values for other PAHs.

GENERAL DESCRIPTION

The polycyclic aromatic hydrocarbons are a large group of organic compounds with two or more fused aromatic rings. Several hundred have been identified in air, emitted from various combustion and pyrolysis sources. The principal PAHs include phenanthrene, fluoranthene, pyrene, anthracene, benzo(a)pyrene (BaP), benzofluoranthene, chrysene, anthanthrene and naphthalene.

PAHs are widespread throughout the environment. They are formed in forest fires and in the combustion of fossil fuels, and are present in emissions from coke ovens, aluminium smelters and motor vehicles. Contamination of drinking water can occur by direct atmospheric deposition and by leaching from bituminous liners in water distribution systems.

There are very few data on concentrations of PAHs in drinking water supplies. Data, such as exist, are mainly for BaP. The typical concentration of BaP in drinking water in the United States is estimated to be 0.00000055 mg/L (0.55 ng/L).

Food is the major source of intake of PAHs. Highest concentrations occur in smoked foods, leafy vegetables and the burnt fat of meats. Intake from foods is extremely variable but significantly higher (by at least an order of magnitude) than from drinking water.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

PAHs have not been found in Australian drinking waters. They are included here to provide guidance in the unlikely event of contamination, and because they have been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

The conventional water treatment processes of coagulation, settling and filtration are capable of reducing the BaP concentration of raw waters to less than 0.000001 mg/L (1 ng/L), even if the influent concentration is high. It is likely that other PAHs would be similarly reduced. Granular activated carbon would also be effective in the removal of these compounds.

MEASUREMENT

Concentrations of BaP and other PAHs in water can be determined by gas chromatography in conjunction with mass spectrometry. The limit of determination is 0.00001 mg/L (10 ng/L). BaP can also be analysed using liquid chromatography with spectrofluorometric detection (USEPA Draft Method 550 1990). The limit of determination is 0.00005 mg/L (50 ng/L)

HEALTH CONSIDERATIONS

Most of the toxicological literature deals specifically with BaP. Few studies are available for the other PAHs. Some PAH compounds have been found to be carcinogenic by non-oral routes, but others are known to have low potential for carcinogenicity.

NOTE: Important general information is contained in PART II, Chapter 6

BaP is absorbed principally through the gastrointestinal tract and the lungs. The rate of absorption increases with increased intake of polyunsaturated fatty acids. BaP is rapidly distributed to the organs and may be stored in mammary and adipose tissue. Metabolism occurs mainly in the liver.

No human health effects have been unequivocally associated with exposure to BaP per se. However, occupations associated with exposures to PAHs, of which BaP is a component, have been clearly associated with human cancer.

In experiments with animals, many PAH mixtures have been associated with an increased incidence of cancer. BaP is one of the most potent carcinogenic compounds, with primary tumours having been reported in a variety of studies, using different administration techniques, in mice, rats, hamsters, guinea pigs, rabbits, ducks and monkeys. Tumours have mostly appeared only at the site of administration.

BaP was reported to be mutagenic in tests with a strain of bacteria; however, the diol-epoxide metabolite was considerably more mutagenic than the parent compound. Mutations have also been reported with *in vitro* tests on human lymphoblastoid cells and with *in vivo* tests using Chinese hamsters (induction of sister chromatid exchanges).

The International Agency for Research on Cancer has concluded that BaP is probably carcinogenic to humans (Group 2A, no adequate human data, but sufficient evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

Data are insufficient to set guideline values for PAHs except for BaP. The guideline value for BaP of 0.00001 mg/L (10 ng/L) is based on consideration of health effects in relation to the limit of determination for analysis using commonly available techniques.

On the basis of a feeding study using mice (Neal and Rigdon 1967) the excess risk of lifetime consumption of water with a BaP concentration of 0.00007 mg/L (70 ng/L) was conservatively estimated by WHO, using a linear multistage model, at one additional cancer per million people.

The guideline value has been set at the limit of determination because this is slightly less than the value derived using a risk assessment calculation, and provides an adequate degree of protection. This is consistent with the general approach adopted for genotoxic carcinogens (see Section 6.3.4).

The WHO guideline value of 0.0007 mg/L was based on a calculation that estimated an additional lifetime risk of one fatal cancer per 100 000 people.

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

Neal J and Rigdon RH (1967). Gastric tumors in mice fed benzo(a)pyrene: a quantitative study. *Texas Reports on Biology and Medicine,* 25, 553–557.

USEPA Draft Method 550 (1990). Determination of polycyclic aromatic hydrocarbons in drinking water by liquid-liquid extraction and HPLC with coupled ultraviolet and fluorescence detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Radionuclides
other beta- and gamma-emitting

(Revised and endorsed 2001)

GUIDELINE

No specific guideline values are set for beta- or gamma-emitting radionuclides.

Specific beta- or gamma-emitting radionuclides should be identified and determined only if gross beta radioactivity (after subtracting the contribution of potassium-40) exceeds 0.5 Bq/L (27.6 Bq of beta activity per gram of stable potassium).

GENERAL DESCRIPTION

Several radionuclides that are classified as beta-particle or gamma-ray emitters may occasionally be present in drinking water. The significant long-lived nuclides in this group are the naturally occurring isotopes potassium-40, lead-210 and radium-228, and artificial radionuclides caesium-137 and strontium-90. Tritium, another nuclide in this group, is present in the environment both from natural sources and as a result of nuclear fall-out and nuclear power generation.

Levels of strontium-90 and caesium-137 in the Australian environment have decreased substantially since atmospheric testing of nuclear weapons ceased, and these radionuclides are not detectable in drinking water. In the absence of a nuclear power industry in Australia, these nuclides are likely to be present in significant concentrations in drinking water only as a result of transient contamination following an event such as a nuclear accident.

Potassium-40 occurs naturally in a fixed ratio to stable potassium. Potassium is an essential element for humans, and is absorbed mainly from ingested food. Potassium-40 does not accumulate in the body but is maintained at a constant level independent of intake. The average concentration of potassium in an adult male is about 2 g/kg of bodyweight, which gives an activity mass concentration of potassium-40 of 60 Bq per kg of bodyweight. The corresponding value for females is slightly less.

Lead-210, like radium-226, is a decay product of the uranium-238 series. Food is the most important route by which lead-210 enters the human body, and the annual intake depends on diet: highest concentrations are found in fish and other aquatic species. Generally, lead-210 concentrations in drinking water are considerably less than concentrations of either radium-226 or radium-228.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Concentrations of potassium-40 in Australian drinking water supplies vary widely, from below 0.05 Bq/L in surface water sources to more that 1 Bq/L in some supplies drawn from groundwater.

There are only limited data on concentrations of other beta- or gamma-emitting radionuclides such as lead-210, strontium-90 and caesium-137 in Australian drinking water supplies. Lead-210 concentrations are probably below 0.05 Bq/L and concentrations of artificial radionuclides are negligible.

TREATMENT OF DRINKING WATER

Treatment processes involving ion exchange or reverse osmosis will effectively remove radionuclides such as lead-210, strontium-90 and caesium-137. There is no suitable treatment to remove tritium.

NOTE: Important general information is contained in PART II, Chapter 7

ANALYSIS

For initial screening, gross beta activity is determined by evaporation of the sample and beta measurement of the residue (AS 2531 1982; ISO 1991). The limit of determination is approximately 0.02 Bq/L, but will vary with the mass of residue.

For potassium-40, the most suitable method is to determine the stable potassium concentration by atomic absorption spectrophotometry. The beta activity due to potassium-40 is then calculated using the ratio of 27.6 Bq of beta activity per gram of stable potassium.

Specific determination of lead-210 and strontium-90 in drinking water is carried out by beta counting after radiochemical isolation of the radionuclide (EML 1990; USEPA 1980). The limit of determination for each nuclide is approximately 0.02 Bq/L by this method. High-resolution gamma spectrometry is the most suitable method for the determination of caesium-137.

Tritium is determined by distillation and liquid scintillation counting (ISO 1989).

HEALTH CONSIDERATIONS

Lead-210 can concentrate in bone, where it remains for many years. The radiation dose from lead-210 is due mainly to the emission of alpha particles from its progeny, polonium-210.

In principle, lead-210 may increase the risk of bone cancers; however, no link has been demonstrated, either in animal studies or epidemiological studies.

Much of what is known of the health effects of ingested strontium-90 and caesium-137 comes from animal studies. Caesium-137, when ingested, is distributed throughout the body, mainly to soft tissues. The organ most at risk is the liver. Dogs exposed to high concentrations of caesium-137 showed an increased incidence of liver cancer. The risks of bone cancer have been estimated from extensive life-span studies of dogs injected intravenously with strontium-90. The studies showed the dose-response relationship to be non-linear for chronic exposure to strontium-90.

Potassium-40 is not considered to be of significance to health because it is present naturally with the stable potassium isotope. The average contribution of this nuclide to the annual effective dose from background radiation is estimated to be 0.18 mSv (UNSCEAR 2000).

ESTIMATION OF DOSE

The dose from beta or gamma emitting radioisotopes should be estimated using the method described in Section 7.5.

REFERENCES

AS 2531 (1982). Australian Standard for Waters – determination of gross alpha and gross beta activities. Standards Association of Australia, Sydney, New South Wales.

EML (1990). EML Procedures Manual, 27th edition. Environmental Measurements Laboratory, Department of Energy, New York, United States.

ISO (1989). Water quality– determination of tritium activity concentration - liquid scintillation counting method. International Organization for Standardization (ISO), International Standard ISO 9698:1989(E), Geneva, Switzerland.

ISO (1991). Water quality - measurement of gross beta activity in non-saline water– Thick source method. International Organization for Standardization (ISO), International Standard ISO 9695, Geneva, Switzerland.

UNSCEAR (2000). Sources, effects and risks of ionising radiation. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), report ISBN 92-1-142143-8, New York, 1988.

USEPA (1980). Prescribed procedures for measurement of radioactivity in drinking water. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory, EPA-600/4-80-032, Cincinnati, United States.

NOTE: Important general information is contained in PART II, Chapter 7

Radium-226 and radium-228

(Revised and endorsed 2001)

GUIDELINE

Radium-226 and Radium-228 should be determined if the gross alpha radioactivity in drinking water exceeds 0.5 Bq/L, or the gross beta activity (with the contribution of potassium-40 subtracted) exceeds 0.5 Bq/L.

GENERAL DESCRIPTION

Radium isotopes are formed as a result of radioactive decay of uranium-238 and thorium-232, both of which occur naturally in the environment. The two most significant isotopes in this process, in terms of radiological health, are radium-226 (uranium series) and radium-228 (thorium series), which have half-lives of 1620 years and 5.8 years, respectively.

Radium-226 is an alpha emitter. It has been used, separated from its parent uranium, in cancer therapy.

Of the radionuclides that comprise the natural thorium and uranium series, radium-226 and radium-228 are those most likely to be found in drinking water, and this occurs more commonly in supplies derived from groundwater. Concentrations in surface water are likely to be extremely low. Concentrations of radium isotopes in groundwater vary according to the type of aquifer minerals and dissolved anions such as chloride, carbonate, and sulfate anions, which tend to increase the mobility of radium.

Radium is widespread in the environment and trace amounts are found in many foods. The average dietary intake is estimated to be 15 Bq per year (UNSCEAR 2000).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In supplies derived from groundwater sources, radium-226 and radium-228 concentrations vary considerably depending on the aquifer, and it is not uncommon in small supplies to find concentrations up to, or exceeding, 0.5 Bq/L. Radium concentrations in Australian surface water supplies are generally below 0.02 Bq/L.

TREATMENT OF DRINKING WATER

Lime softening, reverse osmosis and ion exchange all remove both radium-226 and radium-228 very efficiently from water. Aeration may be effective in certain circumstances.

ANALYSIS

Generally, analysis for radium isotopes is only required if gross alpha and beta activities exceed 0.5 Bq/L (see Chapter 7).

Radium-226 can be determined by several methods involving radiochemistry, by radon emanation, or by liquid scintillation counting (USEPA 1980; ASTM 1989; Cooper and Wilks 1981; EML 1990; APHA 1992). The estimated limit of determination is 5 mBq/L.

Radiochemical techniques are necessary to determine radium-228 (USEPA 1980). The estimated limit of determination is 20 mBq/L.

NOTE: Important general information is contained in PART II, Chapter 7

HEALTH CONSIDERATIONS

The metabolic behaviour of radium is similar to that of calcium, and an appreciable fraction of ingested radium is deposited in bone tissue, where it is retained for a long time.

High levels of exposure to radium have been shown to be carcinogenic. Epidemiological studies of 2000 radium dial painters, and studies of the medical use of the short-lived isotope radium-224, have both shown an increased incidence of bone sarcomas. Animal experiments have also established an association between radium exposure and bone sarcoma.

Studies of populations in the United States exposed to radium in drinking water have produced no conclusive evidence linking cancer with ingestion of radium.

Apart from cancer, the only other health effect resulting from ingestion of radium observed in the studies of radium dial painters was bone necrosis.

DERIVATION OF GUIDELINE

The dose from radium-226 and radium-228 should be estimated using the method described in Section 7.5.

REFERENCES

APHA Method 7500-Ra C (1992). Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

ASTM, Vol. 11.02 (1989). 1989 Annual book of ASTM standards. American Society for Testing and Materials, Philadelphia, United States.

Cooper, MB and Wilks MJ (1981). An analytical method for radium (226Ra) in environmental samples by the use of liquid scintillation counting. Australian Radiation Laboratory report, ARL/TR040.

EML (1990). EML Procedures Manual, 27th edition. Environmental Measurements Laboratory, Department of Energy, New York, United States.

UNSCEAR (1988). Sources, effects and risks of ionising radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, report ISBN 92-1-142143-8, New York, 1988.

USEPA (1980). Prescribed procedures for measurement of radioactivity in drinking water. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory, EPA-600/4-80-032, Cincinnati, United States.

Radon-222

GUIDELINE

Based on a consideration of the potential health impact from radon released from tap water to the air inside a dwelling, the activity concentration of radon-222 in drinking water should not exceed 100 Bq/L.

The guideline value applies to the concentration of radon at the point of use of the water, not at the source, because of the significant decrease in concentration which can occur due to radioactive decay during storage, treatment and reticulation.

GENERAL DESCRIPTION

Radon-222 is a radioactive gas produced from the decay of radium-226 in soil and minerals. It has a half-life of 3.8 days.

Elevated concentrations of radon-222 may occur in drinking water derived from groundwater, due to the release of radon from aquifer rocks and minerals, particularly in granitic areas. In Finland, for example, the weighted average radon concentration in drinking water is 25 Bq/L.

Radon concentrations in surface water supplies are very low because the gas is rapidly lost to the atmosphere.

Studies from Canada, Finland and the United States have shown that dissolved radon-222 in drinking water may be released to air during domestic use and contribute to indoor radon concentrations.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

The data on the concentrations of radon-222 in Australian drinking water supplies are limited, but sufficient to indicate that radon may be significant in some rural supplies.

TREATMENT OF DRINKING WATER

The most effective way of eliminating dissolved radon-222 from water is by aeration, either actively by processes such as spraying, or by passive processes such as open-air storage. Radon concentrations will also decrease by radioactive decay in water stored before use.

ANALYSIS

The concentration of radon-222 in drinking water can be determined by liquid scintillation counting of a small volume of water, or by a de-emanation of radon into a Lucas Cell chamber for counting (EPA 1987, EPA 1991). The limits of determination for these methods are around 1-2 Bq/L and 0.1-0.5 Bq/L respectively. The former method is preferable because because it is quicker and easier to use.

HEALTH CONSIDERATIONS

The main health risk from radon arises from inhalation of the gas, particularly when it accumulates inside dwellings. Radon-222 has several short-lived radioactive progeny that can give rise to an increased risk of lung cancer.

Epidemiological studies of underground miners in the uranium mining industry overseas have established a relationship between the incidence of lung cancer and occupational exposure to radon.

NOTE: Important general information is contained in PART II, Chapter 7

No link has been demonstrated, however, in either experimental or epidemiological studies, between ingestion of radon in drinking water and increased cancer rates.

DERIVATION OF GUIDELINE

The guideline value was determined following consideration of these points:

- Ingestion of radon in water does not pose a sufficient risk to health to warrant consideration of this pathway in setting a guideline value (UNSCEAR 1988).
- The main sources of radon in indoor air are the subjacent ground and building materials, with radon in tap water being normally only a small contributor. The release of radon from tap water into household air will depend upon the volume and nature of water usage in the dwelling. The overall radon concentration in air will be influenced by factors such as the construction of the dwelling, ventilation rates and domestic practices.
- Given the indirect nature of the exposure pathway and the number of assumptions that must be made to assess the dose to an individual arising from the inhalation of radon released to household air from tap water, it is not appropriate to use a level of dose as the basis for a guideline value for radon in drinking water.
- The ratio between the radon concentration in tap water and the concentration in air is commonly estimated at 10 000 to 1 (UNSCEAR 1988). On this basis, a concentration of radon in tap water of 100 Bq/L would give rise to a concentration in air of 10 Bq/m^3, which is 5% of the present NHMRC action level for radon in air in a dwelling. A guideline value of 100 Bq/L would ensure that radon in drinking water would not be a significant contributor to indoor radon.

REFERENCES

NHMRC (1990). Report of the 109th Session. National Health and Medical Research Council, May 1990.

UNSCEAR (1988). Sources, effects and risks of ionising radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, report ISBN 92-1-142143-8, New York, 1988.

USEPA (1987). Two test procedures for radon in drinking water, inter-laboratory collaborative study. United States Environmental Protection Agency, EPA-600/2-87-082, Washington, United States.

Selenium

GUIDELINE

Based on health considerations, the concentration of selenium in drinking water should not exceed 0.01 mg/L.

GENERAL DESCRIPTION

Selenium and selenium salts are widespread in the environment. Selenium is released from natural and human-made sources, with the main source being the burning of coal. Selenium is also a byproduct of the processing of sulfide ores, chiefly in the copper refining industry.

The major use of selenium is in the manufacture of electronic components. It is used in several other industries, and selenium compounds are used in some insecticides, in hair shampoos as an anti-dandruff agent, and as a nutritional feed additive for poultry and livestock.

Selenium concentrations in source waters are generally very low and depend on local geochemistry, pH and the presence of iron salts. Concentrations in drinking water supplies overseas are generally below 0.01 mg/L but groundwater concentrations as high as 6 mg/L have been reported in the United States.

Food is the major source of intake for Australians. Cereal and grain products contribute most to intake, while fish and liver contain the highest selenium concentrations. Average daily intakes for Australian adults are between 0.06 mg and 0.13 mg.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, selenium concentrations are less than 0.005 mg/L. Selenium concentrations in groundwater are not a problem in Australia, as they are in some overseas supplies.

TREATMENT OF DRINKING WATER

Selenium concentrations in drinking water can be reduced by coagulation with ferric chloride and by lime softening. Coagulation with alum is much less effective. Activated alumina absorption is the most effective means of treatment, but only at low pH.

MEASUREMENT

The selenium concentration in drinking water can be determined by hydride generation followed by atomic absorption spectroscopy (APHA Method 3500-Se Part C 1992). The limit of determination is 0.001 mg/L.

HEALTH CONSIDERATIONS

Selenium is an essential element for many species, including humans. Signs of selenium deficiency in humans are not well established but may include a chronic disorder of the heart muscle, other heart diseases and cancer. The Australian recommended dietary intake to maintain health is approximately 0.001 mg/kg body weight per day.

Most water-soluble selenium compounds are effectively absorbed by the gastrointestinal tract. Selenium is then distributed to most organs, with highest concentrations found in the kidney, liver and spleen.

The toxicity of selenium varies considerably among the different selenium compounds. Selenite and selenate are much more toxic than selenium sulfide.

NOTE: Important general information is contained in PART II, Chapter 6

An extensive review and summary of the human and animal toxicity data for selenium is available (IPCS 1987).

There have been a number of reports of ill effects attributed to short- and long-term exposure to selenium; most of these have resulted from occupational exposure or accidental poisoning; acute or chronic nutritional toxicity is comparatively rare. Intakes above about 1 mg/day over prolonged periods may produce nail deformities characteristic of selenosis. Other features of excess selenium intake include nonspecific symptoms such as gastrointestinal disturbances, dermatitis, dizziness, lassitude and a garlic odour to the breath.

A 2-year study on 140 people with an average selenium intake of 0.24 mg/day reported no effect associated with the level of selenium intake.

Domestic animals developed a symptom known as 'blind staggers' when fed plants that had accumulated selenium. The animals had impaired vision, depressed appetite and a tendency to wander in circles. This led to paralysis and death from respiratory failure.

Except for selenium sulfide, experiments with laboratory animals indicate that selenium compounds are not carcinogenic, with some selenium compounds displaying an anticarcinogenic effect. Results for selenium sulfide indicate that it causes liver and skin tumours in mice.

Tests for mutagenic activity using bacteria have reported both positive and negative results. Studies indicate that selenite can cause chromosome damage to mammalian cells.

The International Agency for Research on Cancer has concluded that selenium is not classifiable as to its carcinogenicity in humans (Group 3, inadequate evidence in humans and in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The guideline value for selenium in drinking water was derived as follows:

$$0.01 \text{ mg/L} = \frac{0.24 \text{ mg/day} \times 0.1}{2 \text{ L/day}}$$

where:

- 0.24 mg per day is the acceptable daily intake (Longnecker *et al* 1991)
- 0.1 is the proportion of daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult.

REFERENCES

APHA Method 3500-Se Part C (1992). Selenium: Continuous hydride generation/Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1987). Selenium. Environmental Health Criteria, 58. World Health Organization, International Programme on Chemical Safety.

Longnecker MP, Taylor PR, Levander OA, Howe M, Veillon C, McAdam PA, Patterson KY, Holden JM, Stampfer MJ, Morris JS and Willet WC (1991). Selenium in diet, blood, and toenails in relation to human health in a seleniferous area. *American Journal of Clinical Nutrition*, 53, 1288–94.

Silver

GUIDELINE

Based on health considerations, the concentration of silver in drinking water should not exceed 0.1 mg/L.

GENERAL DESCRIPTION

Silver concentrations in natural source waters are generally very low, less than 0.0002 mg/L. In some countries silver and silver salts are used for disinfection and preservation of water, and this can result in higher silver concentrations.

Silver is a precious metal and is used in the production of tableware, jewellery and coins. It is also used in batteries, mirrors, as a chemical catalyst, and as an antiseptic agent.

Traces of silver can be found in most foods. The daily dietary intake has been estimated at between 0.03 mg and 0.09 mg.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Australian drinking water supplies have not been routinely monitored for silver.

TREATMENT OF DRINKING WATER

Silver can be readily removed from drinking water by conventional coagulation or lime softening.

MEASUREMENT

The concentration of silver in drinking water can be determined by graphite furnace atomic absorption spectroscopy or inductively coupled plasma emission spectroscopy (APHA Method 3500-Ag Parts B or C 1992). The limits of determination are 0.001 mg/L and 0.01 mg/L respectively.

HEALTH CONSIDERATIONS

Although silver can be found in many biological substances, it is not considered an essential trace element for mammals.

It has been estimated that less than 10% of dietary silver is absorbed by the gastrointestinal tract. Silver is stored mainly in the liver and skin and is capable of binding to amino acids and proteins.

The best-known clinical condition of silver intoxication is argyria, which results in a bluish-grey metallic discolouration of the skin, hair, mucous membranes, mouth and eye. Most cases have been associated with self-administration of silver preparations, or occupational exposure to silver and silver compounds.

Experiments with laboratory rats and mice have reported similar results. Very high concentrations of silver in drinking water (over 600 mg/L) for a lifetime caused discolouration in the thyroid and adrenal glands, the choroids of the brain and eye, and the liver and kidney. Some hypoactive behaviour was also reported.

No data are available on the carcinogenicity of silver. Silver salts are not mutagenic in tests with bacteria, but can induce damage in mammalian DNA.

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The guideline value for silver in drinking water was derived as follows:

$$0.1 \text{ mg/L} = \frac{0.4 \text{ mg/day} \times 0.5}{2 \text{ L/day}}$$

where:

- 0.4 mg/day is derived from a human lifetime no effect level of 10 g (Hill and Pillsbury 1939)
- 0.5 is the proportion of total daily intake attributable to the consumption of drinking water
- 2 L/day is the average amount of water consumed by an adult.

No additional safety factors were used, as the calculation was based on a human no effect level.

It is unlikely that silver concentrations in drinking water would ever reach a concentration that could cause adverse effects. Silver or silver salts should not be used as antimicrobial agents unless no other disinfectants are available.

REFERENCES

APHA Method 3500-Ag Part B (1992). Silver: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Ag Part C (1992). Silver: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Hill WR and Pillsbury DM (1939). *Argyria, the pharmacology of silver*. The Williams and Wilkins Co., Baltimore, Maryland.

Sodium

GUIDELINE

Based on aesthetic considerations (taste), the concentration of sodium in drinking water should not exceed 180 mg/L.

No health-based guideline value is proposed for sodium. Medical practitioners treating people with severe hypertension or congestive heart failure should be aware if the sodium concentration in the patient's drinking water exceeds 20 mg/L.

GENERAL DESCRIPTION

The sodium ion is widespread in water due to the high solubility of sodium salts and the abundance of mineral deposits. Near coastal areas, windborne sea spray can make an important contribution either by fallout onto land surfaces where it can drain to drinking water sources, or from washout by rain. Apart from saline intrusion and natural contamination, water treatment chemicals, domestic water softeners and sewage effluent can contribute to the sodium content of drinking water.

Sodium salts are used in the paper, glass, soap, pharmaceutical and general chemical industries, and for a variety of other purposes. Sodium is also used in the food industry and for culinary purposes. Considerable amounts are excreted by humans and it is a common constituent of domestic sewage.

Sodium, as sodium salts such as sodium chloride or sodium sulfate, has a taste threshold of about 135 mg/L. The taste becomes appreciable when the sodium concentration exceeds 180 mg/L.

In most countries the majority of water supplies contain less than 20 mg/L but concentrations of up to 250 mg/L have been reported.

Food is the major contributor to sodium intake. In Australia the average dietary sodium intake has been estimated at about 4 g/day. Low-sodium diets may restrict this to less than 2 g/day.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, sodium concentrations vary from 3 mg/L to 300 mg/L, with a typical value of 50 mg/L. Concentrations can vary markedly with local conditions.

TREATMENT OF DRINKING WATER

Sodium salts cannot be easily removed from drinking water; however, any steps to reduce sodium concentrations are encouraged (such as the use of alternative salts in domestic water softeners). Processes such as reverse osmosis or distillation can be employed but are costly to operate.

MEASUREMENT

The sodium concentration in drinking water can be determined by flame atomic absorption spectroscopy, inductively coupled emission spectroscopy or flame emission spectroscopy (APHA Method 3500-Na Parts B, C or D 1992). The limits of determination are less than 0.1 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Whether water is consumed directly or with food or beverages, virtually all of the sodium in it will be absorbed. Sodium is present in all body tissues and fluids and its concentration is maintained by the kidney; increases in the sodium concentration in plasma give rise to the sensation of thirst.

Sodium is essential to human life but there is no agreement on the minimum daily amount needed to maintain health. It has been estimated that a total daily intake of less than 200 mg/person is required to meet the needs of growing infants and children.

Excessive sodium intake, usually via diet, can severely aggravate chronic congestive heart failure.

While it is clear that reduced sodium intake can reduce the blood pressure of some individuals with hypertension, it is equally clear that this type of therapy is not effective in all cases. Health authorities are of the opinion, however, that reduced sodium intake is beneficial.

DERIVATION OF GUIDELINE

The guideline value for sodium in drinking water is based on the taste threshold for sodium in water of 180 mg/L.

While there is evidence linking excess sodium intake with cardiovascular disease, it must be recognised that sodium intake via the water supply makes only a modest contribution to total intake. Nevertheless, water authorities are strongly encouraged to keep sodium concentrations as low as possible.

People with severe hypertension or congestive heart failure may need to restrict their overall dietary intake of sodium further if the concentration in drinking water exceeds 20 mg/L. Medical practitioners treating people with these conditions should be aware of the sodium concentration in the patient's drinking water.

REFERENCES

APHA Method 3500-Na Part B (1992). Sodium: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Na Part C (1992). Sodium: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Na Part D (1992). Sodium: Flame emission photometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Styrene (vinylbenzene)

GUIDELINE

Based on aesthetic considerations (odour), the concentration of styrene in drinking water should not exceed 0.004 mg/L.

Styrene would not be a health concern unless the concentration exceeded 0.03 mg/L.

GENERAL DESCRIPTION

Styrene may be present in drinking water as a result of contamination from industrial sources. It has occasionally been detected in water supplies in the United States and the Netherlands at concentrations of less than 0.001 mg/L.

The taste threshold of styrene in water at 40°C ranges from 0.02 mg/L to 2.6 mg/L, depending on individual sensitivities. At 60°C the odour threshold in water is 0.004 mg/L.

Styrene is used in the production of plastics and resins. It has been detected in food packaged in polystyrene containers. However, improvements in the use of polystyrene since 1980 have resulted in substantial decreases in the release of the monomer. The daily exposure to styrene has been estimated to be 0.04 mg per person, with smokers receiving a higher dose. Forest fires may contribute to atmospheric concentrations of styrene.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Styrene has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Styrene can be removed from drinking water by reaction with ozone to form aldehydes, ketones and benzoic acid. It can also be adsorbed onto granular activated carbon.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for analysis (USEPA Draft Method 503.1 1986). An inert gas is bubbled through the sample and styrene trapped on an adsorbent. The adsorbent is then heated and styrene analysed using gas chromatography with photoionisation detection. The limit of determination is less than 0.0001 mg/L.

HEALTH CONSIDERATIONS

Approximately 60-90% of styrene is absorbed following ingestion or inhalation. It is widely distributed in the body, with a preference for fatty tissues. It is metabolised by a number of tissues and organs to styrene-7,8-oxide.

An extensive review and summary of the human and animal toxicity data for styrene is available (IPCS 1983).

A number of studies have reported on occupational inhalation of styrene. High doses for long periods have resulted in irritation of the respiratory system and some neurotoxic effects on both central and peripheral nervous systems.

NOTE: Important general information is contained in PART II, Chapter 6

Chromosomal aberrations in lymphocytes have been associated with high styrene exposures, but not with low concentrations, among workers in the glass fibre industry.

In a long-term study using rats, female body weights were depressed at high doses (250 mg/kg body weight per day). No other treatment-related effects were observed.

Most studies using rodents have not found any association between styrene intake and an increased incidence of tumours. Styrene is mutagenic in a variety of test microorganisms, but only after metabolic activation. It also induces gene mutations and chromosomal aberrations in mammalian cells. The mutagenic agent is probably styrene-7,8-oxide, the main metabolic byproduct of styrene and a direct-acting mutagen. Two long-term gavage studies using rats have also reported that styrene-7,8-oxide significantly increased the incidence of fore-stomach tumours at a dose of 250 mg/kg body weight per day.

The International Agency for Research on Cancer has concluded that styrene-7,8-oxide is probably carcinogenic to humans (Group 2A, inadequate evidence in humans, sufficient evidence in experimental animals, and supporting mechanistic evidence) (IARC 1994).

DERIVATION OF GUIDELINE

The assessment of the toxicological data for styrene by the WHO has been used without review. The health-based guideline value of 0.03 mg/L was determined as follows:

$$0.03 \text{ mg/L} = \frac{7.7 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 7.7 mg/kg body weight per day is the no effect level based on a 2-year drinking water study using rats (Beliles *et al* 1985)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for carcinogenic and genotoxic effects).

This health-based value is greater than the odour threshold of 0.004 mg/L.

The WHO guideline value of 0.02 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

Beliles RP, Butala JH, Stack CR and Makris S (1985). Chronic toxicity and three-generation reproduction study of styrene monomer in the drinking water of rats. *Fundamental and Applied Toxicology*, 5, 855–868.

IARC (1994). IARC Monographs on the Evaluation of World Health. Carcinogenic Risks to Humans: Some Industrial Chemicals. World Health Organisation, International Agency for Research on Cancer, 60, Lyons.

IPCS (1983). Styrene. Environmental Health Criteria, 26. World Health Organization, International Programme on Chemical Safety.

USEPA Draft Method 503.1 (1986). Volatile organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Sulfate

GUIDELINE

Based on aesthetic considerations (taste), the concentration of sulfate in drinking water should not exceed 250 mg/L. Purgative effects may occur if the concentration exceeds 500 mg/L.

GENERAL DESCRIPTION

Sulfate occurs naturally in a number of minerals, and is used commercially in the manufacture of numerous products including chemicals, dyes, glass, paper, soaps, textiles, fungicides and insecticides. Sulfate, including sulfuric acid, is also used in mining, pulping, and the metal and plating industries. Barium sulfate is used as a lubricant in drilling rigs for groundwater supply.

In the water industry, aluminium sulfate (alum) is used as a flocculant in water treatment, and copper sulfate is used for the control of blue-green algae (cyanobacteria) in water storages.

The highest concentrations reported in drinking water overseas are from groundwater supplies where the presence of sulfate is due to natural leaching from rocks. Concentrations have been reported up to 2200 mg/L. In source waters, concentrations are typically less than 100 mg/L.

The taste threshold for sulfate is in the range 250–500 mg/L.

Under anoxic conditions, the reduction of sulfate to sulfide by sulfate-reducing bacteria can result in unpleasant taste and odour due to the release of hydrogen sulfide, and can increase corrosion in pipes.

Food is probably the major source of intake of sulfate. In areas where the concentration of sulfate in water is high, drinking water may constitute the principal source of intake.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, sulfate concentrations range from 1 mg/L to 240 mg/L, with a typical concentration of 20 mg/L. Sulfate concentrations can vary markedly in different parts of the country.

TREATMENT OF DRINKING WATER

Most sulfate salts are very soluble and cannot be removed from drinking water by conventional water treatment processes. Desalination methods such as reverse osmosis or distillation are required for sulfate removal.

MEASUREMENT

The sulfate concentration of drinking water can be determined by the methylthymol blue method (APHA 4500-SO_4^{2-} Part F 1992) or using ion chromatography (APHA Method 4500-SO_4^{2-} Part B 1992). Limits of determination are 0.1 mg/L and 1 mg/L respectively.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Sulfate is rapidly absorbed by the gastrointestinal tract but a number of factors, such as the accompanying cation, can influence the rate of absorption. Low doses are probably absorbed more effectively than high doses. Sulfate is found in all body tissue but is highest in the metabolically active areas of bone and tooth formation, and may be important in regulating bone development.

Sulfate is one of the least toxic anions. Ingestion of high doses can result in catharsis (loosening of the bowels) with dehydration as a possible side effect.

No harmful effects have been reported in studies with animals.

Sulfate can interfere with disinfection efficiency by scavenging residual chlorine. It can also increase corrosion of mild steel pipes.

DERIVATION OF GUIDELINE

The guideline value is based on the taste threshold of sulfate in drinking water of 250 mg/L.

REFERENCES

APHA Method 4500-SO_4^{2-} Part F (1992). Sulphate: Methylthymol blue method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 4500-SO_4^{2-} Part B (1989). Sulphate: Ion Chromatographic method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Taste and odour

GUIDELINE

The taste and odour of drinking water should be acceptable to most people.

GENERAL DESCRIPTION

Odour and taste are the primary criteria consumers use to judge the quality and acceptability of drinking water. People's senses of taste and smell tend to vary, and so the acceptability of the same water can vary from person to person, and from day to day for the same person. Similarly, one individual within a group may be more or less sensitive to a particular substance than the group as a whole.

SOURCES OF TASTE AND ODOUR

Taste and odour in drinking water can be naturally occurring, or the result of chemical contamination of water supplies.

Humic and fulvic material resulting from the decay of animal and vegetable matter can result variously in water which smells 'earthy', 'musty' or 'woody'. Compounds most often linked to these tastes and odours are geosmin and methyl isoborneol, which have an extremely low taste threshold of 0.00001 mg/L (10 ng/L). These compounds are also produced by a number of microorganisms including blue-green algae (cyanobacteria).

Other odours produced by particular algae have been described as sweet, aromatic, cucumber, flowery, geranium, nasturtium, violets, fishy, earthy, peaty, grassy, musty, mouldy, and vegetable.

Inorganic compounds are generally present in water in substantially higher concentrations than organic compounds. Taste thresholds for some commonly occurring inorganic ions are about 0.15 mg/L for manganese, 0.3 mg/L for iron, 3 mg/L for copper, 5 mg/L for zinc, 250 mg/L for chloride, and 250-500 mg/L for sulfate.

A number of organic compounds causing tastes and odours can be produced as byproducts of disinfection, particularly chlorination. Some chlorinated phenols, for example, have an antiseptic smell and a very low taste and odour threshold, varying from 0.002 mg/L to 0.0001 mg/L.

Disinfection chemicals can also contribute taste or odour to water. The odour threshold for free chlorine varies with pH, but is between 0.1 mg/L and 0.4 mg/L. Monochloramine and dichloramine have odour thresholds of 0.5 mg/L and 0.15 mg/L respectively.

Contamination of water from spills, discharges or leaks of organic compounds can result in unpleasant taste and odours. Diesel fuel, for example, has a taste and odour threshold of 0.0005 mg/L.

MEASUREMENT

A small panel (5 to 8 people) can be trained to identify specific odours and tastes associated with common contaminants. These panels are useful for assessing complaints by consumers, identifying the source of a contaminant, and for the initial assessment of a new or improved purification process. The Flavour Profile Measurement method (Krasner *et al* 1985, Bartels *et al* 1987, Mallevaille *et al* 1987) is widely recognised as the appropriate procedure for use with small trained panels when assessing drinking water. It provides information on both the strength and characteristics of the odour and taste of the water.

Large panels (over 100 people), generally consisting of consumers, can be used as final assessors of water from a new or improved process, or to check that a contaminant causing complaint has been removed or reduced to a concentration that renders water acceptable for drinking.

NOTE: Important general information is contained in PART II, Chapter 6

The Flavour Rating Assessment method (Zoetman *et al* 1984, APHA Method 2160C 1992) uses a simple rating scale for acceptance of water.

Individuals have different sensitivities to, and perceptions of, odours and tastes, and complaints may consequently be lodged when the majority of consumers do not perceive any problem. It is therefore essential that participants in small panels have sensitivities close to the population norm, to reflect the majority opinion of the water. The composition of large panels, on the other hand, should reflect the range of sensitivities found in the community, to ensure that when more than 90% of the large panel find the water 'acceptable', this will agree essentially with community assessment of water at the tap.

TREATMENT OF DRINKING WATER

Substances producing taste and odour can sometimes be removed by granular activated carbon. Powdered activated carbon is less effective. Volatile compounds can be removed by aeration. Oxidation and biological treatment can also reduce tastes and odours.

HEALTH CONSIDERATIONS

Odour in potable water may indicate pollution of the water or malfunction during water treatment or distribution. Odours of a biological origin can indicate increased biological activity, for example by algae. Some algae can produce toxins and the detection of these algae by taste and odour provides a useful early warning of potential problems, although taste and odour do not necessarily indicate the presence of toxins.

DERIVATION OF GUIDELINE

It is clearly unsatisfactory for a water authority to be supplying water that is objectionable in taste and odour to a significant proportion of customers. Alternatives such as rainwater tanks, bores and bottled water will be heavily used under such conditions.

GUIDELINES IN OTHER COUNTRIES

The 1984 WHO Guidelines require that water not be objectionable to most consumers. The 1993 WHO Guidelines require that taste and odour be acceptable to avoid consumer complaints.

The Canadian Guidelines stipulate that drinking water shall not have an offensive odour.

The European Economic Community Standards and the United States EPA require that the Threshold Odour Number (TON) not exceed 3. (The Threshold Odour Number method is no longer regarded as a reliable method for the determination of odours.)

REFERENCES

APHA Method 2160C (1992). Flavor rating assessment (FRA). Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Krasner SW, McGuire MJ and Ferguson VB (1985). Tastes and odours: The flavour profile method. Journal of the American Water Works Association, 77, March, 34–39.

Mallevaille J and Suffet IH (eds) (1987). Identification and treatment of tastes and odours in drinking water. American Water Works Association, Research Foundation, Lyonnaise des Eaux, 102-210 and 227–250.

Zoeteman BCJ, DeGreef E, Van Oers *et al* (1984). Consumer panels monitoring taste of water in Rotterdam. *Journal of the American Water Works Association,* 76, June, 75–77.

Temperature

GUIDELINE

No guideline is set due to the impracticality of controlling water temperature.

Drinking water temperatures above 20˚C may result in an increase in the number of complaints.

GENERAL DESCRIPTION

Temperature is primarily an aesthetic criterion for drinking water. Generally, cool water is more palatable than warm or cold water.

In general, consumers will react to a change in water temperature. Complaints are most frequent when the temperature suddenly increases.

The turbidity and colour of filtered water may be indirectly affected by temperature, as low water temperatures tend to decrease the efficiency of water treatment processes by, for instance, affecting floc formation rates and sedimentation efficiency.

Chemical reaction rates increase with temperature, and this can lead to greater corrosion of pipes and fittings in closed systems. Scale formation in hard waters will also be greater at higher temperatures.

MEASUREMENT

Temperature measurements should be made with a good quality, mercury-filled Celsius thermometer (APHA Method 2550B 1992).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Water temperatures in major Australian reticulated supplies range from 10˚C to 30˚C. In some long, above-ground pipelines, water temperatures up to 45˚C may be experienced.

CONTROL IN DRINKING WATER SUPPLIES

Control of water temperature in reticulated supplies is seldom practical or effective. Selective withdrawal from deep reservoirs can be used but this may introduce other water quality problems. Aeration can also be used. In some situations it may be possible to place pipes underground to reduce water temperature fluctuations, or to vary the times water remains in pipes and storage tanks.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

The effectiveness of chlorine as a disinfectant is influenced by the temperature of the water being dosed. Generally higher temperatures result in more effective disinfection at a particular chlorine dose, but this may be counterbalanced by a more rapid loss of chlorine to the atmosphere (AWWA 1990).

Chlorine reacts with organic matter in water to produce undesirable chlorinated organic byproducts, and higher temperatures increase the rate of these reactions.

Temperature can directly affect the growth and survival of microorganisms. In general the survival time of infectious bacteria and parasites is reduced as the temperature of the contaminated water increases. *Naegleria fowleri*, which can cause amoebic meningitis, grows between 18°C and 46°C and is likely to occur in nondisinfected water supplies that reach 30°C seasonally. *Legionella pneumophila* (which causes Legionnaires' disease) and related bacteria are found in hot and cold water systems, with colonisation occurring in stagnant water at temperatures between 20°C and 45°C. Increased temperatures can also promote the growth of taste- and odour-producing organisms in lakes and impoundments, and in distribution systems.

GUIDELINES IN OTHER COUNTRIES

The European Economic Community Standards have a guideline value of 12°C and a maximum of 25°C.

The Canadian Guidelines have a recommended value of 15°C.

The 1984 WHO Guidelines do not include a value for temperature as control is usually impractical. The 1993 WHO Guidelines require that temperature should be acceptable to avoid consumer complaints.

REFERENCES

APHA Method 2550B (1992). Temperature: Laboratory and field methods. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

AWWA (1990). *Water Quality and Treatment: A handbook of community water supplies*. American Water Works Association, 4th edition, McGraw-Hill Inc.

Tetrachloroethene

(also known as tetrachloroethylene or perchloroethylene)

GUIDELINE

Based on health considerations, the concentration of tetrachloroethene in drinking water should not exceed 0.05 mg/L.

GENERAL DISCUSSION

Tetrachloroethene is used as a solvent in the dry-cleaning industry. It may be present in drinking water through contamination of water sources by spills or discharges. In the United Kingdom and the United States it has occasionally been detected in drinking water at concentrations below 0.001 mg/L. It has been found at higher concentration in contaminated groundwater.

The odour threshold in water is 0.3 mg/L.

Tetrachloroethene is widespread in the environment through use in dry-cleaning and as a metal-degreasing fluid. It has been reported in trace amounts in food, water, aquatic organisms and human tissue.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Tetrachloroethene has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Tetrachloroethene can be removed from drinking water by adsorption onto granular activated carbon or by aeration.

MEASUREMENT

A solvent extraction procedure is suitable for the analysis of tetrachloroethene (USEPA Draft Method 551 1990). Sodium chloride is added to the sample and tetrachloroethene extracted using methyl tert-butyl ether. The extract is then analysed using gas chromatography with an electron capture detector. The limit of determination is approximately 0.000004 mg/L (4 ng/L).

HEALTH CONSIDERATIONS

Tetrachloroethene is rapidly absorbed after ingestion or inhalation. It is eliminated primarily by the lungs. In the body it is slowly metabolised to trichloroacetic acid.

An extensive review and summary of the human and animal toxicity data for tetrachloroethene is available (IPCS 1984).

The most notable acute effect of short-term exposure is depression of the central nervous system. Short-term studies of up to 3 months using mice and rats reported weight loss, and found some evidence of liver and kidney toxicity at high doses (400 mg/kg body weight per day).

Inhalation exposure to impure tetrachloroethene at 100 ppm and above in air caused hepatocellular carcinomas in mice. Exposure at 200 ppm in air increased the incidence of leukaemia in rats.

NOTE: Important general information is contained in PART II, Chapter 6

Mutagenic activity was not observed in most tests with a number of strains of bacteria. No chromosome aberrations were observed using rat or mouse cells, or human lymphocytes.

The International Agency for Research on Cancer has concluded that tetrachloroethene is possibly carcinogenic to humans (Group 2B, inadequate human data but sufficient evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The guideline value of 0.05 mg/L for tetrachloroethene in drinking water was determined as follows:

$$0.05 \text{ mg/L} = \frac{14 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 14 mg/kg body weight per day is the no effect level from a 90-day drinking water study using rats and mice (Buben and O'Flaherty 1985, Hayes *et al* 1986)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 to account for possible carcinogenicity). An additional factor for the less than lifetime study was not applied as long-term carcinogenicity bioassays were available.

The WHO guideline value of 0.04 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

Buben JA and O'Flaherty EJ (1985). Delineation of the role of metabolism in the heptatoxicity of trichloroethylene and perchloroethylene: A dose effect study. *Toxicology and Applied Pharmacology*, 78, 105–122.

Hayes JR, Condie LW and Borzelleca JF (1986). The subchronic toxicity of tetrachloroethylene (perchloroethylene) administered in the drinking water of rats. *Fundamental and Applied Toxicology,* 7, 119–125.

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1984). Tetrachloroethylene. Environmental Health Criteria, 31. World Health Organization, International Programme on Chemical Safety.

USEPA Draft Method 551 (1990). Determination of chlorination disinfection byproducts and chlorinated solvents in drinking water by liquid-liquid extraction and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Tin

GUIDELINE

No guideline value is considered necessary for tin in drinking water, as concentrations are likely to be considerably lower than the level that can cause health effects.

GENERAL DESCRIPTION

Tin is mainly used for plating. Tin coatings are used in the manufacture of food containers and in food processing equipment. Tin is also used in alloys such as solders, bronzes and pewters. Inorganic tin compounds are used as pigments in the ceramic and textile industries. Organic tin compounds are used as biocides (see Fact Sheet on organotins).

The concentration of inorganic tin compounds in uncontaminated drinking water supplies overseas is extremely low, usually less than 0.000005 mg/L (5 ng/L). The highest concentration reported is 0.03 mg/L but concentrations above 0.002 mg/L are exceptional.

Food, and particularly canned food, is the major source of human exposure to tin. Intake from this source can vary widely and estimates range from 0.1 mg per day up to 100 mg per day, with a median of 0.2 mg per day.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Australian drinking water supplies have not been routinely monitored for tin. Based on measurements made overseas, it is likely that concentrations would be extremely low.

TREATMENT OF DRINKING WATER

Treatment of drinking water to reduce the concentration of inorganic tin is unlikely to be required.

MEASUREMENT

The concentration of tin in drinking water can be determined using graphite furnace atomic absorption spectroscopy (APHA Method 3500-Sn part B 1992). The limit of determination is 0.01 mg/L.

HEALTH CONSIDERATIONS

Tin is thought to be an essential element in animals. It is not known whether it is essential for humans.

Tin, or tin salts, are poorly absorbed from the gastrointestinal tract. Most studies indicate that less than 5% is absorbed. Highest concentrations of tin occur in the bone, kidney and liver. Biological half-lives range from 1 to 4 months, and tin is excreted primarily via the kidneys and bile.

An extensive review and summary of the human and animal toxicity data for tin is available (IPCS 1980).

There is no evidence of adverse effects in humans associated with long-term exposure to tin. The main effects, due to consumption of canned food with high tin concentrations (over 150 mg/kg), are gastric irritation resulting in vomiting, diarrhoea, fatigue and headache.

In animals, long-term ingestion studies over 2 years using rats and mice reported no significant adverse effects. Most studies reported no increase in the incidence of tumours.

Inorganic tin in the form of stannous chloride was found not to be mutagenic in tests with bacteria; however, in mammalian cells in vitro inorganic tin has induced DNA and chromosomal aberrations.

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The low toxicity of tin and inorganic tin compounds is due largely to low absorption, low tissue accumulation and rapid excretion. A guideline value of approximately 0.7 mg/L could be derived from a 2-year feeding study with rats (WHO 1982) but this value is approximately three orders of magnitude higher than tin concentrations in drinking water. Therefore, the presence of tin in drinking water does not represent a hazard to human health and the establishment of a guideline value is not deemed necessary.

REFERENCE

APHA Method 3500-Sn Part B (1992). Tin: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

IPCS (1980). Tin and Organotin Compounds. Environmental Health Criteria, 15. World Health Organization, International Programme on Chemical Safety.

WHO (1982). Toxicological evaluation of certain food additives and contaminants: Tin. The 26th meeting of the Joint FAO/WHO Expert Committee on Food Additives, 17, 297–319, Geneva.

Toluene

GUIDELINE

Based on aesthetic considerations (taste and odour), the concentration of toluene in drinking water should not exceed 0.025 mg/L.

Toluene would not be a health concern unless the concentration exceeded 0.8 mg/L.

GENERAL DESCRIPTION

Toluene occurs naturally as a component of crude oil and is present in petrol. It can enter water sources through atmospheric deposition, by leaching from synthetic coatings used to protect storage tanks, and by point-source pollution. In overseas studies the average concentration of toluene in the Rhine River in the Netherlands is approximately 0.002 mg/L, and approximately 1% of all ground water supplies in the United States have concentrations greater than 0.0005 mg/L.

Toluene is produced in large quantities during petroleum refining and is a byproduct in the manufacture of styrene and coke-oven preparations. It also occurs in natural gas and emissions from volcanoes, forest fires, and cigarettes.

In water, toluene has a taste and odour threshold between 0.025 mg/L to 0.17 mg/L, depending on individual sensitivities and water temperature.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Toluene has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Toluene can be removed from drinking water by aeration, or adsorption onto granular activated carbon.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for the analysis of toluene (USEPA Draft Method 503.1 1986). An inert gas is bubbled through the sample and toluene trapped on an adsorbent. The adsorbent is then heated and the toluene analysed using gas chromatography with photoionization detection. The limit of determination is less than 0.001 mg/L.

HEALTH CONSIDERATIONS

In humans, toluene is readily absorbed from the gastrointestinal tract after ingestion, and is distributed preferentially in adipose tissue, then the kidneys, liver and brain. It is rapidly metabolised by the liver to benzyl alcohol, benzoic acid, and to a lesser extent, phenols.

An extensive review and summary of the human and animal toxicity data for toluene is available (IPCS 1985).

Data on human health effects come mainly from inhalation studies. The predominant effects of acute exposure were impairment of the central nervous system and irritation of the mucous membranes, with fatigue and drowsiness being the most obvious symptoms.

NOTE: Important general information is contained in PART II, Chapter 6

Rats exposed to toluene vapour for 2 years exhibited decreased blood haematocrit values at high toluene concentrations (380 ppm in air). No data are available on long-term oral toxicity; however, a 13-week gavage study using rats and mice reported increased liver weights at doses from 625 mg/kg body weight per day (NTP 1990).

Toluene generally did not exhibit genotoxic activity in tests on bacteria, yeast cells, and mammalian cells *in vitro*.

The International Agency for Research on Cancer has concluded that toluene is not classifiable as to its carcinogenicity in humans (Group 3, inadequate evidence in humans and in animals) (IARC 1989).

DERIVATION OF GUIDELINE

The health-based guideline value of 0.8 mg/L for toluene in drinking water was determined as follows:

$$0.8 \text{ mg/L} = \frac{312 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000} \times \frac{5}{7}$$

where:

- 312 mg/kg body weight per day is the no effect level based on a 13-week oral study using rats (NTP 1990)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 because a less than lifetime study was used)
- 5/7 is used to convert data based on a 5 day per week gavage study to a 7-day week equivalent.

This health-based guideline value exceeds the taste threshold of toluene in water of 0.025 mg/L.

The WHO guideline value of 0.7 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

IARC (1989). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: some organic solvents, resin monomers and related compounds, pigments and occupational exposures in paint manufacture and painting. World Health Organization, International Agency for Research on Cancer, 47.

IPCS (1985). Toluene. Environmental Health Criteria, 52. World Health Organization, International Programme on Chemical Safety.

NTP (1990). Toxicology and carcinogenesis studies of toluene in F344/N rats and B6C3F1 mice. National Toxicology Program, NTP Report No 371. United States Department of Health and Human Services, NIH Publication No. 90-2826.

USEPA Draft Method 503.1 (1986). Volatile organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Total dissolved solids

GUIDELINE

Based on taste, total dissolved solids in drinking water should not exceed 500 mg/L. The equivalent figure in electrical conductivity units (EC units) can be roughly determined by doubling this value.

GENERAL DESCRIPTION

Total dissolved solids (TDS) consist of inorganic salts and small amounts of organic matter that are dissolved in water. Clay particles, colloidal iron and manganese oxides, and silica fine enough to pass through a 0.45 micrometer filter membrane can also contribute to total dissolved solids.

Total dissolved solids comprise sodium, potassium, calcium, magnesium, chloride, sulfate, bicarbonate, carbonate, silica, organic matter, fluoride, iron, manganese, nitrate (and nitrite) and phosphate.

The palatability of drinking water has been rated according to TDS concentrations as follows (Bruvold and Daniels 1990):

mg/L	**quality**
<80	excellent
80-500	good
500-800	fair
800-1000	poor
>1000	unacceptable

Water with extremely low TDS may taste flat and insipid.

High TDS values may be associated with excessive scaling in pipes, fittings and household appliances. Excessive corrosion may also occur with high TDS values.

The electrical conductivity of water, measured in EC units, increases with the concentration of dissolved solids. Electrical conductivity can be used as a measure of TDS, but the factor used to convert EC into TDS will depend on the type of dissolved solids present in the water.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies TDS values range from about 45 mg/L to 750 mg/L.

MEASUREMENT

Three methods can be used to determine total dissolved solids. The most accurate entails a complete analysis of the sample and summation of the concentration of all the anions and cations. The most common and least expensive method is to convert electrical conductivity measurements to TDS values by multiplication with a factor that varies with the type of water (APHA Method 2510A 1992). Gravimetric measurements (i.e. by evaporation and weighing) can also be used (APHA Method 2540C 1992).

TREATMENT OF DRINKING WATER

It is difficult to remove dissolved solids from drinking water. Suitable technologies include reverse osmosis, ion exchange, and distillation, but all of these require considerable energy input and can be expensive to operate. Lime softening may also be effective where high TDS is mainly due to hardness.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

No health effects have been associated specifically with high TDS concentrations. The health effects of individual components of TDS are discussed separately in the discussions on inorganic chemicals (Section 6.3.1 and relevant Fact Sheets).

DERIVATION OF GUIDELINE

Based on taste, water with a total dissolved solids content of less than 500 mg/L is regarded as good quality water (Bruvold *et al* 1990), although water with a total dissolved solids content of up to 1000 mg/L is acceptable to many communities.

In Australian surface water, the major ions contributing to total dissolved solids are sodium and chloride. Individual guideline values for these ions are consistent with a guideline value for total dissolved solids of 500 mg/L (see Fact Sheets on Chloride and Sodium); a higher TDS value may result in these other guideline values being exceeded.

GUIDELINES IN OTHER COUNTRIES

The 1984 WHO guideline value for total dissolved solids is 1000 mg/L. The 1993 WHO Guidelines indicate that concentrations above 1000 mg/L may give rise to consumer complaints.

The European Economic Community Standards have a guideline for total dry residue of 1500 mg/L but also state that electrical conductivity of less than 400 EC units is desirable.

Both the Canadian Guidelines and the United States EPA Regulations set a level of 500 mg/L.

REFERENCES

APHA Method 2510A (1992). Conductivity: Laboratory method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 2540C (1992). Total Dissolved Solids Dried at 180(C. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Bruvold WH and Daniels JI (1990). Standards for mineral content in drinking water. *Journal of the American Water Works Association,* 82, February, 59–65.

Trichloroacetaldehyde (chloral hydrate)

GUIDELINE

Based on health considerations, the concentration of chloral hydrate in drinking water should not exceed 0.02 mg/L.

GENERAL DISCUSSION

Chloral hydrate may be formed as a byproduct during chlorination of water containing naturally occurring organic material. Contamination of drinking water due to industrial spills is unlikely in Australia but has occurred overseas. In the United States chloral hydrate has been detected in a small number of supplies, with concentrations ranging from 0.00001 mg/L (10 ng/L) to 0.1 mg/L.

Chloral hydrate has been used as a sedative and hypnotic drug in humans at oral doses up to 14 mg/kg body weight.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

No data are available on concentrations of chloral hydrate in Australian drinking waters.

LIMITING FORMATION IN DRINKING WATER

The presence of chloral hydrate in drinking water can be minimised by removing naturally occurring organic matter from the source water, by reducing the amount of chlorine added, or by the use of alternative disinfectants.

MEASUREMENT

A solvent extraction procedure is suitable for the analysis of chloral hydrate (USEPA Draft Method 551 1990). Sodium chloride is added to the sample and chloral hydrate extracted using methyl tert-butyl ether. The extract is then analysed using gas chromatography with an electron capture detector. The limit of determination is approximately 0.00003 mg/L (30 ng/L).

HEALTH CONSIDERATIONS

Chloral hydrate is known to be rapidly absorbed in humans and quickly oxidised to trichloroacetic acid or reduced to trichloroethanol.

In its wide use as a sedative or hypnotic drug in humans, concentrated solutions have proved quite irritating to the gastrointestinal tract, and have caused nausea and vomiting. Side effects of the drug have included central nervous system depression, minor sensitivity reactions, and central nervous system excitement. Chronic use may result in development of tolerance, physical dependence and addiction. Addicts have been reported to take as much as 12 grams per day.

There have been a number of animal toxicity studies using rats and mice varying in duration from a few days to 2 years. In a 90-day drinking water study using mice, some enlargement of the liver was reported at doses from 16 mg/kg body weight per day. Other studies have reported that higher doses cause some liver toxicity.

NOTE: Important general information is contained in PART II, Chapter 6

In a 2-year bioassay study in male mice, chloral hydrate administered in drinking water at 166 mg/kg body weight per day induced hepatocellular adenomas and carcinomas and hyperplastic nodules of the liver. One study using mice reported an increase in liver tumours after 1–2 years with a single oral dose of chloral hydrate (10 mg/kg body weight).

Chloral hydrate was mutagenic in tests with some strains of bacteria but did not bind to mouse liver DNA. It increased the frequency of chromosome aberrations in cultured cells but was negative in mouse bone-marrow assays.

The NHMRC Standing Committee on Toxicity reviewed the available toxicity data for chloral hydrate in 1991 and concluded that data were insufficient to set no effect levels.

DERIVATION OF GUIDELINE

The guideline value for chloral hydrate in drinking water was determined as follows:

$$0.02 \text{ mg/L} = \frac{16 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.2}{2 \text{ L/day} \times 5000}$$

where:

- 16 mg/kg body weight per day is the lowest effect level based on a 90-day drinking water study using mice where liver enlargement was observed at the lowest dose (Sanders *et al* 1982)
- 70 kg is the average weight of an adult
- 0.2 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 5000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations, 5 for the less than lifetime study, as considerable human health data is available following its use as a therapeutic agent, and 10 for the use of a lowest effect level instead of a no effect level).

The WHO guideline value of 0.01 mg/L included a safety factor of 10 for the less than lifetime animal study. Given the considerable human exposure to chloral hydrate as a therapeutic drug, it was considered that an overall safety factor of 5000 was adequate.

REFERENCES

Sanders VM, Kauffman BM, White KL, Douglas KA, Barnes DW, Sain LE, Bradshaw TJ, Borzelleca JF and Munson AE (1982). Toxicology of chloral hydrate in the mouse. *Environmental Health Perspectives,* 44, 137–146.

USEPA Draft Method 551 (1990). Determination of chlorination disinfection byproducts and chlorinated solvents in drinking water by liquid-liquid extraction and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Trichlorobenzenes

1,2,3-trichlorobenzene (1,2,3-TCB)
1,2,4-trichlorobenzene (1,2,4-TCB)
1,3,5-trichlorobenzene (1,3,5-TCB)

GUIDELINE

Based on aesthetic considerations (taste and odour), the concentration of trichlorobenzenes in drinking water, either individually or in total, should not exceed 0.005 mg/L.

Trichlorobenzenes would not be a health concern unless the concentration exceeded 0.03 mg/L.

GENERAL DESCRIPTION

Trichlorobenzenes are present in the environment mainly as a result of a variety of industrial processes. They have only occasionally been found in drinking water supplies overseas, and rarely above 0.001 mg/L. Food and air are the primary routes of exposure.

Taste and odour thresholds vary from 0.005 mg/L to 0.03 mg/L, depending on individual sensitivities and water temperature.

Industrial-grade TCB is more than 90% 1,2,4-TCB with the remainder 1,2,3-TCB. The compound has a wide variety of uses. It is used as a solvent for high-melting products, an electrical coolant, a lubricant and an insecticide, and in polyester dyeing and termiticide preparations.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

TCBs have not been found in Australian drinking waters. They are included here to provide guidance in the unlikely event of contamination, and because they have been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

The concentration of TCBs in drinking water can be reduced by adsorption onto granular activated carbon.

MEASUREMENT

TCBs can be analysed using a solvent extraction procedure (USEPA Method 612 1984). The TCBs are extracted using dichloromethane and analysed using gas chromatography with electron capture detection. The limit of determination for 1,2,4-TCB is 0.00005 mg/L (50 ng/L). The purge and trap method can also be used (USEPA Draft Method 502.1 1986).

HEALTH CONSIDERATIONS

The TCBs are readily absorbed from the gastrointestinal tract and distributed in fat, skin and the liver. In rats and rabbits the TCBs are metabolised into trichlorophenols and mercapturic acids.

An extensive review and summary of the human and animal toxicity data for chlorobenzenes is available (IPCS 1991).

NOTE: Important general information is contained in PART II, Chapter 6

There are very few studies on the effects of human exposure. TCBs have caused marked irritation of the mucous membranes following inhalation over short periods of exposure. No data are available on the effects of long-term exposure.

Animal studies are of short-term duration. A 13-week study using rats reported that toxic effects of the three isomers were similar: low doses produced no adverse effects, but higher doses (77 mg/kg body weight per day) caused changes to the liver and thyroid.

No increase in the incidence of tumours was observed in longer-term animal studies. TCBs did not exhibit mutagenic activity in tests with bacteria.

DERIVATION OF GUIDELINE

As the three TCBs have similar toxic effects, the guideline value can be based on the total concentration of all the TCBs rather than on the individual compounds. The health-based guideline value for total TCBs in drinking water was determined as follows:

$$0.03 \text{ mg/L} = \frac{7.7 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 7.7 mg/kg body weight per day is the no effect level from a 13-week dietary study using rats (Côté *et al* 1988)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for a less than lifetime study).

This health-based guideline value exceeds the taste and odour threshold of 0.005 mg/L.

The WHO guideline value of 0.02 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

Côté M, Chu I, Villeneuve DC, Secours VE and Valli VE (1988). Trichlorobenzenes: results of a 13 week feeding study in the rat. *Drug and Chemical Toxicology*, 11, 11–28.

IPCS (1991). Chlorobenzenes other than hexachlorobenzene. Environmental Health Criteria, 128. World Health Organization, International Programme on Chemical Safety.

USEPA Method 612 (1984). Guidelines establishing test procedures for the analysis of pollutants under the Clean Water Act. Federal Register, 40, CFR Part 136, 43234-43442.

USEPA Draft Method 502.1 (1986). Volatile halogenated organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support laboratory (EMSL), Cincinnati, Ohio.

1,1,1-trichloroethane

GUIDELINE

Data are inadequate to set a guideline value for 1,1,1-trichloroethane in drinking water.

GENERAL DESCRIPTION

1,1,1-trichloroethane may be present in drinking water as a result of contamination from industrial discharges and spills. In the United States, 1,1,1-trichloroethane has occasionally been found in water supplies at concentrations ranging from 0.0002 mg/L to 0.02 mg/L.

It is widely used as a cleaning solvent, and is used to clean electrical equipment, motors, electronic components, printed circuit boards, photographic film, and various metal and plastic parts. It is also used as a lubricant in metal-cutting oils and as a component in inks, correction fluid and drain cleaners.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

1,1,1-trichloroethane has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

1,1,1-trichloroethane can be removed from drinking water by adsorption onto granular activated carbon, by aeration and by boiling. If aeration is used for removal, consideration should be given to effects associated with inhalation.

MEASUREMENT

A solvent extraction procedure is suitable for the analysis of 1,1,1-trichloroethane (USEPA Draft Method 551 1990). Sodium chloride is added to the sample and 1,1,1-trichloroethane extracted using methyl tert-butyl ether. The extract is then analysed using gas chromatography with an electron capture detector. The limit of determination is approximately 0.000008 mg/L (8 ng/L).

HEALTH CONSIDERATIONS

1,1,1-trichloroethane is absorbed rapidly and efficiently from the human gastrointestinal tract and the lungs. It is metabolised to a very limited extent (probably less than 6%) by both humans and animals.

An extensive review and summary of the human and animal toxicity data for 1,1,1-trichloroethane is available (IPCS 1992).

Inhalation of high concentrations of 1,1,1-trichloroethane has proved fatal, causing acute congestion of the lungs, fluid build-up and fatty deposits in the liver.

In animals, long-term studies have reported diminished body-weight gains at high doses (above 350 mg/kg body weight) but data were insufficient to determine no effect levels. Liver tumours were observed in mice, but not in rats, fed 1,1,1-trichloroethane for 2 years; however, the study reported a high number of accidental deaths in both the control and study groups, and the results may not be significant.

NOTE: Important general information is contained in PART II, Chapter 6

Mutagenic activity has been reported in tests with some strains of bacteria, but not others.

The International Agency for Research on Cancer has concluded that 1,1,1-trichloroethane is not classifiable as to its carcinogenicity in humans (Group 3, no adequate data in humans, inadequate evidence in animals) (IARC 1987).

DERIVATION OF GUIDELINE

The WHO health-based guideline value of 2 mg/L was based on a short-term inhalation study. The data were not considered to be sufficient to set an Australian guideline.

REFERENCE

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1992). 1,1,1-Trichloroethane. Environmental Health Criteria, 136. World Health Organization, International Programme on Chemical Safety.

USEPA Draft Method 551 (1990). Determination of chlorination disinfection byproducts and chlorinated solvents in drinking water by liquid-liquid extraction and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (ESML), Cincinnati, Ohio.

Trichloroethylene (TCE)

GUIDELINE

Data are inadequate to set a guideline value for trichloroethylene in drinking water.

GENERAL DISCUSSION

TCE may be present in drinking water as a result of direct contamination of water sources, or from atmospheric contamination of rainfall. In the United States, TCE has been detected in the water supplies of about 20% of cities tested, with mean concentrations of 0.02 mg/L or less.

TCE is used in cleaning fluids, as an industrial solvent and as a degreaser for metal components. The most significant route of exposure to humans is inhalation, particularly from use as a cleaning fluid.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

TCE has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

TCE can be removed from drinking water by aeration, or by adsorption onto granular activated carbon.

MEASUREMENT

A solvent extraction procedure is suitable for the analysis of TCE (USEPA Draft Method 551 1990). Sodium chloride is added to the sample and TCE extracted using methyl tert-butyl ether. The extract is then analysed using gas chromatography with an electron capture detector. The limit of determination is approximately 0.000002 mg/L (2 ng/L).

HEALTH CONSIDERATIONS

TCE is readily absorbed by all routes of exposure and distributed to all tissues. It is metabolised to reactive epoxides and the trichloro derivatives of acetaldehyde, ethanol and acetic acid.

An extensive review and summary of the human and animal toxicity data for trichloroethylene is available (IPCS 1985).

In humans, TCE is a known central nervous system depressant and has been used as a general anaesthetic. Liver damage has been reported in people occupationally exposed to high concentrations.

There is some evidence that TCE induces liver and lung tumours in various strains of mice. In an inhalation study, TCE produced a dose-related increase in malignant lymphomas in female mice exposed to 100 ppm or above in air. TCE is a weakly acting mutagen in bacteria and yeast.

The International Agency for Research on Cancer has concluded that TCE is not classifiable as to its carcinogenicity in humans (Group 3, inadequate evidence in humans and limited evidence in animals) (IARC 1987).

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The WHO health-based guideline value of 0.07 mg/L was based on a 6-week feeding study using mice which identified a low effect level but not a no effect level. No long-term studies are available to establish a no effect level. The data were not considered to be sufficient to set an Australian guideline.

REFERENCES

IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

IPCS (1985). Trichloroethylene. Environmental Health Criteria, 50. World Health Organization, International Programme on Chemical Safety.

USEPA Draft Method 551 (1990). Determination of chlorination disinfection byproducts and chlorinated solvents in drinking water by liquid-liquid extraction and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Trihalomethanes (THMs)

trichloromethane (chloroform)
bromodichloromethane
dibromochloromethane
tribromomethane (bromoform)

GUIDELINE

Based on health considerations, the concentration of trihalomethanes, either individually or in total, in drinking water should not exceed 0.25 mg/L.

Trihalomethane concentrations fluctuating occasionally (for a day or two annually) up to 1 mg/L are unlikely to pose a significant health risk.

Action to reduce THMs is encouraged, but must not compromise disinfection, as nondisinfected water poses significantly greater risk than THMs.

GENERAL DESCRIPTION

In Australia, trihalomethanes are present in drinking water principally as the result of disinfection using chlorination or, to a much lesser extent, chloramination. Chlorine, which produces hypochlorous acid when added to water, can react with naturally occurring organic material, such as humic and fulvic acids, to produce trihalomethanes. The brominated trihalomethanes are produced by the oxidation of bromide present in water to form hypobromous acid, which can then react with organic matter in a similar way.

High trihalomethane concentrations may indicate the presence of other chlorination byproducts.

Chloroform is produced commercially and is an important solvent. It is used in the manufacture of refrigerants, and as an ingredient in pharmaceutical and cosmetic preparations. Brominated trihalomethanes are also produced industrially, but less commonly than chloroform.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies concentrations of total trihalomethanes range up to 0.6 mg/L.

LIMITING PRESENCE IN DRINKING WATER

The concentration of trihalomethanes can be minimised by removing precursors, by removing trihalomethanes after formation, or by using alternative disinfectants. Precursors can be removed by activated carbon, by coagulation followed with filtration, or by oxidation with ozone or potassium permanganate. Once produced, trihalomethanes can be removed with air stripping or adsorption onto granular activated carbon. Alternative disinfection agents to chlorine, such as chloramines, ozone and chlorine dioxide, can substantially reduce trihalomethane concentrations, but may produce other byproducts.

NOTE: Important general information is contained in PART II, Chapter 6

MEASUREMENT

There are a number of methods available for the analysis of trihalomethanes, including head-space analysis, solvent extraction, purge and trap, and direct collection on resins. The solvent extraction procedure is relatively simple to use (USEPA Draft Method 551 1990). Sodium chloride is added to the sample and the trihalomethanes extracted using methyl tert-butyl ether. The extracts are then analysed using gas chromatography with electron capture detection. Limits of determination are 0.00002 mg/L (20 ng/L) or less.

HEALTH CONSIDERATIONS

The trihalomethanes are rapidly and efficiently absorbed following ingestion. They are metabolised primarily to carbon dioxide and/or carbon monoxide, and rapidly exhaled. They are fat soluble, and accumulate in tissues with the highest lipid content (such as adipose tissue, brain, kidney and blood).

In animals, the trihalomethanes are central nervous system depressants and liver and kidney toxicants. Chloroform and bromoform are also known to cause central nervous system depression in humans.

Some epidemiological studies have reported associations between the ingestion of chlorinated drinking water (which typically contains THMs) and increased cancer mortality rates. The International Agency for Research on Cancer has concluded that the available data for chlorinated water provide inadequate evidence of carcinogenicity in humans (Group 3, inadequate evidence in humans and limited evidence in animals) (IARC 1991).

Long-term carcinogenicity bioassays with animals have shown that trihalomethanes can produce tumours in rats and mice, but only at doses that are toxic to the animals. Chloroform increased the incidence of liver tumours in mice when administered in food at doses from 25 mg/kg body weight per day, but not in drinking water at the same doses, and has induced kidney tumours in male rats at doses from 263 mg/kg body weight per day. Dibromochloromethane, given by gavage 5 days per week, clearly induced liver tumours in female mice at 100 mg/kg body weight per day, and possibly in male mice, but not in rats. Bromodichloromethane, given by gavage 5 days per week, induced kidney tumours in rats at 100 mg/kg body weight, and in male mice at 50 mg/kg body weight; a rare tumour of the large intestine in male rats at doses of 50 and 100 mg/kg body weight; and liver tumours in female mice at 75 and 150 mg/kg body weight. Bromoform induced a small increase in relatively rare tumours of the large intestine in rats at a gavage dose of 200 mg/kg body weight per day, but not in mice.

Results of studies on the genotoxicity of trihalomethanes in bacteria have been inconsistent, with most reporting negative results. Trihalomethanes have, however, induced chromosomal aberrations in human lymphocyte cells *in vitro*, and in mouse bone-marrow cells *in vivo*.

Available studies indicate that THMs can produce maternal and fetal toxicity at high doses, but not teratogenicity.

The International Agency for Research on Cancer has concluded that chloroform and bromodichloromethane are possibly carcinogenic to humans (Group 2B, inadequate evidence in humans but sufficient evidence in animals); and that bromoform and dibromochloromethane are not classifiable as to their carcinogenicity to humans (Group 3, inadequate evidence in humans and limited evidence in animals)(IARC 1991).

DERIVATION OF GUIDELINE

The guideline value for trihalomethanes in drinking water was determined as follows:

$$0.25 \text{ mg/L} = \frac{7 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 100}$$

where:

- 7 mg/kg body weight per day is the no effect level based on a 90-day study using rats (Chu *et al* 1982). The use of this value was recommended by the NHMRC Standing Committee on Toxicity following
  a review of the available toxicity data for THMs.
- 70 kg is the average weight of an adult.
- 0.1 is the proportion of total daily intake attributable to the consumption of water. A higher value was not used because exposure to chloroform from other sources may be significant.
- 2 L/day is the average amount of water consumed by an adult.
- 100 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations and 10 for intraspecies variations). An additional safety factor for the less than lifetime study was not applied as long-term studies have reported the same effects, and no other forms of toxicity were observed. In addition, the changes observed to the liver at higher doses were mild in nature and disappeared when exposure stopped. The use of this safety factor was recommended by the NHMRC Standing Committee on Toxicity.

Separate guideline values were not derived for each compound as the no effect levels were similar (ranging from 6.5 to 7.8 mg/kg body weight per day), and the compounds are metabolised in the body in similar ways. The guideline value should therefore apply to the concentration of each compound, or the sum of any combination of individual THM concentrations.

WHO has derived separate guideline values for each compound, but in doing so recognises that the compounds have similar toxicological action.

The WHO guideline values for chloroform (0.2 mg/L) and bromodichloromethane (0.06 mg/L) were based on calculations that estimated additional lifetime risks of one fatal cancer per 100,000 people. The use of this approach is questionable because there is evidence that tumours do not occur at low concentrations.

The WHO guideline values for bromoform (0.1 mg/L) and dibromochloromethane (0.1 mg/L) were based on different studies and safety factors from those recommended by the NHMRC Standing Committee on Toxicity, although toxicological effects were similar.

It is recommended that future reviews of the guidelines consider the various THMs individually, as data are emerging that suggest the different THMs have different toxic effects. Data were not sufficient at the time of this review to justify individual assessments

In view of the safety factors used in the derivation of the guideline value, it is unlikely that short-term consumption of water containing significantly higher concentrations of trihalomethanes would pose a health risk.

NOTE: Important general information is contained in PART II, Chapter 6

REFERENCES

Chu I, Villeneuve DC, Secours VE, Becking GC and Valli VE (1982). Trihalomethanes: II Reversibility of toxicological changes produced by chloroform, bromodichloro-methane, chlorodibromomethane and bromoform in rats. *Journal of Environmental Science and Health*, B17, 225–240.

IARC (1991). IARC monographs on the evaluation of carcinogenic risks to humans: Chlorinated drinking water; chlorination byproducts; some other halogenated compounds; cobalt and cobalt compounds. World Health Organization, International Agency for Research on Cancer 52, Lyons.

USEPA Draft Method 551 (1990). Determination of chlorination disinfection byproducts and chlorinated solvents in drinking water by liquid–liquid extraction and gas chromatography with electron capture detection. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Turbidity

GUIDELINE

Based on aesthetic considerations, the turbidity should not exceed 5 NTU.

If disinfection is required, then a turbidity of less than 1 NTU is desirable at the time of disinfection.

GENERAL DESCRIPTION

Turbidity is caused by the presence in the water of fine suspended matter such as clay, silt, colloidal particles, plankton and other microscopic organisms. High turbidity can result in a water sample having a 'muddy' or 'milky' appearance. Turbidity is a measurement of the light scattering property of water, and the degree of scattering is dependent on the amount, size and composition of the suspended matter. Turbidity is sometimes used as a surrogate characteristic for suspended solids. It is not possible to establish a general relationship between the two, as natural waters usually contain heterogeneous mixtures of suspended material of variable composition; however, specific relationships can be developed for particular water bodies.

As a guide, water with a turbidity of 5 NTU would appear slightly muddy or milky in a glass. It would not be possible to see through the glass if the turbidity was over 60 NTU. 'Crystal' clear water usually has a turbidity of less than 1 NTU.

Disinfection is discussed in Information Sheet 1 *Disinfection of drinking water.*

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies turbidity ranges between 5 NTU and less than 1 NTU where supplies are filtered, and between 1 NTU and 65 NTU for unfiltered supplies.

MEASUREMENT

The ratio-recording nephelometric turbidimeter is the preferred method for turbidity measurement, as it can compensate for the effect of dissolved colour. Results are expressed in nephelometric turbidity units (NTU) and are calibrated against a prepared formazin standard (APHA 2130B 1992). The detection limit is about 0.1 NTU.

TREATMENT OF DRINKING WATER

Turbidity can be reduced by selective withdrawal from a water source during periods of low turbidity, by small home water filtration systems, and by the use of complex and expensive multistage water filtration plants (AWWA 1990). Coagulation followed by filtration through granular media is widely used to reduce turbidity to below 1 NTU. Turbidities as low as 0.1 NTU are achievable by this means.

Catchment management practices can have a marked impact on turbidity. Water coming from undisturbed or protected areas will generally have lower turbidity than from areas under intensive cultivation (Donner and Kirner 1985).

Storage can significantly reduce turbidity as the suspended matter settles out over time.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Consumption of highly turbid waters is not necessarily a health hazard, but may constitute a health risk if the suspended particles harbour microorganisms capable of causing disease in humans, or if the particles have adsorbed toxic organic or inorganic compounds.

Turbidity can have a significant effect on the microbiological quality of drinking water. High turbidity can both interfere with the detection of bacteria and viruses, by adsorbing them onto the particulate matter and thus shielding them, and promote bacterial growth through the nutrients which are also adsorbed. High turbidity has also been shown to protect microorganisms from the action of disinfectants (Katz 1986). Low turbidity, however, is no guarantee that water is free from pathogenic microorganisms.

It may be more difficult to maintain adequate disinfection in a water supply if the turbidity exceeds 1 NTU. This does not mean that effective disinfection cannot be achieved if the turbidity exceeds 1 NTU. Effective disinfection is dependent on a number of factors including the nature of the material causing the turbidity, the source of the water, the potential for recontamination or regrowth, the amount of organic matter, and length of the distribution system. Additional information, such as from more frequent bacteriological testing, may be needed if the turbidity exceeds 1 NTU.

In water with high turbidity, heavy metals and pesticides can be adsorbed and so concentrate on the surface of some suspended particles. In addition, the higher demand for chlorine can lead to increased formation of chlorination byproducts, some of which can have undesirable health effects (see Section 6.3.2).

DERIVATION OF GUIDELINE

The guideline value is based on the aesthetic consideration that a turbidity of 5 NTU is just noticeable in a glass of water. Lower turbidity may be required for effective disinfection (see Information Sheet 1 *Disinfection of drinking water*).

GUIDELINES IN OTHER COUNTRIES

The Canadian Guidelines set a maxiumum value for turbidity of 5 NTU, but state that treatment technology is generally available to produce drinking waters with turbidities below 1 NTU.

The 1984 WHO Guideline value for turbidity is 5 NTU, but turbidity of less than 1 NTU is recommended where disinfection is practised. The 1993 WHO Guidelines indicate that a turbidity above 5 NTU may give rise to consumer complaints.

The United States EPA regulations require turbidity to be less than 5 NTU, and less than 1 NTU for more than 95% of the time in filtered supplies.

The European Economic Community Standards maximum admissible level for turbidity is 4 NTU.

REFERENCES

APHA Method 2130B (1992). Turbidity: Nephelometric Method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

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NOTE: Important general information is contained in PART II, Chapter 6

Uranium

GUIDELINE

Based on health considerations, the concentration of uranium in drinking water should not exceed 0.02 mg/L.

GENERAL DESCRIPTION

Uranium may be present in the environment as a result of leaching from natural deposits, release in mill tailings, combustion of coal and other fuels, and use of phosphate fertilisers (which can contain as much as 150 mg/kg uranium). Naturally occurring uranium is a mixture of three radionuclides, U-238, U-234, and U-235. U-238 and U-234 decay solely by alpha particle emission, whereas U-235 emits both gamma rays and alpha particles. In terms of mass, natural uranium consists almost entirely of the U-238 isotope, the other isotopes being less than 1% abundant. Uranium is used primarily as a fuel in nuclear power plants.

Studies overseas have reported uranium concentrations in drinking water of generally less than 0.001 mg/L; however, concentrations as high as 0.7 mg/L have been reported in some private water supplies in Canada.

Food is the major source of uranium intake and highest concentrations are found in shellfish. Dietary intake of uranium is estimated at 0.0014 mg/day. Drinking water contributes less than one tenth of this.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

No data are available on concentrations of uranium in Australian drinking water.

TREATMENT OF DRINKING WATER

Conventional treatment processes are not effective in removing uranium from water supplies.

MEASUREMENT

The concentration of uranium in water can be determined using solid fluorimetry with laser excitation (Blanchard *et al* 1985), or inductively coupled plasma mass spectrometry (Boomer *et al* 1987). The limit of determination is about 0.0001 mg/L.

The isotopes of uranium can be determined by radiochemical techniques using high resolution alpha spectrometry to measure their activity (EML 1990; USEPA 1980). The limit of determination is about 0.005 Bq/L (equivalent to approximately 0.0005 mg/L uranium).

HEALTH CONSIDERATIONS

a) Chemical toxic effects

Absorption of dietary uranium by the gastrointestinal tract has been estimated at less than 1%. Highest uranium concentrations occur in the kidney and bone, with little in the liver. The overall biological half-life has been estimated at 6–12 months.

In humans, the main toxic effect of short-term exposure to high concentrations of uranium is inflammation of the kidney. Little information is available on the effects of long-term exposure. One study, where 324 people drank contaminated water from wells with uranium concentrations up to 0.7 mg/L, reported no increase in the incidence of kidney disease or any other symptomatic complaint (Moss *et al* 1983).

NOTE: Important general information is contained in PART II, Chapter 6 and 7

In a number of studies carried out in rats, rabbits and dogs, although there are significant differences between species, most report that uranium has an effect on the kidney.

No data are available on chemically induced mutagenic effects in relation to uranium.

b) Radiological effects

Studies have shown high specific activity uranium isotopes to be carcinogenic in animals, causing malignant tumours in mice and bone sarcomas in rats. Similar studies using natural uranium (uranium-238) have not shown similar effects, possibly due to the lower radiation doses involved. Epidemiological data are inadequate to show whether exposure to uranium in drinking water will lead to an increased risk of cancer.

DERIVATION OF GUIDELINE

The guideline value for uranium in drinking water of 0.02 mg/L was set after consideration of the following points:

i) From chemical toxicity data:

$$0.02 \text{ mg/L} = \frac{0.057 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 10}$$

where:

- 0.057 mg/kg body weight per day is the no effect level based on the absence of kidney lesions in a 90-day study using rats (Gilman 1980)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed per day by an adult
- 10 is the safety factor in applying the results of animal studies to humans. No allowance is made either for interspecies variations, as there are sufficient data to indicate that humans are less sensitive to uranium than rats, or for a less than lifetime study, as the lesions were reversible.

ii) From radiological data:

$$3.8 \text{ Bq/L} = \frac{0.1 \text{ mSv /year}}{730 \text{ L/year} \times 3.6 \times 10^{-5} \text{ mSv/Bq}}$$

where:

- 0.1 mSv/year is the committed effective dose limit for an individual radionuclide; this is set at approximately a twentieth of the average background radiation dose from all sources (UNSCEAR 1988)
- 730 L/year is the annual consumption of drinking water (2 L/day x 365 days) for an adult
- 3.6×10^{-5} mSv/Bq is the committed effective dose received per unit intake of uranium-238 activity (Bq) (NRPB 1991).

iii) Comparing the chemical and radiological data:

An activity concentration of 3.8 Bq/L is equivalent to a chemical concentration of uranium of 0.3 mg/L. This is considerably greater than the guideline of 0.02 mg/L derived from the chemical toxicity data. The guideline value derived from chemical toxicity data is therefore also protective of radiological effects.

REFERENCES

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NOTE: Important general information is contained in PART II, Chapter 6

Vinyl chloride

GUIDELINE

No safe concentration for vinyl chloride in drinking water can be confidently set. However, for practical purposes, the concentration should be less than 0.0003 mg/L, which is the limit of determination.

GENERAL DESCRIPTION

Vinyl chloride is used industrially in the production of poly vinyl chloride (PVC), which has wide application in the plastics, rubber, paper and glass industries.

Vinyl chloride may be present in drinking water through pollution of water sources by chemical spills. Water bottled and stored for long periods in PVC containers may contain very low concentrations of vinyl chloride. It has occasionally been detected in drinking water supplies that use PVC pipes in the United States and Germany, with a maximum reported concentration of 0.01 mg/L. In Australia there are stringent requirements on the maximum permissible residual vinyl chloride concentrations in PVC pipes and fittings.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Vinyl chloride has not been found in Australian drinking waters. It is included here to provide guidance in the unlikely event of contamination, and because it has been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

There are no published reports on methods for the removal of vinyl chloride from drinking water.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for the analysis of vinyl chloride (USEPA Draft Method 502.1 1986). An inert gas is bubbled through the sample and vinyl chloride trapped on an adsorbent. The adsorbent is then heated and vinyl chloride analysed using gas chromatography with electron capture detection. The limit of determination is 0.0003 mg/L.

HEALTH CONSIDERATIONS

Vinyl chloride is readily absorbed following ingestion. It is metabolised to chloroethylene oxide, which can rearrange spontaneously to chloroacetaldehyde. Both substances are highly reactive and mutagenic.

In humans, vinyl chloride is a narcotic agent, and occupational exposure to high doses causes a number of symptoms including Raynaud's phenomenon, a painful disorder of the hands. This is not a concern for environmental exposure.

Vinyl chloride is a well-documented human carcinogen, with inhalation of high concentrations causing tumours in the liver, particularly angiosarcoma. Tumours in the brain and lung and malignancies of the lymphatic and haematopoietic tissues have also been reported.

No data are available on oral exposure in humans. Vinyl chloride is also carcinogenic to animals. When administered by inhalation at doses above 100 ppm in air, it induced tumours of the liver and of some other organs in rats, mice and hamsters.

NOTE: Important general information is contained in PART II, Chapter 6

Oral administration resulted in dose-related tumours of the liver at a dose of 14 mg/kg body weight per day. Some tumours were also observed in other organs, including the lungs and mammary glands.

Vinyl chloride has exhibited mutagenic activity in a variety of tests on bacteria and mammalian cells.

The International Agency for Research on Cancer has concluded that vinyl chloride is carcinogenic to humans (Group 1, sufficient evidence of carcinogenicity in humans) (IARC 1987).

DERIVATION OF GUIDELINE

Vinyl chloride is a genotoxic human carcinogen, and there is no safe or acceptable concentration for vinyl chloride in drinking water. The guideline of less than 0.0003 mg/L is based on a consideration of health effects in relation to the limit of determination.

i) The excess risk of lifetime consumption of drinking water with a vinyl chloride concentration of 0.0005 mg/L was conservatively estimated by the WHO, using a linear multistage model, at one additional cancer per million people.

ii) A value of 0.0005 mg/L can also be derived as follows:

$$0.0005 \text{ mg/L} = \frac{0.13 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000}$$

where:

- 0.13 mg/kg body weight per day is the no effect level from lifetime studies using rats (Feron *et al* 1981, Til *et al* 1991). Tumours were reported at higher doses.
- 70 kg is the average weight of an adult.
- 0.1 is the proportion of total daily intake attributable to the consumption of water.
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for evidence of carcinogenicity).

The limit of determination is slightly less than the values derived from health considerations, and provides an adequate degree of protection. This is consistent with the general approach adopted for genotoxic human carcinogens (see Section 6.3.4).

The WHO guideline value of 0.005 mg/L was based on a calculation that estimated an additional lifetime risk of one fatal cancer per 100 000 people.

REFERENCES

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IARC (1987). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Overall Evaluations of Carcinogenicity. An updating of IARC monographs volumes 1 to 42. World Health Organization, International Agency for Research on Cancer, Supplement 7.

Til HP, Feron VJ and Immel HR (1991). Lifetime (149-week) oral carcinogenicity study of vinyl chloride in rats. *Food and Chemical Toxicology*, 29, 713–718.

USEPA Draft Method 502.1 (1986). Volatile halogenated organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Xylenes

GUIDELINE

Based on aesthetic considerations (taste and odour), the concentration of xylenes in drinking water should not exceed 0.02 mg/L.

Xylenes would not be a health concern unless the concentration exceeded 0.6 mg/L.

GENERAL DESCRIPTION

Xylenes occur naturally as a component of crude oil and are present in petrol, but in small quantities. They can enter water from accidental spills and from solvents used in adhesives for bonding plastic drinking water fittings. Studies overseas have reported drinking water concentrations in the range 0.0001 mg/L to 0.01 mg/L.

Xylenes are produced in the petroleum refining process and are used in the manufacture of insecticides, pharmaceuticals, detergents, paints, adhesives and other products.

They are readily biodegraded in surface waters and they volatilise to air very quickly.

The taste and odour threshold in water varies from 0.02 mg/L to 1.8 mg/L.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Xylenes have not been found in Australian drinking waters. They are included here to provide guidance in the unlikely event of contamination, and because they have been detected occasionally in drinking water supplies overseas.

TREATMENT OF DRINKING WATER

Xylenes can be removed from drinking water by aeration or by adsorption onto granular activated carbon.

MEASUREMENT

A purge and trap gas chromatographic procedure can be used for the analysis of xylenes (USEPA Draft Method 503.1 1986). An inert gas is bubbled through the sample and the xylenes trapped on an adsorbent. The adsorbent is then heated and the xylenes analysed using gas chromatography with photoionization detection. The limit of determination is less than 0.001 mg/L.

HEALTH CONSIDERATIONS

Xylenes are readily absorbed after inhalation and metabolised almost completely to methyl benzoic acid. They can cross the placenta.

No data are available on human absorption after ingestion, or on health effects of oral exposure in humans.

A 2-year gavage study using rats and mice reported decreased growth at high doses (500 mg/kg body weight per day) but no xylene-related lesions (NTP 1986).

There was no evidence of carcinogenicity in oral and skin administration studies using rats and mice, and xylenes were not mutagenic in tests using bacteria and mammalian cells.

The International Agency for Research on Cancer has concluded that xylenes are not classifiable as to their carcinogenicity in humans (Group 3, inadequate evidence in humans and in animals) (IARC 1989).

NOTE: Important general information is contained in PART II, Chapter 6

DERIVATION OF GUIDELINE

The health-based guideline value for xylenes in drinking water was determined as follows:

$$0.6 \text{ mg/L} = \frac{250 \text{ mg/kg body weight per day} \times 70 \text{ kg} \times 0.1}{2 \text{ L/day} \times 1000} \times \frac{5}{7}$$

where:

- 250 mg/kg body weight per day is the no effect level based on a 2-year gavage study using rats (NTP 1986)
- 70 kg is the average weight of an adult
- 0.1 is the proportion of total daily intake attributable to the consumption of water
- 2 L/day is the average amount of water consumed by an adult
- 1000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variations, 10 for intraspecies variations and 10 for the limited toxicological end point)
- 5/7 is used to convert data based on a 5 day per week feeding study to a 7-day week equivalent.

This health-based guideline value exceeds the taste threshold of xylenes in water of 0.02 mg/L. The WHO guideline value of 0.5 mg/L was based on an adult body weight of 60 kg. The difference in guideline values is not significant.

REFERENCES

IARC (1989). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: some organic solvents, resin monomers and related compounds, pigments and occupational exposures in paint manufacture and painting. World Health Organization, International Agency for Research on Cancer, 47.

NTP (1986). Toxicology and carcinogenesis gavage studies of xylenes (mixed) in F344/N rats and B6C3F1 mice. National Toxicology Program, NTP Report No. 327, United States Department of Health and Human Services.

USEPA Draft Method 503.1 (1986). Volatile organic compounds in water by purge and trap gas chromatography. United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory (EMSL), Cincinnati, Ohio.

Zinc

GUIDELINE

Based on aesthetic considerations (taste), the concentration of zinc in drinking water should be less than 3 mg/L.

No health-based guideline value is proposed for zinc.

GENERAL DESCRIPTION

Zinc is widely distributed and occurs in small amounts in almost all rocks, commonly as the sulfide.

It is used as a coating to prevent corrosion of iron and steel products, and in the manufacture of brass. Zinc oxide is an important component in the manufacture of paint and rubber products, including tyres.

In surface and ground waters, the concentration of zinc from natural leaching is usually less than 0.01 mg/L. Tap water can contain much higher concentrations as a result of corrosion of zinc-coated pipes and fittings. Zinc concentrations in galvanised iron rainwater tanks are typically 2 mg/L to 4 mg/L but have been reported as high as 11 mg/L.

Taste problems can occur if the zinc concentration in drinking water exceeds 3 mg/L. Water with a zinc concentration above 5 mg/L tends to be opalescent, develops a greasy film when boiled, and has an undesirable dry 'metallic' taste.

Zinc is present in plant and animal tissues, and food is the major source of zinc intake. Drinking water usually makes a negligible contribution to total intake.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies, the concentration of zinc ranges up to 0.26 mg/L, with a typical concentration of 0.05 mg/L.

TREATMENT OF DRINKING WATER

Zinc concentrations in drinking water can be reduced by alum coagulation at pH 6.5 to pH 7 (30% removal) or by lime softening at pH 9.5 to pH 10 (60% removal).

MEASUREMENT

The concentration of zinc in drinking water can be determined by flame atomic absorption spectroscopy or inductively coupled plasma emission spectroscopy (APHA Method 3500-Zn Parts B or C 1992). The limits of determination are approximately 0.02 mg/L.

NOTE: Important general information is contained in PART II, Chapter 6

HEALTH CONSIDERATIONS

Zinc is an essential element for humans. The recommended intake for adults is 12 mg per day. Nutritional zinc deficiency results in retarded growth, anorexia, mental lethargy, skin changes and night blindness.

Approximately 20-30% of dietary zinc is absorbed by the gastrointestinal tract. Highest concentrations are found in the liver, kidney, bone, retina, prostate and muscle.

In humans, consumption of very high amounts of zinc can result in nausea, vomiting, diarrhoea and abdominal cramps. The major effects of long-term exposure to zinc are copper deficiency, anaemia and gastric erosion.

In animal studies, zinc has been reported to reduce the toxic effects of nickel and cadmium. High doses over long periods may, however, be toxic to nerve cells of mammals.

There is no evidence that occupational exposure to zinc increases the risk of cancer.

Zinc has been shown to induce chromosomal aberrations in mammalian cells, but is inactive in bacterial mutation tests.

DERIVATION OF GUIDELINE

The guideline value for zinc in drinking water has been based on the taste threshold of 3 mg/L. Higher zinc concentrations can impart an undesirable taste and a cloudy appearance. Zinc concentrations over 0.5 mg/L may indicate corrosion problems.

REFERENCES

APHA Method 3500-Zn Part B (1992). Zinc: Atomic Absorption Spectrometric method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA Method 3500-Zn Part C (1992). Zinc: Inductively Coupled Plasma method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

Drinking Water Treatment Chemicals

Aluminium chlorohydrate

Drinking water treatment chemical

Aluminium chlorohydrate is used as a primary coagulant in the treatment of drinking water. It is effective over a range of pH values and forms strong floc. It is particularly effective in some low alkalinity waters.

GENERAL DESCRIPTION

Aluminium chlorohydrate, $Al_2(OH)_5Cl$ (also known as ACH, polyaluminium chlorohydrate or aluminium chlorhydroxide), solution is a clear colourless, odourless liquid. It has a specific gravity of 1.32–1.35 at 25°C, a pH of 3.5–4.5, and is completely soluble in water.

ACH is of the polyaluminium chloride family, with a high aluminium oxide content and high basicity. It is supplied with an aluminium content of 12.2 to 12.7% (23–24% as equivalent alumina) and a basicity of 83–84%. The chemical coagulates over a wide pH range (pH 6–9) and does not usually require alkalinity adjustment.

The formula $Al_2(OH)_5Cl$ is simply a representation of the proportions of aluminium, hydroxide and chloride in the solution and it does not imply the predominant aluminium species is dimeric (see below). A generic formula for the ACH species may be given as $Al_n(OH)_mCl_{(3n-m)}$ where the m/n ration exceeds 1.05.

ACH can be stored in fibreglass-reinforced plastic, polyethylene, polypropylene or phenol formaldehyde, but can be corrosive to metals.

CHEMISTRY

ACH is manufactured from aluminium metal, which is reacted with either hydrochloric acid or aluminium chloride solution under controlled conditions.

ACH solution is a complex, dynamic mixture of positively charged polynuclear aluminium species, with no single species predominating and with molecular weights exceeding 1000. When applied to water, these species interact with and destabilises negatively charged colloidal matter, such as inorganic particles and the high molecular weight organic compounds that largely constitute natural organic matter. The polynuclear species also hydrolyse to form dense flocs of aluminium hydroxides that further act to entrap particles and remove some organic. An example of one of the many polynuclear species that may be present in ACH solution is the so called Al-13 ion that has the formula $[AlO_4.Al_{12}(OH)_{24}(H_2O)_{12}]^{13+}$.

The hydrolysis of ACH produces far less acid than the hydrolysis of aluminium sulfate owing to the very high degree of hydroxylation of the aluminium. As a result, ACH requires little of no pH correction with alkali when applied to water and results in only marginal increase in the concentration of dissolved salt. The hydrolysis reaction proceeds as follows:

$$Al_2(OH)_5.Cl + H_2O \Leftrightarrow 2Al(OH)_3 + H^+ + Cl^-$$

As the hydrolysis reactions proceed, mononuclear hydroxide products can form polynuclear species. The reactions are complex and the species formed are quite variable. Examples of the species formed are:

- mononuclear: Al OH^{2+}, $Al(OH)_2^+$, $Al(OH)_3$ (solid precipitate), $Al(OH)_4^-$
- polynuclear: $Al_8(OH)_{20}^{4+}$, $Al_{13}O_4(OH)_{24}^{7+}$.

NOTE: Important general information is contained in PART II, Chapter 8

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, ACH is used as a primary coagulant. It is effective in cold temperatures and is particularly suited for use in low alkalinity raw water. It is commonly used for coagulation before membrane filtration, because this appears to reduce membrane fouling and prolong the life of the filter. The concentration of coagulant used depends on the properties of the raw water, including factors such as turbidity, dissolved organic carbon, temperature and alkalinity.

Typical ACH doses (with 23% Al_2O_3 content) are 3–100 mg/L. The actual concentration required should be determined by laboratory trials; higher doses may be required with particularly dirty water.

CONTAMINANTS

The contaminants that may be present in ACH are:

- antimony
- arsenic
- barium
- beryllium
- cadmium
- chromium
- copper
- fluoride
- iron
- lead
- magnesium
- manganese
- mercury
- nickel
- phosphorus
- selenium
- silver
- thallium
- zinc

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, ACH should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Most of the aluminium ions resulting from the use of ACH as a coagulant are removed by conventional water treatment processes. Residual chloride is usually at low levels that do not adversely affect drinking water quality.

STATUS

ACH was endorsed by the NHMRC for use as a drinking water treatment chemical in 2005.

REFERENCES

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Fitzgerald JJ and Rosenberg AH (1999). Chemistry of aluminium chlorohydrate and activated aluminium chlorohydrates. In *Cosmetic Science and Technology Series, 20. Antiperspirants and deodorants*, second edition, Laden K (ed). Marcel Dekker Inc, 83–136.

Rosenberg AH, Hodges RD and Harper TL (1995). *Chemical characterisation of polyaluminium chlorides and TOC removal.* American Water Works Association Water Quality Technology Conference.

Ruehl KE (1998). Effective coagulation for variable source water: a coagulant comparison by bench and full sale evaluations. American Water Works Association Water Quality Technology Conference.

NOTE: Important general information is contained in PART II, Chapter 8

Aluminium sulfate (alum)

Drinking water treatment chemical

Aluminium sulfate (alum) is a general purpose coagulant that is used in water treatment to remove turbidity, natural organic matter (NOM) (including colour), microorganisms and many inorganic chemicals. Removal of NOM reduces the formation of disinfection byproducts, because it removes the organic precursors of the byproducts.

GENERAL DESCRIPTION

For use in water treatment, aluminium sulfate (alum) is generally supplied as a bulk liquid, but it can also be supplied in granular form. The concentration of the supplied liquid solution varies, and users should establish the concentration with the supplier. Typically, alum solutions contain 7.5–8.4% Al_2O_3 w/w (i.e. 43–50% w/w $Al_2(SO_4)_3{\cdot}14H_2O$), and have a specific gravity of 1.28–1.34 at 20°C. Solutions at the upper end of the available strengths may become unstable at low temperatures.

Alum is also available as a crystalline solid with varying degrees of hydration (14–18 H_2O). It has a pH of 1.2–3.0 and can be stored in rubber-lined containers or in fibreglass, stainless steel (type 316) or plastic.

CHEMISTRY

Alum is produced by the reaction of sulfuric acid with an aluminium-rich ore such as refined bauxite.

In water, the aluminium ion reacts with natural alkalinity (hydroxyl or bicarbonate) or added alkalinity (lime, caustic soda or soda ash) to form aluminium hydroxide species. The hydrolysis proceeds as follows:

$$Al_2(SO_4)_3{\cdot}6H_2O \Leftrightarrow 2Al(OH)_3 + 6H^+ + 3SO_4^{2-}$$

As the hydrolysis reactions proceed, mononuclear products can form polynuclear species. The reactions are complex and the species formed are quite variable. Examples of the species formed are:

- mononuclear: $Al\ OH^{2+}$, $Al(OH)_2^+$, $Al(OH)_3$ (solid precipitate), $Al(OH)_4^-$
- polynuclear: $Al_8(OH)_{20}^{4+}$, $Al_{13}O_4(OH)_{24}^{7+}$

The generally positively charged Al species are available to interact with negatively charged colloidal matter in water. Such matter includes inorganic turbidity particles and the high molecular weight fraction of organic compounds present in NOM. The interaction destabilises the repulsive forces between the negatively charged particles, allowing them to collide and agglomerate to form microfloc (a process referred to as adsorption–destabilisation).

At higher concentrations of alum, metal hydroxides precipitate and can enmesh any colloidal particles in a process known as 'sweep coagulation', which renders water suitable for clarification.

Alum has an optimum pH for coagulation of 5.5–7.5, with the lower end of the range (pH 5.5–6.2) being used for organics removal and enhanced coagulation (see below), and the higher end (pH 6.5–7.5) being used for sweep coagulation. Adsorption–destabilisation to form small floc, which can be removed by contact and direct filtration, typically occurs in the pH range 6–7.

'Enhanced coagulation' refers to coagulation at low pH with high doses of alum, and is used to remove NOM. The pH and alum dose need to be optimised, to maximise the removal of dissolved organic carbon (DOC).

NOTE: Important general information is contained in PART II, Chapter 8

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

The dose of alum used depends on the properties of the raw water, including (but not limited to) the turbidity, DOC, temperature and alkalinity. Waters of low turbidity often need higher doses of alum to bring about coagulation than more turbid waters. Indeed, waters of low turbidity and high colour are the most difficult to treat.

Typical alum doses (expressed as mg/L Al2(SO4)3·14H2O) range from 5 to 200 mg/L and may even be as high as 500 mg/L if the water is particularly dirty.

The dose rate for alum is expressed in different units throughout Australia, and it is important to take this into account when comparing rates.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. In Australia, alum is produced by reacting aluminium trihydroxide or refined bauxite with sulfuric acid, and most of the impurities in the alum are derived from these raw materials.

The following chemical contaminants may be present in alum (NRC 1982):

- antimony
- arsenic
- barium
- beryllium
- cadmium
- chromium
- copper
- fluoride
- iron
- Lead
- magnesium
- manganese
- mercury
- nickel
- phosphorus
- selenium
- silver
- thallium
- zinc

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, alum should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Aluminium residuals after filtration can cause floc to form in the distribution system, which can cause customer complaints. To minimise residual levels of aluminium, alum should be used at pH and dosage conditions that exceed the solubility of aluminium. At 25°C, aluminium is least soluble at a pH near 6. At colder temperatures, the pH of minimum solubility increases. For example, at 4°C, aluminium is least soluble at pH 6.5–7. Hence, if water is treated at pH 6 throughout the year, levels of residual dissolved aluminium will be higher in winter. Poor dosage selection or inadequate mixing also leads to elevated aluminium residuals.

STATUS

Aluminium sulfate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The 2003 revision did not change the status of this chemical for the treatment of drinking water.

REFERENCES

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NRC (National Research Council) (1982). *Water Chemicals Codex*. Committee on Water Treatment Chemicals, Food and Nutrition Board, Assembly of Life Sciences, NRC, Washington, DC.

NOTE: Important general information is contained in PART II, Chapter 8

Ammonia

Drinking water treatment chemical

Ammonia, NH_3 is added to drinking water to react with chlorine to form chloramine disinfectants. Chloramination is not as powerful as chlorination but provides a longer lasting residual in the water distribution system.

GENERAL DESCRIPTION

Ammonia, NH_3, is a colourless gas or liquid, with a sharp, intensely irritating odour. It is lighter than air and easily liquefied by pressure. Ammonia has a boiling point of –33.5°C, a freezing point of –77.7°C, and a specific gravity of 0.8 as a liquid. Ammonia gas is combustible and is very soluble in water. When hydrated, ammonia can attack copper, zinc and alloys containing these metals. Ammonia can be supplied as a compressed liquid (anhydrous ammonia), dissolved in water (aqueous ammonia) or as solutions of ammonium salts (e.g. ammonium sulphate).

Gaseous ammonia is compatible with some steels, stainless steel (type 316), neoprene and monel. Aqueous ammonia can be stored in iron, steel, stainless steel, fibreglass-reinforced plastic or rubber-lined vessels.

CHEMISTRY

Ammonia is prepared commercially in vast quantities, mostly using the Haber process to combine nitrogen directly with hydrogen. It can also be made using the cyanamide process, and is produced as a byproduct of the destructive distillation of coal. Most of the ammonia produced is used to make fertilisers.

The reactions between ammonia and chlorine are complex, but the simplified equations shown below are often used. The chloramines produced are monochloramine (NH_2Cl — equation 1), dichloramine ($NHCl_2$ — equation 2) and trichloramine or nitrogen trichloride (NCl_3 — equation 3).

$$NH_3^+ + HOCl \rightarrow NH_2Cl + H_2O \quad (1)$$

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O \quad (2)$$

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O \quad (3)$$

Other products are also formed, such as nitrogen (N_2) and nitrate (NO^{3-}).

The sum of the concentrations of the three chloramine species is referred to as 'combined chlorine' and is often expressed as Cl_2, in the units of mg/L. The sum of the combined chlorine concentration and the free chlorine concentration (i.e. hypochlorous acid and hypochlorite ion) is referred to as 'total chlorine'. The relative amounts of the three species of chloramine formed depend on the ratio of chlorine to ammonia, the pH and the temperature. Monochloramines are preferred because they do not cause the taste and odour problems that can arise with dichloramines and trichloramines. Users should refer to available data on how pH and the ratio of chlorine to ammonia affect the distribution of chloramines (see discussion in the following section), and should be aware of the breakpoint phenomenon (whereby chlorine applied in sufficient doses will oxidise ammonia and eliminate chloramines, forming a free chlorine residual).

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking-water treatment, ammonia is added with chlorine (at a fixed ratio of ammonia to chlorine) to produce chloramine disinfectants. Chloramines react with bacteria and oxidisable material more slowly than free chlorine, but last longer than free chlorine. Depending on the order and process used

NOTE: Important general information is contained in PART II, Chapter 8

trihalomethanes (THMs) may form. Chloramines thus tend to be used as a secondary disinfectant to provide a disinfectant residual in the distribution system, but may also be used as a primary disinfectant if an appropriate contact time is allowed. Chloramines are particularly suited to providing disinfectant residuals in long distribution systems, where it is difficult to maintain a residual using chlorine.

To produce monochloramine, the pH should be between 8 and 9, and the chlorine to ammonia ratio should be between 3:1 and 4:1. A ratio above 4:1 may produce chlorinous odours. Ammonia may be added before or after chlorine. In primary disinfection, chlorine is usually added first, because it kills bacteria, viruses and spores much more efficiently than does monochloramine, provided that sufficient contact time is allowed for disinfection before the ammonia is added. Ammonia and chlorine can be added together, provided that contact time is sufficient to ensure disinfection.

Chloramines present in water are harmful to people on kidney dialysis and to animal species in aquaria; therefore, it is important for water utilities using chloramination to inform consumers at risk.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. Ammonia is generally supplied at 99.9 % purity or better, but the product may include a very small amount of oil (hydrocarbons), heavy metals and water.

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, ammonia should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*. Free ammonia liberated in the distribution system may contribute to nitrification problems or biological growth.

Chloramines may form some halogenated organic byproducts. THMs may also be produced, but to a much lesser extent than with chlorination. More information on chloramines can be obtained from the Chloramine Fact Sheet in the Australian Drinking Water Guidelines.

STATUS

Aqueous ammonia was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983.The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th Edition. American Public Health Association, Washington, DC.

Connell GF (1996). *The Chlorination/Chloramination Handbook*. Water Disinfection Series, American Water Works Association. Denver, Colorado.

Hass CN (1999). Disinfection. In *Water Quality and Treatment, A Handbook of Community Water Supplies*, Letterman RD (ed). American Water Works Association, 5th edition. McGraw-Hill Professional, New York, 14.1–14.60.

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Ammonium sulfate

Drinking water treatment chemical

Ammonium sulfate is used as a source of ammonia to react with chlorine in drinking water treatment, to form chloramines. Chloramination is not as powerful as chlorination but provides a longer lasting residual in the water distribution system.

GENERAL DESCRIPTION

Ammonium sulfate, $(NH_4)_2SO_4$, is an off-white crystal which is soluble in water (up to a concentration of 10 g/L). It has a specific gravity of 1.77 (at 20ºC), and is available in several grades as 60–100 % effective product.

Ammonium sulfate can be stored in rubber-lined vessels or in containers made from stainless steel (type 316), neoprene, monel, fibreglass-reinforced plastic, polyethylene or polyvinyl chloride. If the ammonium sulfate is dry, cast iron can also be used.

CHEMISTRY

Ammonium sulfate is byproduct of the manufacture of caprolactam (a nylon-base material), coal gas and coke. It can also be prepared by the reaction of ammonia with sulfuric acid. It dissolves in water to form ammonium hydroxide (NH_4OH — equation 1), which then releases ammonia gas (NH_3 — equation 2):

$$(NH_4)_2 + 2H_2O \rightarrow 2NH_4OH + H_2SO_4 \quad (1)$$

$$NH_4OH \Leftrightarrow NH_3 + H_2O \quad (2)$$

Solutions of ammonium salts or aqueous ammonia (ammonia dissolved in water) have an alkaline pH. The actual pH depends on the concentration and the temperature. It is important to vent facilities storing ammonium salt solutions, because of the formation of ammonia gas. Ammonium salt solutions and aqueous ammonia have the same characteristics; therefore, the same care should be taken during handling.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Ammonium sulfate is used as a source of ammonia for disinfection (see ammonia fact sheet for further details).

The amount of ammonium sulfate to be added can be determined by multiplying the required ammonia level by the molecular ratio of 7.77 (i.e. $(NH_4)_2SO_4 = 7.77 \times NH_3$). The ammonia fact sheet includes information on levels needed for chloramination.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. Ammonium sulfate may contain moisture and insoluble material as well as the following chemical contaminants (JECFA, NRC 1982):

- aluminium
- arsenic
- chloride
- lead
- pyridine
- selenium
- iron

NOTE: Important general information is contained in PART II, Chapter 8

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, ammonium sulfate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Excessive dosage can lead to biological growth in distribution system (see ammonia fact sheet for further details).

STATUS

Ammonium sulfate was originally endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B302-00. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

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NRC (National Research Council) (1982). *Water Chemicals Codex*. Committee on Water Treatment Chemicals, Food and Nutrition Board, Assembly of Life Sciences, NRC.

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Calcium hydroxide

Drinking water treatment chemical

Calcium hydroxide (hydrated lime) is used to raise pH and adjust alkalinity for coagulation optimisation, corrosion control and water softening. It can also be used to dewater sludge.

GENERAL DESCRIPTION

Calcium hydroxide, $Ca(OH)_2$ (also known as lime or hydrated lime), adds hydroxide ions to water, thereby increasing its pH and alkalinity. It is a soft, white, crystalline powder.

The hydrated lime available commercially is a powder that contains mainly calcium hydroxide, or a mixture of calcium hydroxide and magnesium hydroxide. Pure hydrated lime has a specific gravity of 2.3–2.4. The bulk density of commercial lime varies from 450 to 560 kg/m^3, and it usually contains 80–96% calcium hydroxide. Its solubility at 20ºC is 0.165% (or 0.165 g/100 g of saturated solution).

Hydrated lime can be stored in rubber-lined containers or in fibreglass-reinforced plastic, polyethylene, polyvinyl chloride, cast iron or steel.

CHEMISTRY

Calcium hydroxide is obtained by hydrating quicklime with sufficient water to satisfy its chemical affinity for water. Quicklime is the product of the calcination of limestone, and consists mainly of the oxides of calcium (CaO) and magnesium (MgO). Calcium hydroxide is added to water to provide hydroxide ions to raise pH and alkalinity, and to neutralise free carbon dioxide or carbonic acid. It reacts with carbon dioxide to form calcium bicarbonate.

$$Ca(OH)_2 + 2CO_2 \rightarrow Ca(HCO_3)_2$$

To remove carbonate hardness, hydroxide ions are used to raise the pH of water. This causes precipitation, as bicarbonate ions are converted to the carbonate (pH > 10), precipitating calcium carbonate.

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3\,(s) + 2H_2O$$

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In production of drinking water, calcium hydroxide is used:

- at the start of the water treatment process, to adjust pH and boost alkalinity, to assist coagulation
- at the end of the treatment process, to adjust final pH and alkalinity, and to minimise corrosion
- to soften hard waters by raising the pH, and thus precipitating calcium carbonate
- with carbon dioxide, to increase soft water's resistance to pH changes during distribution and to decrease its corrosivity
- to reduce the moisture content of sludge — if the concentration of calcium hydroxide is sufficiently high it will collapse the sludge structure, helping to reduce the water content of the sludge.

Lime is usually made up as a solution or as a slurry of up to 10% concentration; a slurry with a concentration of 1–5% is most commonly employed.

Typical lime concentrations used in drinking water treatment depend on the quality of the water to be treated and the purpose of the treatment (water softening, pH adjustment, alkalinity increase). Lime concentrations can vary from 5 to 500 mg/L, and the appropriate concentration should be determined by laboratory trials.

NOTE: Important general information is contained in PART II, Chapter 8

Poor mixing, poor pipe design, lime scaling and impurities often lead to blockages in lime dosing systems. To overcome such problems, the design of the system should minimise areas of solids accumulation, and the dosing system should be flushed each time it is turned off with water, chlorinated water or weak acid. Regular cleaning of the batch and dosing tanks using a solution of weak acid is also recommended.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in calcium hydroxide, depending on the source of the raw materials (JECFA, KIWA 1994, NRC 1982):

- aluminium
- arsenic
- barium
- cadmium
- chromium
- fluoride
- iron
- lead
- magnesium
- manganese
- mercury
- nickel
- selenium
- silica
- silver

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, calcium hydroxide should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Adding lime to water can significantly raise the turbidity. It can also increase the concentrations of iron, aluminium and manganese. Thus, it is often best to add lime at the start of the water treatment process, so that any impurities added with the lime can be removed during the treatment process.

The sludge resulting from water softening consists mainly of calcium carbonate, or a mixture of calcium carbonate and magnesium hydroxide. This sludge is generally dense, stable and inert; dries well; has a solids content of about 5% from the clarifier (although it can range from 2 to 30%); and has a pH greater than 10.5.

STATUS

Calcium hydroxide was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B202-02. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

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NOTE: Important general information is contained in PART II, Chapter 8

Calcium hypochlorite

Drinking water treatment chemical

Calcium hypochlorite is a drinking water disinfectant used only for small systems.

GENERAL DESCRIPTION

Calcium hypochlorite, $Ca(OCl)_2$, is a white crystalline solid. It has a specific gravity of 2.35, decomposes in water and alcohol, is not hygroscopic and is practically clear in a water solution. The chemical is a highly active oxidiser and is relatively stable. The oxidising capability of 1 g calcium hypochlorite (65% strength) is equivalent to the oxidising capability of 0.65 g chlorine gas.

Calcium hypochlorite is available commercially as a dry solid, with a strength of up to 74% available chlorine. In this form, it loses about 0.013% of its strength per day under normal storage conditions, although the rate can be higher if the chemical is in contact with water or is exposed to the atmosphere. It is also available in a tablet form for use in automatic feed equipment at low-flow treatment plants or for dosing of in-system reservoirs.

Appropriate handling materials for calcium hypochlorite include glass, ceramics, fibreglass-reinforced plastic, polyethylene, polyvinyl chloride. Rubber-lined containers can also be used.

CHEMISTRY

Calcium hypochlorite is formed by the addition of chlorine to a slurry of 'milk of lime' (calcium hydroxide)

Calcium hypochlorite granules dissolve in water to form hypochlorous acid (HOCl), which partially dissociates to the hypochlorite ion (OCl^-).

$$Ca(OCl)_2 + 2H_2O \rightarrow 2HOCl + Ca(OH)_2$$

$$Ca(OCl)_2 \rightarrow Ca^{2+} + 2\ OCl^-$$

$$OCl^- + H_2O \Leftrightarrow HOCl + OH^-$$

As with the addition of chlorine gas, the relative distribution of hypochlorous acid and hypochlorite ion resulting from the addition of calcium hypochlorite to water will depend on pH and temperature.

Calcium hypochlorite is a base and therefore raises the pH of water, whereas chlorine gas produces an acidic reaction that lowers the pH of the solution. The extent of the pH change depends on the alkalinity of the water.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Calcium hypochlorite is generally used as a disinfectant in smaller water treatment plants or in new water mains or in-system reservoirs.

As a disinfectant in water systems, calcium hypochlorite must be dissolved in water before it is added to the main supply. Doses usually range from 1 to 5 mg/L (as available chlorine), with 2–3 mg/L typical. Selection of the appropriate chlorine dose should take into account the Ct (disinfectant concentration × contact time) and chlorine residual required, and the levels of disinfection byproducts likely to be formed. A free chlorine residual of ≥ 0.2 mg/L throughout the distribution system is preferred. Superchlorination (doses of 10 to 50 mg/L) may be used to disinfect or clean tanks and pipelines.

NOTE: Important general information is contained in PART II, Chapter 8

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. Chemical contaminants that may be present in calcium hypochlorite include:

- aluminium
- arsenic
- barium
- cadmium
- chromium
- fluoride
- iron
- lead
- magnesium
- manganese
- mercury
- nickel
- selenium
- silica
- silver

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, calcium hypochlorite should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

The use of calcium hypochlorite as a disinfectant results in the formation of free chlorine, combined chlorine residuals and disinfection byproducts. The byproducts formed include trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs), haloketones, chloral hydrate and chloropicrin. Although many specific chlorine disinfection byproducts have been identified, many of the total organic halogens are as yet unidentified.

Among the many factors affecting the species formed as disinfection byproducts are pH, temperature and levels of total organic carbon (TOC), bromide and chlorine. THMs (e.g. chloroform, bromodichloromethane, dibromochloromethane and bromoform) are the most widely known chlorination byproducts. Chlorinated THM, HAA and HAN species are generally found at higher levels than brominated species; however, brominated species predominate in waters containing high levels of bromides.

The disinfection byproducts most likely to occur and to be of concern to health are total THMs and THM species, total HAAs and HAA species.

STATUS

Calcium hypochlorite was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B300-99. AWWA CD-ROM (April 2003). Details at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th Edition. American Public Health Association, Washington, DC.

Connell GF (1996). *The Chlorination/ Chloramination Handbook*. Water Disinfection Series, American Water Works Association, Denver.

White GC (1992). *Handbook of chlorination and alternative disinfectants*, 3rd edition. Van Nostrand Reinhold, New York.

NOTE: Important general information is contained in PART II, Chapter 8

Calcium oxide

Drinking water treatment chemical

Calcium oxide is used (after hydrating to produce 'slaked lime') to correct pH and adjust alkalinity, for coagulation optimisation, corrosion control and water softening. It can also be used to assist in the dewatering of sludge.

GENERAL DESCRIPTION

Calcium oxide, CaO, is also known as calx, quicklime, unslaked lime and burnt lime. It is a grey-white, hard, odourless solid, which sometimes has a yellowish or brownish tint due to the presence of iron. It crumbles on exposure to moist air and is soluble in acid. Calcium oxide reacts with water to form calcium hydroxide (slaked lime), releasing heat as it does so.

Calcium oxide is available in several grades, and is the least expensive way of obtaining calcium hydroxide. Quicklime has a specific gravity of 3.2–3.4. Its bulk density is 1030 kg/m^3 for pebble quicklime or 1050 kg/m^3 for powder quicklime; it usually contains approximately 94% calcium oxide.

Appropriate handling materials for calcium oxide include fibreglass-reinforced plastic, polyethylene, polyvinyl chloride, cast iron and steel. Rubber-lined containers can also be used.

CHEMISTRY

Calcium oxide is formed by calcination of limestone, and it can also contain magnesium oxide, MgO. Before being used in drinking water treatment, calcium oxide must be hydrated or 'slaked' to calcium hydroxide or slaked lime:

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Slaked lime is added to water to provide hydroxide ions to raise pH and alkalinity, and to neutralise free carbon dioxide or carbonic acid. It reacts with carbon dioxide to form calcium bicarbonate:

$$Ca(OH)_2 + 2CO_2 \rightarrow Ca(HCO_3)_2$$

To remove carbonate hardness, hydroxide ions are used to raise the pH of water. This causes precipitation, as bicarbonate ions are converted to the carbonate (at pH > 10), precipitating calcium carbonate.

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3\,(s) + 2H_2O$$

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In production of drinking water, slaked lime is used:

- at the start of the water treatment process, to adjust pH and boost alkalinity in order to assist coagulation
- at the end of the treatment process, to adjust final pH and alkalinity, and to minimise corrosion
- to soften hard waters by raising the pH, thus precipitating calcium carbonate;
- with carbon dioxide, to increase soft water's resistance to pH changes during distribution and to decrease its corrosivity
- to reduce the moisture content of sludge — if the concentration of calcium hydroxide is sufficiently high it will collapse the sludge structure, helping to reduce the water content of the sludge.

Slaked lime is usually made up as a solution or a slurry of up to 10% concentration; a slurry with a concentration of 1–5% is most commonly employed.

NOTE: Important general information is contained in PART II, Chapter 8

Typical slaked lime concentrations used in drinking water treatment depend on the quality of the water to be treated and the purpose of the treatment (e.g. water softening, pH adjustment or alkalinity increase). Slaked lime concentrations can vary from 5 to 500 mg/L, and the appropriate concentration should be determined by laboratory trials.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the source of the raw materials and on the manufacturing process. The following chemical contaminants may be present in calcium oxide (JECFA, KIWA 1994, NRC 1982):

- aluminium
- arsenic
- barium
- cadmium
- chromium
- fluoride
- iron
- lead
- magnesium
- manganese
- mercury
- nickel
- selenium
- silica
- silver

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, calcium oxide should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Adding slaked lime to water can significantly raise the turbidity and the concentrations of iron, aluminium and manganese. Thus, it is often best to add slaked lime at the start of the water treatment process, if possible, so that any impurities added with it can be removed during the treatment process.

STATUS

Calcium oxide was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B202-02. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

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NOTE: Important general information is contained in PART II, Chapter 8

Carbon, granulated activated

Drinking water treatment chemical

Granular activated carbon is used in drinking water treatment to adsorb or biologically degrade dissolved organic matter, pesticides, algal toxins and compounds causing taste or odour problems. Use of activated carbon used before disinfection reduces the formation of disinfection byproducts, by reducing the amount and reactivity of organic precursors of these byproducts.

GENERAL DESCRIPTION

Granular activated carbon (GAC) is a black, solid, extremely porous material that can adsorb impurities and contaminants from air and water. It has a complex, porous internal structure, with internal surface areas averaging about 900 m^2/g and a bulk density of 250–600 kg/m^3. Activated carbon is insoluble in water and organic solvents.

The properties of activated carbon depend on its degree of activation and the raw material from which it is produced. Coal, wood and coconut-based activated carbons each have different pore structures and different characteristics.

GAC may act as a biological carrier by housing bacteria in its internal honeycomb structure. When GAC filters are used in an enhanced biological mode, they are referred to as biological activated carbon (BAC) filters. BAC filters work through two mechanisms: biodegradation of contaminants (e.g. taste and odour compounds, and organics) and biological regeneration of the carbon's adsorption sites.

Dry activated carbon can be stored in cast iron or steel silos. Wet activated carbon can be stored in plastic, rubber or silicon-lined containers, or in stainless steel (type 316), monel or bronze.

CHEMISTRY

Carbon is 'activated' by heating carbonaceous material such as wood, coal or coconut husks to high temperatures in a controlled atmosphere of steam, or at moderate temperatures in the presence of chemicals such as acid.

The adsorptive properties of GAC vary with pore size, pore-size distribution, internal surface area of the pores and surface properties. The properties of the GAC available in the market are variable. In selecting an activated carbon product, it is important to consider factors such as the adsorptive capacity of the activated carbon, the desired application, abrasion resistance during backwashing and cost. The quality of the activated carbon can be determined by its ability to remove contaminants such as 2-methylisoborneol (MIB), geosmin, toxins and pesticides, and by a number of other factors that are listed below, together with typical ranges (actual values will depend on the raw material and the activation processes):

- iodine number: 900–1300 mg/g carbon
- apparent density: 0.2-0.6 g/cc
- moisture content: 3-8%
- abrasion resistance: 75-99%
- particle size distribution: 5% maximum on upper sieve
  90% minimum between sieves
  5% maximum through lower sieve
- ash content: 3–15%

NOTE: Important general information is contained in PART II, Chapter 8

The adsorptive capacity of activated carbon can be inferred from the iodine number, methylene blue number or molasses number.

Effective sizes of GAC are typically 0.7–1.2 mm, with a uniformity coefficient (UC) generally specified to be less than 1.8. The GAC is installed over supporting layers of sand and gravel.

After installation in the filter bed, the GAC is carefully wetted over several hours. In some carbons, significant flotation of the carbon may occur in the wetting phase, and the floating portion of GAC is removed and disposed of. The floatable component of the GAC may vary between 0 and 30%.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In water treatment, activated carbon is used to control taste and odour-causing compounds, and to remove contaminants such as nitrates, pesticides, algal toxins, disinfection byproducts, organic carbon and other trace organic chemicals.

GAC is generally used as a filter medium in beds or tanks, with the water being treated as it passes through the filter. Contaminants are removed through adsorption and biological degradation. Many taste and odour compounds (e.g. 2-methylisoborneol (MIB), geosmin and 20–50% of natural organics) can be biologically degraded, and GAC filters used in this way can operate for 10–15 years. If the contaminant is not biodegradable, the GAC medium can be used continuously until its adsorption capacity is exhausted; and can then be reactivated using a thermal process (currently not available in the Australian drinking water industry). In adsorption mode, a GAC bed is effective for about 1 month to 2 years, depending on the concentration of contaminants in the water.

GAC beds can be used either before or after conventional treatment (i.e. pre-filtration or post-filtration). GAC can also be used for a combination of filtration and adsorption, either as a full GAC bed, or as a layer of sand topped with a layer of GAC medium. The process can be preceded by ozonation, which encourages biological activity on the filter (creating a BAC filter), thus prolonging the life of the filter. Ozonation generally produces water that is more biologically stable and has a lower chlorine demand.

GAC and BAC filters are designed for a specific empty bed contact time (EBCT), which typically ranges from 5 to 25 minutes. The most economic EBCT can be determined by analysing particular contaminants of concern, at either laboratory or pilot scale.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in the ash that may be found in activated carbon:

- aluminium
- arsenic
- chromium
- iron
- lead
- manganese
- mercury
- phosphorus
- silver
- zinc

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, activated carbon should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Degraded GAC can pass through a water treatment plant, causing black specks and deposits in the distribution system, although it is unlikely that significant quantities of carbon residues will be present in finished water.

STATUS

Activated carbon was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard B604-96. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

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Carbon, powdered activated

Drinking water treatment chemical

Powdered activated carbon is used in drinking water treatment to adsorb dissolved organic matter, pesticides, algal toxins and compounds causing taste or odour problems. Adding activated carbon before disinfection reduces the formation of disinfection byproducts, by reducing the amount and reactivity of organic precursors of these byproducts.

GENERAL DESCRIPTION

Powdered activated carbon (PAC) is a black, solid, extremely porous material that can adsorb impurities and contaminants from air and water. It has a complex, porous internal structure, with internal surface areas averaging about 900 m^2/g and a bulk density of 250–600 kg/m^3. Activated carbon is insoluble in water and organic solvents.

The properties of activated carbon depend on its degree of activation and the raw material from which it is produced. Coal, wood and coconut-based activated carbons each have different pore structures and different characteristics.

Dry activated carbon can be stored in cast iron or steel silos. Wet activated carbon can be stored in plastic, rubber, or silicon-lined containers, or in stainless steel (type 316), monel or bronze.

CHEMISTRY

Carbon is 'activated' by heating carbonaceous material such as wood, coal or coconut husks to high temperatures in a controlled atmosphere of steam, or at moderate temperatures in the presence of chemicals such as acid.

The adsorptive properties of PAC vary with particle size, pore size, pore-size distribution, internal surface area of the pores and surface properties. The properties of the PAC available in the market are variable. In selecting an activated carbon product, it is important to take into account factors such as the adsorptive capacity of the activated carbon, the desired application and the cost. The quality of the activated carbon can be determined by its ability to remove contaminants such as 2-methylisoborneol (MIB), geosmin, toxins and pesticides, and by a number of other factors that are listed below, together with typical ranges (actual values will depend on the raw material and the activation processes):

- iodine number: 800–1400 mg/g carbon
- apparent density: 0.2-0.6 g/cc
- moisture content: 3-8%
- particle size distribution: 90% minimum through 100 µm mesh
  95% minimum through 200 µm mesh
- ash content: 3–15%

The adsorptive capacity of activated carbon can be inferred from the iodine number, methylene blue number or molasses number. The quality can also

Effective sizes of PAC are typically 20–50 µm.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, PAC can be added as a powder by dry-feed equipment; for higher dosing, it can be added as a slurry by metering pumps or feeders. It is important to add PAC early in the treatment process, before addition of chemicals such as chlorine, to ensure sufficient contact time and to

NOTE: Important general information is contained in PART II, Chapter 8

avoid chemicals being adsorbed onto the carbon. For intermittent or low dosing, Ideally, PAC is added 30 minutes before coagulation; often near the raw water source. Care should be taken to avoid areas where PAC may build up (e.g. low-velocity pipes). The carbon is mixed for a short time before being removed by settling or filtration.

If PAC is added in the coagulation zone, additional PAC may be required, because the carbon can become bound in flocs, diminishing its effectiveness. Jar testing reflecting the operating conditions can determine the effective dose rate and contact time for optimal performance of PAC.

Occasionally, PAC is dosed immediately before filtration, where it reacts with organics above and within the filter bed. Care should be taken to avoid breakthrough of PAC caused by normal sludge removal processes (e.g. clarifier sludge blowdowns, flotation or filter backwashing).

The amount of PAC required will depend on the type and concentration of organics in the water. Typical values range from 2 to 60 mg/L, but can be as high as 100 mg/L. A contact time of 10–30 minutes between the PAC and the water generally removes most taste and odour compounds, but a longer time may be needed for removal of MIB and geosmin (the compounds most often linked with tastes and odours — see the fact sheet on taste and odour).

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in the ash that may be found in activated carbon:

- aluminium
- arsenic
- chromium
- copper
- iron
- lead
- manganese
- mercury
- phosphorus
- zinc

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, PAC should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Powdered carbon slurry applied to raw water is easily removed by other water treatment processes (e.g. by settled sludge, floated sludge or filtration). PAC can pass through a water treatment plant, causing black specks and deposits in the distribution system, although it is unlikely that significant quantities of carbon residues will be present in finished water.

STATUS

Activated carbon was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

AWWA (American Water Works Association) / ANSI (American National Standards Institute) (1997). Standard B604-96. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

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NOTE: Important general information is contained in PART II, Chapter 8

Chlorine

Drinking water treatment chemical

Chlorine is widely used as a primary disinfectant in the treatment of drinking water and to provide secondary disinfection in reticulation. It is also used to oxidise metals, to break down organics and to minimise biofouling. Chlorine produces potentially harmful disinfection byproducts with some organics.

GENERAL DESCRIPTION

Chlorine, Cl_2, is a dense, greenish-yellow, diatomic gas with a pungent and irritating odour. It is noncombustible, but supports combustion as an oxidizing agent. The liquefaction pressure of chlorine is 7.86 atm (25°C).

Chlorine is relatively inexpensive and easy to use, although the risks associated with its transportation, storage and handling must be managed. Liquefied chlorine gas is supplied in pressurised containers of varying sizes, typically 70 kg and 990 kg. Free chlorine can also be generated on-site from electrolysis of sodium chloride solutions (brine).

Appropriate materials for handling chlorine gas include steel, copper and black iron. Aqueous chlorine can be stored in fibreglass-reinforced plastic or polyvinyl chloride.

CHEMISTRY

Chlorine is manufactured by the electrolytic dissociation of salt (sodium chloride), using mercury, diaphragm or membrane cells.

The dissolution of chlorine gas in water results in rapid hydrolysis, forming chloride ion (Cl^-), and hypochlorous acid (HOCl). Being a weak acid, HOCl is partially dissociated to hypochlorite ion (OCl^-). The degree of dissociation in equation 2 varies with temperature and pH. An increase in pH will shift the equilibrium to the right.

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (1)$$

$$HOCl \Leftrightarrow H^+ + OCl^- \quad (2)$$

The sum of the three species (i.e. Cl_2, HOCl and OCl^-) is referred to as 'free available chlorine' (FAC). The concentrations of the individual species and their sum are expressed as Cl_2, in units of mg/L.

At 25°C, hypochlorous acid is the predominant species between pH 1 and pH 7.5, and hypochlorite ion predominates at pH values greater than 7.5. Oxidation reactions and disinfecting properties of chlorine tend to be more effective at low pH values, because of the predominance of hypochlorous acid, which is a stronger oxidant.

The pH of water dosed with chlorine is affected by the amount used and the alkalinity in the water. In water with low alkalinity, the pH will drop after addition of gaseous chlorine, although it will rise if sodium hypochlorite is added.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Chlorine is employed as a strong oxidant or disinfectant, and also to provide a disinfectant residual in water distribution systems.

NOTE: Important general information is contained in PART II, Chapter 8

Chlorine can be added at various points of the treatment process:

- for oxidation of organics or metals
- for disinfection purposes
- to maintain a chlorine residual in the distribution system (pre-coagulation, intermediate or post-filtration chlorination).

Doses are usually 1–5 mg/L, although 2–3 mg/L is typical. The selection of the appropriate chlorine dose should take into account the amount of disinfection byproducts formed and the required Ct value (concentration × contact time) and chlorine residual; the WHO recommendation is 0.5 mg/L for 30 minutes. A free chlorine residual of ≥ 0.2 mg/L throughout the distribution system is preferred. In some systems, rechlorination is employed within the distribution system, where chlorine is added after water has left the treatment plant, to boost chlorine residuals.

Superchlorination (10–50 mg/L) may be used to disinfect or clean tanks or pipelines, or to temporarily treat tastes and odours associated with high ammonia levels. This process is usually followed by dechlorination, to chemically remove excess chlorine. Knowledge of the breakpoint phenomenon (whereby chlorine applied in sufficient doses will oxidise ammonia and eliminate chloramines, resulting in the formation of a free chlorine residual) is also necessary when dealing with water containing ammonia.

The fact sheet on ammonia discusses the use of chorine with ammonia to produce chloramines.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in chlorine (NRC 1982, JECFA):

- arsenic
- carbon tetrachloride
- lead
- manganese
- mercury
- trihalomethanes

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, chlorine should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

The use of a disinfectant such as chlorine results in the formation of free chlorine and combined chlorine residuals and disinfection byproducts, including trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs), haloketones, chloral hydrate and chloropicrine. Although many specific chlorine disinfection byproducts have been identified, several of the total organic halogens have yet to be identified.

Factors affecting the distribution of disinfection byproduct species include pH, temperature and the levels of total organic carbon (TOC), bromide and chlorine. THMs (e.g. chloroform, bromodichloromethane, dibromochloromethane and bromoform) are the best known chlorination byproducts. Chlorinated THM, HAA and HAN species generally dominate over brominated species. However, brominated species predominate in high-bromide waters.

STATUS

Chlorine was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The

revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

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NOTE: Important general information is contained in PART II, Chapter 8

Copper sulfate

Drinking water treatment chemical

Copper sulfate is an active constituent in registered algicide products used in drinking water reservoirs. There are different State and Territory environment protection regulations on the use of copper sulfate in reservoirs. Further information should be sought form the relevant State or Territory agency.

GENERAL DESCRIPTION

Copper sulfate, $CuSO_4$, is a blue crystal, or blue crystalline granule or powder, but is white when dehydrated. The chemical has a nauseous metallic taste and is poisonous. The anhydrous form contains nearly 50% copper; the commonly used pentahydrate form ($CuSO_4 \cdot 5H_2O$) contains 25.5% copper.

Appropriate handling materials for copper sulfate include fibreglass-reinforced plastic, polyethylene, polyvinyl chloride, cast iron and stainless steel. Rubber-lined and silicon-lined containers can also be used.

CHEMISTRY

Copper sulfate is the product of the reaction of sulfuric acid with copper metal, cupric oxide or basic copper salts.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Copper sulfate is an algicide, and is used to treat toxic or odorous algal blooms in water reservoirs and other water supply storages. Copper sulfate may kill aquatic plants, insects, invertebrates and fish. Copper sulfate is subject to registration and labelling requirements of the Australian Pesticides and Veterinary Medicines Authority. Copper sulfate is not registered for general use as an algicide in all jurisdictions therefore, before copper sulfate is used in a water storage system, the State or Territory environment protection authority must be advised. In some States and Territories, a licence must be obtained for its use. The Australian *and New Zealand Guidelines for Fresh and Marine Water Quality* (2002) contain information on the effect of copper sulfate on various ecosystems. There is a range of alternative water treatment and storage management methods for controlling the risks of toxic algal bloom including reducing the amounts of nutrient inflow to water reservoirs.

The application of copper sulfate products to storages should be in accordance with the registered chemical label. Copper sulfate can be applied by:

- dissolving crystals of the chemical into the water using porous bags pulled by a boat
- applying the crystals directly using a hopper feeder
- spraying dissolved copper sulfate on the water surface.

To determine the appropriate dose rate and ensure efficient application, knowledge of algal habitat and distribution is needed. Experience with the use of copper sulfate to treat cyanobacteria indicates that it is best to start applying the chemical early in the morning, and to apply it during calm conditions. This is because cyanobacteria tend to be most buoyant at this time, and are likely to be near the surface. For a stratified reservoir, calculation of the total amount of algicide to be added is based on the amount needed to treat the surface of the water body, because this is where most cyanobacteria will be located. Treatment of algae should be concentrated in areas of algae scum.

The amount of copper sulfate required will depend on various factors, such as pH, alkalinity and water temperature (algae are more likely to bloom in warm water).

NOTE: Important general information is contained in PART II, Chapter 8

Copper sulfate is most effective at pH values of around 8, and alkalinity less than 50 mg/L. In conditions of high alkalinity or pH, addition of an acid (e.g. citric acid) may also be needed for the copper sulfate to be effective. The concentrations of copper sulfate added are typically in the range 0.2–1 mg Cu/L, depending on the specific type of organism being controlled.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. Chemical contaminants that may be present in copper sulfate include (JECFA):

- arsenic
- chloride
- iron
- lead
- nickel

RESIDUE AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, copper sulfate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*. A limit of 2 mg/L based on health considerations and of 1 mg/L for aesthetic considerations has been established for copper residues resulting from the use of copper sulfate.

Copper sulfate breaks down algae, resulting in the release of algal toxins and odorous substances that decay over time. Hence, a withholding period is needed after copper sulfate has been used as an algicide, and it may be necessary to monitor copper residues, toxins and odours during a follow-up period.

Copper sulfate products should not be used to treat more than half of a lake or pond at one time, in order to avoid depletion of oxygen caused by decaying vegetation. One to two weeks should be allowed between copper sulfate treatments to allow water oxygen levels to recover.

Copper entering a water treatment plant may be removed to some degree through coagulation with clarification/filtration. Elevated pH assists in copper removal.

STATUS

Copper sulfate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B602-02. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

ANZECC (Australia and New Zealand Environment and Conservation Council) / ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand) (2002). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. National Water Quality Management Strategy, ANZECC / ARMCANZ, Canberra.

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Ferric chloride

Drinking water treatment chemical

Ferric chloride is used as a primary coagulant in the treatment of drinking water, particularly when a broad coagulation pH range is required It is used to remove turbidity, natural organic matter (NOM) (including colour), microorganisms and many inorganic chemicals. Removal of NOM reduces the formation of disinfection byproducts, because it removes the organic precursors of the byproducts.

GENERAL DESCRIPTION

Ferric chloride, $FeCl_3$ (anhydrous) or $FeCl_3 \cdot 6H_2O$ (crystalline), has a brownish-yellow or orange colouration when in crystalline form and is very hygroscopic. In solution, it has the appearance of a dark-brown syrup. Solutions of ferric chloride are acidic and corrosive to most metals. The typical pH range of a 1% solution of ferric chloride is 3–4. The chemical is significantly more soluble in hot water (535.7 g/100 mL at 100 °C) than in cold water (74.4 g/100 mL at 0°C), and is very soluble in alcohol, ether and methanol.

Ferric chloride is available as a powder and in solution at 30–42%. A 42% solution of ferric chloride has a specific gravity of 1.45 at 20°C, contains 14.5% iron and has a pH of 1–2.

Ferric chloride is highly corrosive to most metals, including stainless steel; however, it can be stored or transported in fibreglass, rubber-lined carbon steel, polyvinyl chloride, polyethylene or polypropylene. Polytetrafluoroethylene and polyvinylidene difluoride are also suitable as lining materials.

CHEMISTRY

Ferric chloride is obtained from ores containing iron and titanium oxides. It is also produced through the reaction of chlorine gas with iron, ferrous sulfate or ferrous chloride.

The positively charged Fe species are available to interact with negatively charged colloidal matter in water. Such matter includes inorganic turbidity particles and the high molecular weight fraction of organic compounds present in natural organic matter (NOM). Fe cations interact with the natural alkalinity to form hydroxides that then act in a charge neutralisation fashion similar to that for aluminium. Charge neutralisation destabilises the repulsive forces between the negatively charged particles, allowing them to approach closely, collide and agglomerate. Metal hydroxides precipitate and can enmesh any colloidal particles. Iron floc is generally large and settles rapidly though it may be weaker than alum floc. As for aluminium, sweep coagulation can also occur at higher doses.

The stoichiometry of the precipitation of iron hydroxide is described as follows:

$$FeCl_3\ (s) \rightarrow Fe^{+3} + 3Cl^-$$

$$Fe^{+3} + 3OH^- \rightarrow Fe\ (OH)_3(s)$$

Ferric chloride is an effective coagulant at a pH between 4 and 11. When added to water, ferric chloride consumes more alkalinity than does alum.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Ferric chloride is used as a primary coagulant, especially when a broader coagulation pH range is required.

The amount of ferric chloride added depends on the properties of the raw water, including factors such as turbidity, NOM, temperature and alkalinity.

NOTE: Important general information is contained in PART II, Chapter 8

Typical ferric chloride doses are 2–100 mg/L $FeCl_3 \cdot 6H_2O$, although higher doses may be required if water is particularly dirty. At high doses, product water should be tested to ensure that maximum contaminant levels have not been exceeded.

The dose rate for ferric chloride may refer to crystalline or anhydrous ferric chloride, supplied as liquid or as iron. Care should be taken when interpreting dose rates to ensure that comparisons are relevant.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product (KIWA 1994, NRC 1982:

- antimony
- arsenic
- cadmium
- chromium
- cobalt
- copper
- cyanide
- lead
- manganese
- mercury
- nickel
- phosphorus
- selenium
- silver
- titanium
- vanadium
- zinc

Manganese concentrations in ferric chloride may be high enough to affect the treated water.

RESIDUE AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, ferric chloride should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Conventional water treatment processes, if optimised, remove almost all of the ferric ions produced when ferric chloride is used for coagulation. Residual chloride is usually at low levels, which do not adversely affect drinking water quality.

The presence of any ferrous iron in the product reduces its effectiveness in water treatment and increases the possibility of soluble iron carry over. This could cause post precipitation of ferric hydroxide (red water) in the distribution system.

STATUS

Ferric chloride was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

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NRC (National Research Council) (1982). *Water Chemicals Codex*. Committee on Water Treatment Chemicals, Food and Nutrition Board, Assembly of Life Sciences, NRC, Washington, DC.

NOTE: Important general information is contained in PART II, Chapter 8

Ferric sulfate

Drinking water treatment chemical

Ferric sulfate is used as a primary coagulant in the treatment of drinking water, particularly when a broad coagulation pH range is required. It is used to remove turbidity, natural organic matter (NOM) (including colour), microorganisms and many inorganic chemicals. Removal of NOM reduces the formation of disinfection byproducts, because it removes the organic precursors of the byproducts.

GENERAL DESCRIPTION

Ferric sulfate, $Fe_2(SO_4)_3$, is a yellow crystal or greyish-white powder that is soluble in water. In water treatment, it is usually supplied as an aqueous solution of 39–45% w/w ferric sulfate (11–12.5% Fe). The liquid solution has a specific gravity of 1.5–1.6 and is red-brown in colour. A 1% solution of ferric sulfate is acidic (pH 3–4).

Ferric sulfate is also available in granular form with an iron content of 18.5–20% and a pH of less than 1. It is not as corrosive as ferric chloride. Ferric sulfate can be stored or transported in stainless steels, lead, fibreglass, rubber-lined carbon steel, polyvinyl chloride, polyethylene or polypropylene.

Ferric sulfate can be used in a system built for alum dosing, whereas ferric chloride cannot.

CHEMISTRY

Ferric sulfate is produced by the oxidation of ferrous sulfate or by dissolving ferric oxide in sulfuric acid.

In water, the ferric (iron III) ion hydrolyses and precipitates, to an extent that depends on pH and dosage. Iron precipitates formed are goethite, $HFeO_2$, and iron hydroxide, $Fe(OH)_3$, which are less soluble than aluminium precipitates. At equilibrium, the concentration of the soluble species is very low. Fe cations interact with the natural alkalinity to form hydroxides that then act in a charge neutralisation fashion similar to that for aluminium. Charge neutralisation destabilises the repulsive forces between the negatively charged particles, allowing them to approach closely, collide and agglomerate. Metal hydroxides precipitate and can enmesh any colloidal particles. Iron floc is generally large and settles rapidly though it may be weaker than alum floc. As for aluminium, sweep coagulation can also occur at higher doses.

The stoichiometry of the precipitation of iron hydroxides is described as follows:

$$Fe_2(SO_4)_3 \rightarrow 2Fe^{+3} + 3SO_4^{2-}$$
$$Fe^{+3} + 3OH^- \rightarrow Fe(OH)_3(s)$$

Ferric sulphate is an effective coagulant at pH values between 4 and 11.

TYPICAL USE IN DRINKING WATER TREATMENT

Ferric sulfate is used as a primary coagulant in the treatment of drinking water, particularly when a broad coagulation pH range is required.

The dose of ferric sulfate used depends on the properties of the raw water, including factors such as turbidity, natural organic matter (NOM), temperature and alkalinity.

Typical ferric sulfate doses, expressed as mg/L $Fe_2(SO_4)_3$, range from 2 mg/L to 100 mg/L although higher doses may be required if the raw water is excessively dirty. At high doses, product water should be tested to ensure that maximum contaminant levels have not been exceeded.

NOTE: Important general information is contained in PART II, Chapter 8

The dose rate of ferric sulfate may be expressed as crystalline ferric sulphate, as supplied liquid or as iron. Care should be taken when interpreting dose rates to ensure that any comparisons made are relevant.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies depending on the manufacturing process. Chemical contaminants that may be present in ferric sulfate are (JECFA, KIWA 1994, NRC 1982):

- antimony
- arsenic
- cadmium
- chromium
- cobalt
- copper
- cyanide
- lead
- manganese
- mercury
- nickel
- phosphorus
- selenium
- silver
- titanium
- vanadium
- zinc

In some products, manganese concentrations may be high enough to affect the treated water.

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, ferric sulfate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Almost all of the ferric ions used for coagulation are removed by optimised conventional water treatment processes. Residual sulfate is usually at low levels which do not adversely affect drinking water quality.

The presence of any ferrous iron in the product reduces its effectiveness in water treatment and increases the possibility of soluble iron carry over. Iron residuals after filtration can cause floc to form in the distribution system, which can give rise to customer complaints. To minimise residual levels of iron, pH and dosage conditions should exceed the solubility of iron. Poor dosage selection or inadequate mixing also leads to elevated iron residuals.

STATUS

Ferric sulfate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

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NRC (National Research Council) (1982). *Water Chemicals Codex*. Committee on Water Treatment Chemicals, Food and Nutrition Board, Assembly of Life Sciences, NRC, Washington, DC.

NOTE: Important general information is contained in PART II, Chapter 8

Hydrochloric acid

Drinking water treatment chemical

Hydrochloric acid is used to correct pH, regenerate deionisers and generate chlorine dioxide on site.

GENERAL DESCRIPTION

Hydrochloric acid, HCl, also known as spirits of salts, is a colourless or slightly yellow, fuming, pungent liquid. This strong and highly corrosive acid should be handled with extreme caution (particularly when adding the concentrated acid to water), as it can cause severe burns and eye damage. Hydrochloric acid is generally available as a 25–42% solution. A 28% solution has a specific gravity of 1.14 at 20°C. The acid is soluble in water and benzene, and is noncombustible.

Hydrochloric acid is highly corrosive to most metals or alloys, liberating extremely flammable hydrogen gas. Chlorine gas may also be liberated in reactions with oxidants or sodium hypochlorite. Hydrochloric acid may be stored and piped in rubber-lined carbon steel, fibreglass-reinforced plastic with acid-resistant resins, plastic liners and pipes (u-polyvinyl chloride, polythene and polypropylene).

CHEMISTRY

Hydrochloric acid is manufactured by the combustion of chlorine gas in hydrogen to produce hydrogen chloride gas, which is then dissolved in water.

Hydrochloric acid disassociates in water to produce a strong acid:

$$HCl \Leftrightarrow H^+ + Cl^-$$

To reduce fuming, the acid should be diluted (by adding acid to water) to about 20% HCl.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, hydrochloric acid is used to correct pH (for softening, corrosion control, coagulation, prevention of post-precipitation), regenerate deionisers and generate the disinfectant chlorine dioxide on site.

Doses of hydrochloric acid required vary widely, depending on the application and conditions.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product (JECFA, KIWA 1994):

- arsenic
- chlorine
- chromium
- iron
- lead
- methylene chloride
- nickel
- sulfate
- sulphur dioxide

NOTE: Important general information is contained in PART II, Chapter 8

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, hydrochloric acid should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

STATUS

Hydrochloric acid was endorsed by the NHMRC for use as a drinking water treatment chemical in 2005.

REFERENCES

Clesceri *Wastewater*, 20th edition. American Public Health Association, Washington, DC.

JECFA (Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Joint Expert Committee on Food Additives). *Compendium of Food Additive Specifications*. FAO Food and Nutrition Papers 52 (two volumes). Available at <www.fao.org/es/esn/jecfa/database/cover.htm>

KIWA (1994) *Guideline quality of materials and chemicals for drinking water supplies*. Inspectorate of Public Health and Environmental Planning, Publication 94-01. Rijswijk, The Netherlands.

Hydrofluorosilicic acid

Drinking water treatment chemical

Hydrofluorosilicic acid is used to artificially fluoridate water, to reduce the occurrence of dental caries. When dissolved in water, hydrofluorosilicic acid forms the fluoride ion F^-.

GENERAL DESCRIPTION

Hydrofluorosilicic acid, H_2SiF_6 (also known as fluorosilicic acid, hexafluorosilicic acid), is a colourless to pale yellow liquid, poisonous and corrosive, with a pungent odour and irritating fumes. It can etch glass. It has a specific gravity of 1.18 at 20 ºC at 22% strength.

The acid is usually delivered by road tanker but can be supplied in drums. It is incompatible with glass and stoneware but can be stored in polythene drums, rubber-lined mild steel or polyvinyl chloride-lined plastic tanks.

CHEMISTRY

Hydrofluorosilicic acid is a byproduct of the preparation of chemical fertilisers from phosphate rock. The rock is ground up and treated with sulphuric acid, forming a gas byproduct, which then reacts with water to produce a weak acid. This hydrofluorosilicic acid solution is subsequently concentrated to strengths of up to 30%. Manufacture of hydrofluorosilicic acid is limited, but because the acid is a byproduct of the agricultural industry, it is generally readily available in Australia.

The dissolution of hydrofluorosilicic acid in water forms the fluoride ion (F^-) as follows:

$$H_2SiF_6 \Leftrightarrow 2H^+ + SiF_6^{2-}$$

$$SiF_6^{2-} \Leftrightarrow SiF_4 + 2F^-$$

$$SiF_4 + 2H_2O \Leftrightarrow SiO_2 + 4F^- + 4H^+$$

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Hydrofluorosilicic acid is used to fluoridate drinking water, to reduce the occurrence of dental caries. In each State and Territory, except for South Australia, the fluoridation of drinking water is regulated by an Act of Parliament; New South Wales and Queensland also have regulations in force.

In adding hydrofluorosilicic acid to drinking water, it is good practice to add the chemical after the water has been treated, because fluoride ions may be adsorbed onto the surfaces of suspended matter in water. In water that has been treated and disinfected, fluoridation is usually accomplished with a 20% hydrofluorosilicic acid stock solution. The acid solution, despite its pH of 1.2, has little effect on the pH of highly alkaline water, because relatively low amounts are used. However, the pH effect can be significant with water of low alkalinity.

The target levels of fluoride in fluoridated water in Australia vary between 0.7 and 1.0 mg/L. The lower concentrations apply in warmer climates, where more water is consumed. For an acid solution of 20% strength (15.8% F^-), this range translates to a dose of hydrofluorosilicic acid of 4.4–6.3 mg/L.

NOTE: Important general information is contained in PART II, Chapter 8

CONTAMINANTS

Chemical contaminants that may occur in hydrofluorosilicic acid solutions include inorganic and organic substances, and the following chemicals:

- arsenic
- lead

The concentrations of contaminants depend on the purity of the raw materials used in fertiliser production. Hydrofluorosilicic acid solutions also contain free hydrofluoric acid, which prevents the precipitation of solid silica when the acid is diluted in water.

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, hydrofluorosilicic acid should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Fluoride forms precipitates with many metals and other elements, but is notably insoluble with calcium; thus, scaling can occur when concentrated lime solution and concentrated fluoride solution come into contact. Points for adding these solutions should be separated, to avoid this situation.

STATUS

Hydrofluorosilicic acid was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B703-00. AWWA CD-ROM (April 2003). Details at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Department of Health, South Africa (2003). *Water fluoridation, a manual for water plant operators*. Available at <www.doh.gov.za/docs/misc/fluoridation/>

NSW Health (1957). Code of Practice for the fluoridation of public water supplies. *NSW Fluoridation of Water Supplies Act 1957*, NSW Government Gazette No. 135.

Hydrogen peroxide

Drinking water treatment chemical

Hydrogen peroxide is used as an oxidant in the treatment of drinking water (often in conjunction with ozone) to oxidise metals or organics, reduce tastes and odours, or act as an algicide, disinfectant or biocide. It can also be used to destroy ozone residual.

GENERAL DESCRIPTION

Hydrogen peroxide, H_2O_2, is a colourless syrupy liquid that is available in concentrations ranging from 20 to 60%, with a specific gravity between 1.07 and 1.24 at 20°C and pH 1–4.

There are strict handling and storage requirements that must be adhered to for hydrogen peroxide, which is especially dangerous at concentrations over 52%, because it is a strong oxidant and extremely corrosive. Materials suitable for handling and storing hydrogen peroxide include passivated aluminium or stainless steel (types 304L and 316L). Plastic piping (polyvinyl chloride or polyethylene) is only suitable for short-term use.

CHEMISTRY

Hydrogen peroxide is manufactured by electrolytic or organic auto-oxidation processes. A common example is the auto-oxidation of alkylated anthraquinones through hydrogenation with oxidation in the presence of a catalyst.

Used with ozone, hydrogen peroxide produces the powerful hydroxyl radical:

$$2H_2O_2 + 2O_3 = 4OH^{\bullet} + 3O_2$$

For the destruction of ozone in water, this reaction proceeds to water and oxygen.

Hydrogen sulfide, a common taste and odour compound, is oxidised to sulfate by hydrogen peroxide as follows, or to colloidal sulfur.

$$4H_2O_2 + H_2S \Leftrightarrow SO_4^{2-} + 4H_2O + 2\,H^+ \qquad \text{pH} > 8$$

$$H_2O_2 + H_2S \Leftrightarrow S + 2H_2O \qquad \text{pH } 7$$

Hydrogen peroxide also oxidises iron and manganese, which are then precipitated.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In water treatment, hydrogen peroxide is used with ozone to produce the hydroxyl radical, which is a powerful oxidant. The combination of hydrogen peroxide and ozone is used to:

- oxidise iron, manganese, sulfide and hazardous synthetic organic compounds such as trichloroethylene and atrazine
- remove taste and odour-causing substances, such as hydrogen sulfide (H_2S) which is commonly found in groundwater
- reduce colour and natural organic matter
- improve the performance of coagulants, or reduce the required amount of coagulants.

Hydrogen peroxide is a biocide, and can be used before treatment to control the growth of aquatic organisms such as algae in the pretreatment basin. It may also be used as a primary disinfectant to meet the Ct (disinfectant concentration × contact time) requirements. Alternatively, hydrogen peroxide can be used after the ozonation stage to destroy ozone residual and minimise its release to the atmosphere.

NOTE: Important general information is contained in PART II, Chapter 8

Hydrogen peroxide is often added at the head of a treatment plant, before or at the rapid mix basin. However, it can also be added after clarification and before filtration, when a substantial portion of the oxidant demand has been removed.

To determine the optimum hydrogen peroxide concentration for a particular application, it is best to undertake pilot-plant and jar-testing trials. For use with ozone, the hydrogen peroxide to ozone ratio is typically 0.4–0.5; whereas, for destroying ozone residual, a concentration of 1.4 mg/L of H_2O_2 (50% strength) would be required for each mg/L of ozone.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in hydrogen peroxide (JECFA):

- acetanilide
- acetophenetidin
- arsenic
- copper
- iron
- sulfuric acid
- tin

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

Hydrogen peroxide decomposes to oxygen and water.

When employed in drinking water treatment, hydrogen peroxide should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

STATUS

Hydrogen peroxide was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

IARC (International Agency for Research on Cancer) (1999). *Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man*. World Health Organization, Geneva, 71: 683.

JECFA (Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Joint Expert Committee on Food Additives). *Compendium of Food Additive Specifications*. FAO Food and Nutrition Papers 52 (two volumes). Available at <www.fao.org/es/esn/jecfa/database/cover.htm>

Rueff J et al (1993). DNA strand breaks and chromosomal aberrations induced by H_2O_2 and ^{60}Co gamma-radiation. *Mutation Research* 289 (2): 197–204.

White GC (1992). *Handbook of chlorination and alternative disinfectants*, 3rd edition. Van Nostrand Reinhold, New York.]

Hydroxylated ferric sulfate

Drinking water treatment chemical

Hydroxylated ferric sulfate is used as a coagulant for the treatment of drinking water. It is effective over a broad pH range and generally produces a stronger floc than other ferric salts.

GENERAL DESCRIPTION

Hydroxylated ferric sulfate (HFS), $Fe_x(SO_4)_y(OH)$, also known as polymerised ferric sulphate, is one of several hydroxylated iron coagulants produced from ferrous sulfate. It is a translucent, dark reddish liquid, with no odour. It is available in various ferric iron and basicity concentrations, but typically contains 12.5 % Fe.

HFS has a pH of less than 2 and a specific gravity of 1.45–1.6 at 25°C. It is corrosive, but can be stored in fibreglass, rubber-lined steel, stainless steel, polyethylene, polyvinyl chloride or polytetrafluoroethylene.

For commercial coagulant solutions, the basicity varies from about 5 to 15% for prehydrolysed iron salts. As the basicity exceeds 15%, it becomes increasingly difficult to keep the metal hydroxide precipitate from forming in the product solution during shipping and extended storage. The typical basicity for HFS is 10 %.

CHEMISTRY

HFS is produced by oxidising ferrous sulfate. It can also be produced by dissolving ferrous oxide in sulfuric acid under controlled conditions. The chemical is similar to ferric sulfate, but its small polymeric chains provide additional coagulation properties, so it may be preferable to ferric sulfate for water that is difficult to treat.

In water, ferric (iron III) ion hydrolyses and precipitates, to an extent that depends on pH and dosage. Iron precipitates formed are goethite ($HFeO_2$) and iron hydroxide ($Fe(OH)_3$), which are less soluble than aluminium precipitates. At equilibrium, the concentration of the soluble species is very low. The stoichiometry of the precipitation of iron hydroxide is described as follows:

$$Fe^{+3} + 3OH^- \rightarrow Fe\ (OH)_3\ (s)$$

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

HFS coagulates relatively quickly over a wide pH range (pH 4–11). It forms a dense floc and does not cause significant variation in pH. The floc produced is usually similar in characteristics to alum floc, but has less impact on pH and alkalinity. HFS generally produces a more robust floc than other iron salts. It is often preferred over conventional coagulants for low alkalinity waters containing colour because it does not consume as much alkalinity as other coagulants; thus, the need to add alkali in addition to coagulant is reduced.

The dose of HFS used depends on the properties of the raw water, including factors such as turbidity, natural organic matter, temperature and alkalinity. As with other coagulants, higher doses are required as turbidity and colour increase, and colder temperatures slow down reaction times.

Typical HFS doses (expressed as supplied HFS in mg/L) are 5–100 mg/L, although higher doses may be required if the water is particularly dirty. At high doses, product water should be tested to ensure that maximum contaminant levels have not been exceeded.

NOTE: Important general information is contained in PART II, Chapter 8

The dose rate of HFS may be expressed as ferric sulfate, supplied HFS liquid or iron. Care should be taken when interpreting dose rates to ensure that relevant comparisons are made. Because of its reactivity, HFS should be used neat if possible, or not pre-diluted such that is hydrolyses before contact with the water to be treated.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in HFS:

- antimony
- arsenic
- cadmium
- chromium
- cobalt
- copper
- cyanide
- lead
- manganese
- mercury
- nickel
- phosphorus
- selenium
- silver
- titanium
- vanadium
- zinc

In some products, manganese concentrations may be significant.

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, HFS should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Almost all ferric ions used for coagulation are removed by conventional water treatment processes. Residual sulfate is usually at low levels that do not adversely affect drinking water quality.

STATUS

HFS was endorsed by the NHMRC for use as a drinking water treatment chemical in 2005.

REFERENCES

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Ozone

Drinking water treatment chemical

Ozone is used as an oxidant and disinfectant in the treatment of drinking water. It can oxidise metals and organic compounds, including algal toxins, tastes and odours. Ozonation does not produce a residual so cannot be used to maintain a disinfection residual in the distribution system.

GENERAL DESCRIPTION

Ozone (O_3) is an unstable blue or colourless gas with a pungent odour. It can be liquefied at –12°C, and has a boiling point of –112°C and a freezing point of –192°C. It is more soluble in water than oxygen. As a strong oxidant and disinfectant, ozone effectively inactivates bacteria, viruses and protozoa *(Cryptosporidium* and *Giardia)*, controls tastes and odours, and breaks down organic contaminants and algal toxins. Ozone also aids in coagulation and flocculation, by breaking down organic chains and starting microflocculation. Ozone does not produce halogenated disinfection byproducts, except in bromide-rich waters where bromate ion is generated.

Disadvantages of ozone are that it is relatively costly and does not produce a persistent disinfectant residual (and therefore cannot be used to maintain a disinfection residual in the distribution system). Also, ozone produces biodegradable organic material that increases biofouling problems in the water distribution system. This biodegradable material can be achieved by using biologically activated carbon (BAC) filters after ozone treatment.

Ozone in water is highly corrosive; therefore, only it can only be used with certain materials, such as 316 and 305 stainless steel, glass and Teflon. Ozone is produced on site using electrical discharges in the presence of oxygen. The maximum concentration of ozone generated is 50 g/m^3 and the maximum practical solubility of ozone in water is approximately 40 mg/L.

CHEMISTRY

Ozone is produced on site, as described above, and is highly unstable in the gaseous phase. Ozone has a half-life of 20–100 hours in clean vessels, at room temperature.

Two types of reactions occur when ozone is added to water:

- direct oxidation (a slow and extremely selective reaction favoured by low pH conditions)
- autodecomposition to the hydroxyl radical (a reaction catalysed by hydroxyl radicals, organic radicals, hydrogen peroxide, ultraviolet light or high concentrations of hydroxide ion; and favoured by high pH conditions or high concentrations of organic matter).

Ozone breaks down more slowly in water that has a high concentration of bicarbonate or carbonate. Therefore, an ozone residual will last longer in highly buffered water with low pH.

The reaction of ozone with contaminants in the water requires a sufficient contact time and a high transfer efficiency coefficient, which can be provided by well-designed ozone contactors and mixing devices. The gas vented from the contactors contains ozone, which has to be destroyed or reinjected before the air is released to the atmosphere.

TYPICAL VALUES USED IN AUSTRALIAN DRINKING WATER TREATMENT

Ozone is a very strong oxidant that is moderately soluble in water. Typical concentrations used in drinking water are 0.5–5 mg (O_3)/L, depending on the organic content of the water. The required dose should be determined through bench-scale ozone demand tests or pilot-plant testing, using available

NOTE: Important general information is contained in PART II, Chapter 8

Ct (concentration × contact time) data for the inactivation of various microorganisms. The contact time required for ozone inactivation of microorganisms varies from seconds to minutes (the longer time being required for inactivation of protozoan cysts) and is temperature dependent; it is significantly shorter than the contact time required for chlorine or chloramines.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process and impurities in the air or oxygen used to generate the ozone. The following chemicals may be present in ozone:

- acetylene
- argon
- carbon dioxide
- carbon monoxide
- hydrocarbons
- nitrous oxide

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, ozone should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Ozone can react with bromide to form brominated ozone, which includes bromate ion (BrO_3^-). If natural organic material is present, nonhalogenated organic disinfection byproducts are formed. These include aldehydes (formaldehyde being dominant), ketoacids and carboxylic acids. If both natural organic material and bromide are present, hypobromous acid is formed, together with brominated organohalogen compounds.

CONCLUSION

Ozone was endorsed by the NHMRC for use as a drinking water treatment chemical in 2005.

REFERENCES

APHA (1998). APHA 4500-O3, Ozone (residual), in Standard Methods for the Examination of Water and Wastewater, 20th Edition, American Public Health Association, Washington, DC.

Water Treatment Plant Design (1990). American Water Works Association, 3rd Ed. McGraw-Hill Companies, Inc.

Polyacrylamide

Drinking water treatment chemical

Polyacrylamide is used in water treatment as an aid to coagulation, flocculation, clarification, filtration or handling of sludge.

GENERAL DESCRIPTION

Polyacrylamide, $(CH_2CHCONH_2)_n$, is a white crystalline solid. It is hydrophilic, with molecular weights of 1–30 million daltons, and chain lengths of 1.4×10^4 to 4.2×10^5 monomer units. Polyacrylamide is available in anionic, cationic or non-ionic forms, and in a variety of molecular weights and charge densities, to suit the particular characteristics of the water to be treated. It may be supplied as a powder, as an aqueous solution, dispersed in a light mineral oil or bound up in a solid cake that slowly dissolves when immersed.

Appropriate handling materials for polyacrylamide include fibreglass-reinforced plastic, polyethylene, polypropylene, polyvinyl chloride, stainless steel and coated steel.

CHEMISTRY

Polyacrylamide is usually manufactured by the polymerisation of the acrylamide monomer (AM) to form a non-ionic polymer, polymerisation of AM with acrylic acid salts to form an anionic polymer, or polymerisation of AM with cationic monomer to form a cationic polymer.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, polyacrylamide may be added:

- as a coagulation aid, immediately after coagulation, to strengthen the precipitate formed
- as a flocculation aid, at the start of flocculation, to increase the agglomeration of the floc
- as a clarification aid, before clarification, to help settle floc, bind dissolved air bubbles to floc (in dissolved air flotation, DAF) or bind floc to microsand
- as a filtration aid, before filtration, to minimise floc shearing and to improve adsorption of floc onto the filter medium
- to backwash water, to minimise filter ripening periods
- to sludge for thickening or dewatering, to improve performance.

As a coagulation, flocculation or clarification aid, polyacrylamide is typically used at concentrations of 0.05–0.3 mg/L. As a filter aid, it is usually applied in lower doses (0.01–0.1 mg/L). For sludge handling, typical doses of polyacrylamide are 0.5–2 kg per tonne of dry solids for thickening, and 1–4 kg for dewatering.

High doses of polyacrylamide can cause clogging and blockages, particularly in filter beds. Therefore, where high doses of polymers are used in water treatment, it is best to clean filters by both air scouring and water washing. Even with relatively low doses of polyacrylamide, filter beds should be inspected regularly for signs of polymer build-up. Regular measurement of the headloss accumulation rate in a filter is also useful.

Care should be taken in making up polymer solutions to minimise the formation of lumps of undissolved polymer (referred to as 'fish eyes'). The polymer should be mixed with the water using a well designed eductor, so that each grain of polymer is separately introduced to the water.

NOTE: Important general information is contained in PART II, Chapter 8

The polymer solution should also be suitably aged before dosing to obtain best performance. Aging requires gentle mixing of the polymer solution for 1–4 hours (refer to manufacturer for specific polymer aging times).

While most polymers are at least chlorine resistant, making up polymer solutions with chlorinated water can reduce their effectiveness.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product, depending on the raw materials used:

- acetamide
- acetone
- acrylamide
- acrylic acid
- acrylonitrile
- copper
- hydroquinone
- methacrylamide
- methyl ether hydroquinone
- peroxide
- propanamide
- sulfate

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

Polyacrylamides contain varying residual amounts of unreacted acrylamide monomer.

When employed in drinking water treatment, polyacrylamide should be used in such a way that any contaminants or byproducts formed by the use of the chemical do not exceed guideline values in the *Australian Drinking Water Guidelines*.

STATUS

Polyacrylamide, acrylic acid polymers and copolymers were endorsed by the NHMRC as drinking water treatment chemicals in 1977 and 1979. The revision undertaken in 2003 did not result in any change to the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association)Standard no B453-01. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Brown L and Rhead MM (1979). Liquid chromatographic determination of acrylamide monomer in natural and polluted aqueous environments. *Analyst* 104:391–399.

Letterman RD and Pero (1990). Contaminants in Polyelectrolyets used in Water Treatment. *American Water Works Association* 82(11): 87–97.

NICNAS (National Industrial Chemicals Notification and Assessment Scheme) (2002). *Priority Existing Chemical Assessment No 23: Acrylamide*, NICNAS, Canberra.

Polyaluminium chloride

Drinking water treatment chemical

Polyaluminium chloride is used as a primary coagulant in the treatment of drinking water. It is effective over a range of pH values. It is particularly effective on some waters and usually requires a lower dose than alum.

GENERAL DESCRIPTION

Polyaluminium chloride (PACl), $Al_2(OH)_3Cl_3$, is also known as aluminium hydroxy chloride or basic aluminium chloride. In solution, PACl is colourless to pale yellow, clear to slightly cloudy liquid. It is usually supplied with a minimum of 10% Al_2O_3 content, a pH of 2.2–2.8 and a basicity of about 50% (w/w). PACl solution has a specific gravity of 1.18–1.22 at 20°C and is completely soluble in water. Its use requires less alkalinity adjustment than most coagulants because of its basicity.

The formula $Al_2(OH)_3Cl_3$, is simply a representation of the proportions of aluminium, hydroxide and chloride in the solution. A generic formula for the PACl species may be given as $Al_2(OH)_mCl_{(6-m)}$ where the value of m typically ranges from 2.5 to 3.5.

PACl can be stored in fibreglass or plastics (polyethylene, polypropylene or polyfluorene), but is corrosive to most materials, including stainless steel (although 316 stainless steel can be used).

CHEMISTRY

PACl is manufactured by the reaction of hydrochloric acid with aluminium-containing raw materials such as aluminium metal, alumina trihydrate, aluminium chloride or aluminium sulfate.

PACl solution is a complex, dynamic mixture of positively charged polynuclear aluminium species, with no single species predominating. When applied to water, these species interact with and destabilise negatively charged colloidal matter, such as inorganic particles and the high molecular weight organic compounds that largely constitute natural organic matter. The polynuclear species also hydrolyse to form dense flocs of aluminium hydroxides that further act to entrap particles and remove some organic. An example of one of the many polynuclear species that may be present in PACl solution is the so called Al-13 ion that has the formula $[AlO_4.Al_{12}(OH)_{24}(H_2O)_{12}]^{13+}$.

The hydrolysis of PACl produces less acid than the hydrolysis of aluminium sulfate owing to the high degree of hydroxylation of the aluminium. As a result, PACl generally requires less pH correction with alkali than if alum were the coagulant.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

PACl is used as a primary coagulant to reduce turbidity, metals, colour and natural organic matter.

The amount of PACl added as a coagulant depends on the properties of the raw water, including factors such as turbidity, dissolved organic carbon, temperature and alkalinity.

Typical PACl doses (with 10% Al_2O_3 content) are 5–100 mg/L, although higher doses can be required if the water is particularly dirty. Doses should be determined by laboratory trials.

PACl is the next most commonly used aluminium salt after alum. Compared to alum, it produces a relatively robust floc, generally requires lower doses and is effective over a wider pH range.

NOTE: Important general information is contained in PART II, Chapter 8

CONTAMINANTS

PACl solution is usually low in trace metals, because it is made from clean raw materials. However, the following chemical contaminants may be present in this product:

- antimony
- arsenic
- barium
- beryllium
- cadmium
- chromium
- copper
- fluoride
- iron
- lead
- magnesium
- manganese
- mercury
- nickel
- phosphorus
- selenium
- silver
- thallium
- zinc

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, PACl should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Most of the aluminium ions resulting from the use of PACl as a coagulant are removed by conventional water treatment processes. Residual chloride will be present, but at low levels that do not adversely affect drinking water quality.

STATUS

Polyaluminum chloride was endorsed by the NHMRC for use as a drinking water treatment chemical in 1979. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B408-98. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th Edition. American Public Health Association, Washington, DC.

Polyaluminium silica sulfates

Drinking water treatment chemical

Polyaluminium silica sulfates are a relatively new group of coagulants in the treatment of drinking water. They are effective for removal of metals, colour and turbidity, and readily forms floc even in clean water.

GENERAL DESCRIPTION

Polyaluminium silicate sulfate, $Al_A(OH)_B(SO_4)_C(SiO_x)_D \cdot E(H_2O)$ (also known as aluminium hydroxide silicate sulfate) are pale yellow in colour and appears slightly cloudy to clear. It is usually supplied with a minimum of 9.8% Al_2O_3, a basicity of about 54% and a specific gravity of 1.32–1.36 (at 25°C). It has a pH of 2.8–3.6. It can be stored in fibreglass, plastics and stainless steel.

CHEMISTRY

Polyaluminium silicate sulfate is manufactured from alum, soda ash, sodium silicate and sodium aluminate.

Polyaluminium silicate sulfate solution is a polymerised coagulant solution containing aluminium in short chains. The high basicity of polyaluminium silicate sulfate assists in flocculation, because the coagulant does not require alkalinity to form the initial floc. The charge on colloidal particles and dissolved organics is neutralised by adsorption onto the very small flocs that form initially. Silicate compounds in PASS help to form larger flocs faster than with many other coagulants.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Polyaluminium silicate sulfate is used as a coagulant in the treatment of water and wastewater and to assist sludge blanket formation at start up. Polyaluminium silicate sulfate forms floc rapidly, even in cold water. It tends to form floc even with clean dilution water; therefore, it should be added as supplied (i.e. undiluted).

Typical concentrations of polyaluminium silicate sulfate used in drinking water treatment depend on the quality of the water to be treated and the purpose of the treatment. Polyaluminium silicate sulfate doses are typically 5–100 mg/L, but may be higher if the water is particularly dirty. The appropriate concentration should be determined by laboratory trials. Polyaluminium silicate sulfate must be used undiluted in jar tests.

CONTAMINANTS

The following contaminants may be present depending on the manufacturing process:

- antimony
- arsenic
- barium
- beryllium
- cadmium
- chromium
- copper
- fluoride
- iron
- lead
- magnesium
- manganese
- mercury
- nickel
- phosphorus
- selenium
- silver
- thallium
- zinc

NOTE: Important general information is contained in PART II, Chapter 8

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, polyaluminium silicate sulfate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

STATUS

Polyaluminium silicate sulfate was endorsed by the NHMRC for use as a drinking water treatment chemical in 2005.

REFERENCES

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Clifford DA (1999). Ion Exchange and Inorganic Adsorption. In: *Water Quality and Treatment, A Handbook of Community Water Supplies*, Letterman RD (ed), American Water Works Association, 5th edition. McGraw-Hill Professional, New York, 9.1–9.91.

Lewis RJ Sr (1993). *Hawley's Condensed Chemical Dictionary*, 12th edition. Van Nostrand Reinhold, New York.

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Polydiallyldimethylammonium chloride

Drinking water treatment chemical

Polydiallyldimethylammonium chloride (polyDADMAC) is used in the treatment of drinking water as a primary coagulant or, together with an inorganic coagulant, as a coagulation aid. PolyDADMAC reduces the quantities of floc and sludge produced.

GENERAL DESCRIPTION

Polydiallyldimethylammonium chloride $(C_8H_{16}N{\cdot}Cl)_n$, (also known as polyDADMAC), is a cationic polyelectrolyte with a medium molecular weight range of 10^5–10^6 and a high charge density (50–100%). The chemical is available as a powder or aqueous solution (10–60%). PolyDADMAC is not pH sensitive and is chlorine resistant.

Appropriate handling materials for polyDADMAC include fibreglass-reinforced plastic, polyethylene, polypropylene, polyvinyl chloride, stainless steel and coated steel.

CHEMISTRY

PolyDADMAC is produced from the diallyldimethylammonium chloride (DADMAC) monomer, which is made from allyl chloride and dimethylamine.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

PolyDADMAC can be used in a conventional treatment process as a primary coagulant for neutralisation and precipitation, in place of metal salts. The positively charged polyDADMAC reacts with turbidity particles and humic substances, which are generally negatively charged. The reaction eliminates the charge, allowing the particles to agglomerate. PolyDADMAC is usually most effective with particulate material; it may be less useful than aluminium and iron salts for treating dilute inorganic suspensions and water with significant amounts of colour.

PolyDADMAC can also be used as a secondary coagulant, to partially replace inorganic salts. A small dose of polyDADMAC may significantly reduce the amount of inorganic salt required (thus reducing floc volume and improving filter run times); often, it also improves treated water quality. PolyDADMAC is used particularly in direct and contact filtration processes, where the objective of coagulation is to produce small, high-density aggregates.

In treatment of drinking water, typical concentrations of polyDADMAC are 0.2–6 mg/L (as 100% polyDADMAC). When polyDADMAC is used, together with an inorganic salt, as a secondary coagulant, concentrations are usually lower (0.2–1 mg/L). The amount of polyDADMAC required should be determined through jar testing. The chemical can be added at concentrations of up to 10 mg/L, provided that the residual concentration of the monomer (DADMAC) does not exceed 2% of the polymer, and that the concentration of the residual monomer does not exceed 0.2 mg/L in the clarified water.

At concentrations above 40%, polyDADMAC is difficult to pump, because of its relatively high viscosity. Excessive polymer concentrations can adversely affect coagulation and filtration by redispersing the impurities.

Being highly charged, polyDADMAC should be diluted before it is added to the main water stream, so that it mixes more easily.

PolyDADMAC is usually supplied as a liquid. If supplied as a solid, individuals should seek advice from the supplier of the polymer as how to best prepare it.

NOTE: Important general information is contained in PART II, Chapter 8

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product:

- 5-hexenal
- allyl chloride
- DAD monomers
- diallyl ether
- dimethylamine

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, polyDADMAC should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Diallyldimethylammonium chloride residues are present in polyDADMAC.

STATUS

PolyDADMAC was endorsed by the NHMRC for use as a drinking water treatment chemical in 1982. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B451-98. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

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Letterman RD and Pero (1990). Contaminants in Polyelectrolytes used in Water Treatment. *American Water Works Association* 82(11): 87–97.

Potassium permanganate

Drinking water treatment chemical

Potassium permanganate is mainly used for the oxidation and removal of iron and manganese; it can also be used as a disinfectant, or to control tastes and odours.

GENERAL DESCRIPTION

Potassium permanganate, $KMnO_4$, is a dark purple crystal with a blue metallic sheen. It has a sweetish, astringent taste, is odourless and is an oxidant. The chemical is commercially available in crystalline form. Potassium permanganate is highly soluble in water, but heating is usually needed to prepare solutions with concentrations of more than 2.5%.

Appropriate handling materials include iron, steel, stainless steel, fibreglass-reinforced plastic, polyethylene and polyvinyl chloride.

CHEMISTRY

Potassium permanganate is produced by fusing manganese dioxide with potassium hydroxide to form potassium manganate; a solution of the manganate is then electrolysed at about 60°C using iron electrodes.

Under most treatment applications, permanganate (MnO_4^-) is reduced to insoluble manganese dioxide (MnO_2 (s)).

Divalent manganese (Mn2+) is removed from water by the oxidation to insoluble manganese dioxide (MnO2). As the oxidant, the permanganate ion MnO4- is itself reduced to manganese dioxide. The reaction proceeds as follows:

$$3Mn^{2+} + 2MnO_4\text{-} + 4OH \rightarrow 5MnO_2 + 2H_2O$$

The stoichiometric ratio of $KMnO_4$ to soluble Mn^{2+} is 1.92:1; however, reactions with organics usually require significantly higher ratios. The alkalinity consumed is 1.2 mg of $CaCO_3$ per milligram of Mn^{2+}, and the sludge produced (based on MnO_2 as the precipitate) is 2.6 kg/kg Mn^{2+}.

Potassium permanganate can also be used to oxidise iron and organics. The stoichiometric ratio of $KMnO_4$ to soluble Fe^{2+} is 0.94:1; however, reactions with organics usually require higher ratios. The alkalinity consumed is 1.5 mg per mg of Fe^{2+} and the sludge produced (based on $Fe(OH)_3$ as the precipitate) is 2.4 kg/kg Mn^{2+}.

Manganese dioxide resulting from permanganate reduction is an effective adsorbent for ferrous iron (Fe^{2+}), manganous manganese (Mn^{2+}), radium (Ra^{2+}) and other trace inorganic cationic species. These contaminants can be removed by permanganate treatment.

Manganese dioxide also adsorbs natural organic materials that serve as precursors for disinfection byproducts. This characteristic of manganese dioxide is particularly pronounced in hard waters, presumably because of the bridging action of calcium and manganese.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, potassium permanganate can be fed into solution directly using a dry chemical feeder or as a liquid bulk supply using dosing pumps. Alternatively, a concentrated solution can be prepared on site, from which the desired concentration is added to the water.

NOTE: Important general information is contained in PART II, Chapter 8

Permanganate is often added at the head of the treatment plant, as close to the intake as possible. This allows sufficient time for the permanganate to perform its oxidative function and to be reduced completely to solid manganese dioxide before filtration. In some cases, an alkali (usually lime) is added before, or soon after, addition of potassium permanganate, to assist in the oxidation process. Potassium permanganate can be effective over a range of pH values, but is most effective at pH 8.5 or higher.

The adsorptive property of $MnO_2(s)$ is the principle underlying the historical manganese greensand process, in which the filter medium is coated with manganese dioxide, which subsequently serves as an adsorbent for Fe^{2+}, Mn^{2+} and other metals in the filter influent. Filter media can be coated with manganese oxide by applying a potassium permanganate solution to the filter bed and oxidising it (through chlorination or aeration). Low doses of chlorine or permanganate are applied to the filter influent to catalyse the oxidation of the adsorbed metals, thereby creating additional adsorption sites. Alternatively, the filter backwash water may be treated with chlorine or permanganate.

Concentrations of potassium permanganate used in drinking water treatment depend on the concentrations of metals and organics, but are usually 0.3–5 mg/L. Overdosing of the chemical should be avoided because of the pink colour of unreacted permanganate. The potassium permanganate levels required should be determined by jar testing.

Advantages of potassium permanganate include its ease of use and the fact that it is effective for the oxidation of both iron and manganese and for certain types of taste and odour. As a disinfectant, it produces no halogenated disinfection byproducts, but has only a limited disinfection capability.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product (NRC 1982):

- cadmium
- chloride
- chromium
- mercury
- sulfate

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, potassium permanganate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

The manganese dioxide produced is a black precipitate that can be removed by a conventional clarification or filtration process. If manganese dioxide is not properly removed, the precipitates will create particulate deposits in the distribution system and on household plumbing fixtures. At manganese concentrations above 0.02 mg/L, an increase in consumer complaints is common.

STATUS

Potassium permanganate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B603-98. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

NRC (National Research Council) (1982). *Water Chemicals Codex*. Committee on Water Treatment Chemicals, Food and Nutrition Board, Assembly of Life Sciences, NRC, Washington, DC.

White GC (1992). *Handbook of chlorination and alternative disinfectants*, 3rd edition. Van Nostrand Reinhold, New York.

NOTE: Important general information is contained in PART II, Chapter 8

Sodium aluminate

Drinking water treatment chemical

Sodium aluminate is used as a primary coagulant in drinking water treatment, especially in water with low alkalinity; it can also be used in combination with alum to control alkalinity and pH.

GENERAL DESCRIPTION

Sodium aluminate, $Na_2Al_2O_4$, is a white powder that is hygroscopic, soluble in water and strongly alkaline. The aqueous solution is a clear, colourless to pale amber liquid, with a pH of 14.

Sodium aluminate can be supplied as a powder or as a solution. The solid product contains 70–90% $Na_2Al_2O_4$, whereas the liquid form contains 29–35% $Na_2Al_2O_4$. The liquid solution has a specific gravity of 1.4–1.6, with an excess alkali (as sodium hydroxide, NaOH) of 8–13% and Al_2O_3 equivalent of 18–21%.

Appropriate handling materials for sodium aluminate include iron, fibreglass-reinforced plastic, polyethylene, rubber, steel, stainless steel and concrete.

CHEMISTRY

Sodium aluminate is produced by combining aluminium oxide with excess caustic soda.

The aluminium ion neutralises the negative charges on turbidity particles and also forms insoluble metal hydroxides that agglomerate the neutralised particles:

$$Na_2Al_2O_4 + 4H_2O \rightarrow 2Na^+ + 2Al^{+3} + 8OH^-$$

$$Al_2O_3 + 3H_2O \Leftrightarrow 2Al(OH)_3(s)$$

1 mg/L of $Na_2Al_2O_4$ (88%) increases the alkalinity of the water by 0.54 mg/L and reduces carbon dioxide, CO_2, by 0.47 mg/L.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, sodium aluminate is used as a primary coagulant, especially in water with low alkalinity. It can also be used in combination with alum to control alkalinity and pH. An advantage of sodium aluminate is that the chemical provides both aluminium and alkali. However, its use as a coagulant in water treatment is limited by cost and by its chemical properties, which make it more difficult to handle than alum or other metal salts.

Because sodium aluminate contains a high percentage of aluminium, a concentration of 1 mg/L of $Na_2Al_2O_4$ is equivalent to 3.5 mg/L of alum (on a dry weight basis).

Typical concentrations used are 2–60 mg/L (as $Na_2Al_2O_4$). The appropriate level should be determined by jar testing.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product:

- arsenic
- cadmium
- chromium
- iron
- lead
- mercury
- selenium
- silver

NOTE: Important general information is contained in PART II, Chapter 8

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium aluminate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines.*

Aluminium residuals remaining after filtration can cause floc to form in the distribution system, which can lead to customer complaints.

STATUS

Sodium aluminate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B405-00. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Sodium bicarbonate

Drinking water treatment chemical

Sodium bicarbonate is used to correct pH, control corrosion, soften water for coagulation and prevent post-precipitation.

GENERAL DESCRIPTION

Sodium bicarbonate, $NaHCO_3$ (also known as baking soda, bicarbonate of soda, sodium acid carbonate or sodium hydrogen carbonate), is in the form of a white powder or crystalline lumps, and has a slightly alkaline taste. It is soluble in water (96 g/L at 20ºC) and stable in dry air, but slowly decomposes in moist air. Its specific gravity is 2.159 at 20ºC, with a bulk density of 1000 kg/m^3. Sodium bicarbonate is available in several grades, but is usually supplied as > 99% sodium bicarbonate. A 10 g/L solution has a pH of 8.4. The chemical decomposes with heat (> 50ºC) and reacts with acid to release carbon dioxide.

Suitable storage materials for sodium bicarbonate include rubber linings and stainless steel.

CHEMISTRY

Sodium bicarbonate is most economically produced by bubbling carbon dioxide gas through a solution of purified sodium carbonate; the bicarbonate precipitates out and can be collected and dried. Sodium bicarbonate is also an intermediate product in the Solvay process for making sodium carbonate.

Sodium bicarbonate provides bicarbonate alkalinity without significantly changing the pH of the water:

$$NaHCO_3 \Leftrightarrow Na^+ + HCO_3^-$$

It can further break down to carbon dioxide in the presence of acid:

$$HCO_3^- + H^+ \Leftrightarrow CO_2 + H_2O$$

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, sodium bicarbonate is used to correct pH, control corrosion, soften water for coagulation and prevent post-precipitation. It is used as a source of alkalinity for the treatment of waters with low alkalinity, but is more expensive than soda ash or lime. When it is used to improve coagulation, additional alkalinity or pH adjustment is often required.

The concentration of sodium bicarbonate required depends on the alkalinity and pH of the raw water and the targets for the treated water. Jar testing should be used to determine requirements.

Sodium bicarbonate can increase alkalinity with little increase in pH. It imparts a change of 0.60 g/L $CaCO_3$ alkalinity per mg/L as $NaHCO_3$.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water will vary depending on the manufacturing process. The following chemical contaminants may be present in this product (JECFA):

- ammonium
- arsenic
- chloride
- iron

NOTE: Important general information is contained in PART II, Chapter 8

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium bicarbonate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Sodium, alkalinity, carbonate and carbon dioxide are the only significant residues that are expected to occur from sodium bicarbonate, but none of these is likely to become a problem at normal doses.

STATUS

Sodium bicarbonate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

JECFA (Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Joint Expert Committee on Food Additives). *Compendium of Food Additive Specifications*. FAO Food and Nutrition Papers 52 (two volumes). Available at <www.fao.org/es/esn/jecfa/database/cover.htm>

Singer PC and Reckhow DA (1999). Chemical oxidation. In: *Water Quality and Treatment, A Handbook of Community Water Supplies*, Letterman RD (ed), American Water Works Association, 5th edition. McGraw-Hill Professional, New York, 12.1–12.51.

Sodium carbonate

Drinking water treatment chemical

Sodium carbonate is used to correct pH, control corrosion, soften water for coagulation and prevent post-precipitation.

GENERAL DESCRIPTION

Sodium carbonate, Na_2CO_3 (also known as soda ash), is a hygroscopic, greyish-white powder. It is supplied in the form of crystalline granules containing more than 99% sodium carbonate. It is soluble in water (to 250 g/L) and noncombustible. The chemical is available in different grades. Dense soda ash (specific gravity 2.15, bulk density 1000 kg/m^3) is most commonly employed in the water industry, but light soda ash (specific gravity 2.53, bulk density 500 kg/m^3) may also be used. Liquid soda ash is also available as a solution of various concentrations. Liquid soda ash is typically supplied as a 10 % w/v solution that has a specific gravity of 1.1(25°C) and a pH of up to 12.5. A 1% solution has a pH of 11.3.

Appropriate materials for handling sodium carbonate include rubber linings, iron, steel, fibreglass reinforced plastic and polyethylene.

CHEMISTRY

Sodium carbonate is found in natural deposits and is mined. It is also recovered, with other chemicals, from lake brines. However, most is produced through the Solvay process, in which ammonia and carbon dioxide are passed into a saturated sodium chloride solution, forming first ammonium hydrogen carbonate, then soluble ammonium chloride and a precipitate of sodium hydrogen carbonate (sodium bicarbonate). The precipitate is filtered off and heated to produce sodium carbonate.

Sodium carbonate produces hydroxide and bicarbonate ions in water:

$$Na_2CO_3 + H_2O \Leftrightarrow 2Na^+ + HCO_3^- + OH^-$$

Sodium carbonate is used together with lime to remove noncarbonate hardness (that portion of calcium and magnesium present as noncarbonate salts) as shown below:

$$MgSO_4 + Ca(OH)_2 \Leftrightarrow Mg(OH)_2 + CaSO_4$$
$$CaSO_4 + Na_2CO_3 \Leftrightarrow CaCO_3 + Na_2SO_4$$

The solubility of magnesium hydroxide varies with pH. A pH of 11–11.3 is usually needed to remove magnesium effectively; this will require a concentration of lime higher than the stoichiometric requirement.

The quantity of sodium carbonate needed to remove noncarbonate hardness can be estimated using the following equation:

$$Na_2(CO)_3 \text{ (mg/L)} = 1.05 \times \text{(noncarbonate hardness removed (mg/L))}$$

Noncarbonate hardness is expressed as $CaCO_3$.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, sodium carbonate is used mainly as a source of alkalinity and pH adjustment. It is more expensive than lime but is generally easier to handle, because of its higher solubility. If hard water is used for making up or diluting a solution of sodium carbonate, calcium carbonate may precipitate. This reduces the strength of the solution and can produce scale in the delivery

pipelines. In this situation, the service water supplied to the soda ash system needs to be softened.

Sodium carbonate is usually made up as a solution of up to 20% concentration. Concentrations of sodium carbonate used in drinking water treatment depend on the quality of the water to be treated and the purpose of the treatment (water softening, pH adjustment or alkalinity increase). Based on stoichiometry, 1 mg/L of sodium carbonate provides alkalinity equivalent to about 0.7 mg/L of hydrated lime. Typical sodium carbonate concentrations used can vary from 5 to more than 500 mg/L, and the appropriate concentration should be determined by laboratory trials.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in sodium carbonate (JECFA, KIWA 1994, NRC 1982):

- arsenic
- cadmium
- calcium
- chloride
- chromium
- iron
- lead
- magnesium
- mercury
- nickel
- sulfate

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium carbonate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*. Sodium residue derived from using sodium carbonate in water softening is 30–300 mg/L.

STATUS

Sodium carbonate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B201-98. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Benefield LD and Morgan JM (1999) Chemical Precipitation. In: *Water Quality and Treatment, A Handbook of Community Water Supplies*, Letterman RD (ed), American Water Works Association, 5th edition. McGraw-Hill Professional, 10.1–10.60.

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater,* 20th edition. American Public Health Association, Washington, DC.

JECFA (Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Joint Expert Committee on Food Additives). *Compendium of Food Additive Specifications.* FAO Food and Nutrition Papers 52 (two volumes). Available at <www.fao.org/es/esn/jecfa/database/cover.htm>

KIWA (1994) *Guideline quality of materials and chemicals for drinking water supplies.* Inspectorate

of Public Health and Environmental Planning, Publication 94-01. Rijswijk, The Netherlands.

Lewis RJ (1993). *Hawley's Condensed Chemical Dictionary,* 12th edition. Van Nostrand Reinhold, New York.

NRC (National Research Council) (1982). *Water Chemicals Codex*. Committee on Water Treatment Chemicals, Food and Nutrition Board, Assembly of Life Sciences, NRC, Washington, DC.

Sodium fluoride

Drinking water treatment chemical

Sodium fluoride is used to artificially fluoridate water, to reduce the occurrence of dental caries. Use of sodium fluoride is more common in small fluoridation facilities.

GENERAL DESCRIPTION

Sodium fluoride, NaF, is a white, odourless powder (or crystals), supplied in 25 kg bags. It is easily soluble in water, and the solubility varies little with temperature. It has a specific gravity of 2.78 at 20°C. The typical commercial grade of sodium fluoride is 97% purity, with about 44% fluorine. It has a bulk density of 1040–1440 kg/m^3. The pH of a 1% solution is 6.5; that of a 4% solution is 7.6. Suitable materials for handling sodium fluoride include iron, steel, fibreglass-reinforced plastic and polyethylene.

CHEMISTRY

Sodium fluoride is produced by neutralising hydrofluoric acid with either sodium carbonate or sodium hydroxide.

The dissolution of sodium fluoride in water forms fluoride ions (F^-) and sodium ions (Na^+) as follows:

$$NaF \Leftrightarrow Na^+ + F^-$$

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Sodium fluoride is used to artificially fluoridate water, to reduce the occurrence of dental caries. In each State and Territory, except for South Australia, the fluoridation of drinking water is regulated by an Act of Parliament; New South Wales and Queensland also have regulations in force.

Sodium fluoride can be used in solution feed systems at a strength of 1–2%, or in a saturator system where water is passed through a bed of sodium fluoride crystals, thus producing a saturated solution. The water used for dissolving sodium fluoride should not have a hardness greater than 75 mg/L (as calcium carbonate, $CaCO_3$), because the presence of calcium and magnesium causes the formation of insoluble fluorides which may cause clogging problems.

When using sodium fluoride, it is good practice to add the chemical after drinking water has been treated, because fluoride ions may be adsorbed onto the surfaces of suspended matter in water.

The target levels of fluoride in fluoridated water in Australia vary between 0.7 and 1.0 mg/L. The lower concentrations apply in warmer climates, where more water is consumed.

For sodium fluoride of 97% strength (44% F^-), this range translates to a dose of sodium fluoride of 1.6–2.3 mg/L.

CONTAMINANTS

Sodium fluoride can contain traces of free acid or alkali, and also:

- arsenic
- lead
- silicate
- sulfate

NOTE: Important general information is contained in PART II, Chapter 8

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium fluoride should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Fluoride forms precipitates with many metals and other elements, but is notably insoluble with calcium; thus, scaling can occur when concentrated lime solution and concentrated fluoride solution come into contact. Locations for adding concentrated lime and fluoride solutions should be separated, to avoid this situation.

STATUS

Sodium fluoride was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B701-99. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Department of Health, South Africa (2003). *Water fluoridation, A manual for water plant operators*. Available at <www.doh.gov.za/docs/misc/fluoridation/>

NSW Health (1957). Code of Practice for the fluoridation of public water supplies. *NSW Fluoridation of Water Supplies Act 1957*, NSW Government Gazette No. 135.

Sodium fluorosilicate

Drinking water treatment chemical

Sodium fluorosilicate, Na_2SiF_6 is used to artificially fluoridate water, to reduce the occurrence of dental caries.

GENERAL DESCRIPTION

Sodium fluorosilicate (Na_2SiF_6, also known as sodium silicofluoride, sodium hexafluorosilicate and disodium hexafluorosilicate) is a white or yellowish white, odourless, crystalline powder with a specific gravity of 2.7. Sodium fluorosilicate has very low solubility in water. The chemical is usually supplied at 98.5% purity (59.5% F^-) in 25 kg bags. It has a bulk density of 880–1150 kg/m^3. Suitable handling material includes cast iron, rubber linings, steel and stainless steel, fibreglass-reinforced plastic, polyethylene and polyvinyl chloride.

CHEMISTRY

Sodium fluorosilicate is produced by neutralising hydrofluorosilicic acid with sodium carbonate or sodium hydroxide, and then evaporating the solution.

The dissolution of sodium fluorosilicate in water forms the fluoride ion (F^-), as follows:

$$Na_2SiF_6 \Leftrightarrow 2Na^+ + SiF_6^{2-}$$

$$SiF_6^{2-} \Leftrightarrow SiF_4 + 2F^-$$

$$SiF_4 + 2H_2O \Leftrightarrow SiO_2 + 4F^- + 4H^+$$

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

Sodium fluorosilicate is used to fluoridate drinking water, to reduce the occurrence of dental caries. In each State and Territory, except for South Australia, the fluoridation of drinking water is regulated by an Act of Parliament; New South Wales and Queensland also have regulations in force.

It is good practice to add sodium fluorosilicate after drinking water has been treated, because fluoride ions may be adsorbed onto the surfaces of suspended matter in water. In water that has been treated and disinfected, sodium fluorosilicate is usually added at a concentration of 0.2%. A good mixing system is required because sodium fluorosilicate has low solubility in water.

The targeted levels of fluoride in fluoridated water in Australia vary between 0.7 and 1.0 mg/L. The lower concentrations apply in warmer climates, where more water is consumed. For sodium fluorosilicate of 98.5% strength (59.5% F^-), this range translates to a dose of sodium fluorosilicate of 1.2–1.7 mg/L.

CONTAMINANTS

Sodium fluorosilicate may contain traces of free acid and moisture, and also:

- arsenic
- cadmium
- iron
- phosphorus

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium fluorosilicate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

NOTE: Important general information is contained in PART II, Chapter 8

Fluoride forms precipitates with many metals and other elements, but is notably insoluble with calcium; thus, scaling can occur when concentrated lime solution and concentrated fluoride solution come into contact. Points for adding concentrated lime and fluoride solutions should be separated, to avoid this situation.

STATUS

Sodium fluorosilicate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B702-99. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

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Sodium hexametaphosphate

Drinking water treatment chemical

Sodium hexametaphosphate can be used for control of corrosion, prevention of scale formation, and sequestration of unwanted precipitants.

GENERAL DESCRIPTION

Sodium hexametaphosphate, $Na(PO_3)_6$ (also known as SHMP, glassy phosphate or vitreous phosphate) is a white granular powder with a bulk density of 800–1500 kg/m^3. It is highly soluble in water.

Sodium hexametaphosphate can be stored in rubber-lined containers, or in plastics, fibreglass-reinforced plastic, or stainless steel (type 316).

CHEMISTRY

Sodium hexametaphosphate is produced by treating soda ash or caustic soda with phosphoric acid.

Polyphosphates keep metal ions in solution for a period of time, thus preventing deposition.

With time, sodium hexametaphosphate naturally reverts to orthophosphate, and thus loses its sequestering capability. This reversion can be accelerated by low pH, high temperature and the presence of oxides of certain materials (e.g. iron, calcium, copper and zinc). The reversion can occur in hot water systems or in reverse osmosis (RO) membranes, where it can cause fouling.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In water treatment plants, a thin layer of sodium hexametaphosphate formed on metal surfaces is used to control corrosion. The chemical is also used as a sequestering agent, to prevent unwanted precipitates or scales (e.g. iron, manganese, calcium or magnesium) from depositing.

Control of ferrous iron through sequestering is only effective up to concentrations of 3 mg/L ferrous iron. In water treatment, the amount of sodium hexametaphosphate should be controlled to ensure that concentrations do not exceed levels that would complex manganese or iron by more than 10%. Control of calcium carbonate ($CaCO_3$) scale rarely requires more than 1 mg/L of polyphosphate.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product (JECFA):

- arsenic
- fluoride
- iron
- lead

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium hexametaphosphate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Sodium and orthophosphate residues are present in finished water. Sodium hexametaphosphate naturally reverts to orthophosphate over time. Residual orthophosphate encourages biological growth.

The use of sodium hexametaphosphate in the water supply adds to the phosphorous load at the sewage treatment plant. Its use should therefore be considered in consultation with the manager of the sewage treatment plant.

NOTE: Important general information is contained in PART II, Chapter 8

STATUS

Sodium hexametaphosphate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B502-01. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Gosselin RE, Smith RP and Hodge HC (1984). *Clinical Toxicology of Commercial Products*, 5th edition. Williams and Wilkins, Baltimore, II-121.

JECFA (Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Joint Expert Committee on Food Additives). *Compendium of Food Additive Specifications*. FAO Food and Nutrition Papers 52 (two volumes). Available at <www.fao.org/es/esn/jecfa/database/cover.htm>

Lewis RJ (1993). *Hawley's Condensed Chemical Dictionary*, 12th edition. Van Nostrand Reinhold, New York.

NRC (National Research Council) (1981). *Drinking Water & Health*, Volume 4. National Academy Press, Washington, DC.

Sodium hydroxide

Drinking water treatment chemical

Sodium hydroxide is a commonly used alkali suitable for pH adjustment, water softening and corrosion control. It requires only a simple dosing system but needs care in handling.

GENERAL DESCRIPTION

Sodium hydroxide, NaOH (also known as caustic soda), is a white, deliquescent solid. It absorbs water and carbon dioxide from the air. The chemical is supplied as flake or pearl solids, or liquid (usually 30% or 46–50%). It has a specific gravity of 1.33 (at 30%) and 1.48 (at 46%). Liquid solutions of sodium hydroxide can freeze in cold climates, depending on concentration. Climate considerations are relevant for any caustic soda concentrations above 30%, because such solutions can freeze at temperatures above 0˚C.

Appropriate handling materials for sodium hydroxide include rubber linings and steel, stainless steel, polyvinyl chloride, polypropylene, fibreglass-reinforced plastic.

CHEMISTRY

Sodium hydroxide is commonly produced by the electrolytic dissociation of sodium chloride, with chlorine gas as a byproduct.

For pH and alkalinity adjustment, caustic soda simply produces hydroxide ions in water:

$$NaOH \Leftrightarrow Na^{+} + OH^{-}$$

The chemical reactions of sodium hydroxide–soda softening are as follows:

$$CO_2 + 2NaOH \Leftrightarrow Na_2CO_3 + H_2O \quad (1)$$

$$Ca(HCO_3)_2 + 2NaOH \Leftrightarrow CaCO_3 + Na_2CO_3 + 2H_2O \quad (2)$$

$$Mg(HCO_3)_2 + 4NaOH \Leftrightarrow Mg(OH)_2 + 2Na_2CO_3 + 2H_2O \quad (3)$$

$$MgSO_4 + 2NaOH \Leftrightarrow Mg(OH)_2 + Na_2SO_4 \quad (4)$$

$$CaSO_4 + Na_2CO_3 \Leftrightarrow CaCO_3 + Na_2SO_4 \quad (5)$$

Sodium carbonate produced from equation (1) precipitates calcium noncarbonate hardness, as shown in equation (5). Sodium hydroxide can be used in combination with lime, depending on the amount of calcium noncarbonate to be removed.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, sodium hydroxide is often used instead of powdered alkalis such as lime or soda ash, because the systems for adding sodium hydroxide are less complicated and require less maintenance. The chemical can also be used in place of lime to soften water by removing carbonate and noncarbonate hardness. Sodium hydroxide can also partially or fully substitute for the soda ash requirement.

Sodium hydroxide is used to raise pH and to convert excess carbon dioxide to alkaline species. Typical concentrations used are 2–100 mg/L (as caustic soda), but higher concentrations may be required with waters of poor quality.

Sodium hydroxide imparts a change of 1.55 mg/L calcium carbonate ($CaCO_3$) alkalinity per mg/L as NaOH. Control of pH is difficult when sodium hydroxide is added to poorly buffered water.

NOTE: Important general information is contained in PART II, Chapter 8

For concentrations up to about 30%, caustic soda freezes at below 0°C. At 40% concentration, caustic soda will freeze at 15°C, dropping back to around 5°C at 46%. Concentrations above 50% freeze at 12°C or higher. In cold climates it may be necessary to dilute caustic solutions or heat caustic storage and delivery facilities. Softened water should be used for dilution to minimise scaling.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product (JECFA, KIWA 1994, NRC 1982):

- arsenic
- iron
- cadmium
- lead
- chloride
- mercury
- chromium
- nickel

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium hydroxide should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

The amount of sodium added to water when sodium hydroxide is used to adjust pH is generally insignificant.

STATUS

Sodium hydroxide was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B501-98. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Benefield LD and Morgan JM (1999). Chemical Precipitation. In: *Water Quality and Treatment, A Handbook of Community Water Supplies*, Letterman RD (ed), American Water Works Association, 5th edtion. McGraw-Hill Professional, New York, 10.1–10.60.

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

JECFA (Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Joint Expert Committee on Food Additives). *Compendium of Food Additive Specifications*. FAO Food and Nutrition Papers 52 (two volumes). Available at <www.fao.org/es/esn/jecfa/database/cover.htm>

KIWA (1994) *Guideline quality of materials and chemicals for drinking water supplies*. Inspectorate of Public Health and Environmental Planning, Publication 94-01. Rijswijk, The Netherlands.

Lewis RJ (1993). *Hawley's Condensed Chemical Dictionary*, 12th edition. Van Nostrand Reinhold, New York.

NRC (National Research Council) (1982). Water Chemicals Codex. Committee on Water Treatment Chemicals, Food and Nutrition Board, Assembly of Life Sciences, NRC, Washington, DC.

Sodium hypochlorite

Drinking water treatment chemical

Sodium hypochlorite is used as a disinfectant and oxidant in the treatment of drinking water. It provides available chlorine in a liquid form, with less risk than storing and handling chlorine gas.

GENERAL DESCRIPTION

Sodium hypochlorite, NaOCl, or liquid bleach, is a strong oxidising agent that is usually stored and used in solution. It has a disagreeable, sweetish odour and a pale greenish colour. Sodium hypochlorite solution releases vapours that cause corrosion in the presence of moisture.

Sodium hypochlorite is usually supplied as 10–13% w/v available chlorine. More concentrated solutions are not practical because of the instability of sodium hypochlorite, which forms chlorate and chlorite (both of which are of potential concern to health) as solution strength increases. Other factors that affect the stability of sodium hypochlorite are temperature, period of storage, impurities and exposure to light. The oxidising capability of 1 L of sodium hypochlorite (12.5% strength) is equivalent to the oxidising capability of 125 g of chlorine gas. Sodium hypochlorite is generated by combining chlorine and sodium hydroxide.

Suitable materials for storing and handling sodium hypochlorite include ceramics, glass, fibreglass-reinforced plastic, polyethylene and polyvinyl chloride, and rubber or plastic linings.

CHEMISTRY

Sodium hypochlorite is generated by combining chlorine and sodium hydroxide.

Sodium hypochlorite hydrolyses in water forming hypochlorous acid (HOCl), which partially dissociates to hypochlorite ion (OCl^-):

$$NaOCl \rightarrow Na^+ + 2\ OCl^-$$

$$OCl^- + H_2O \Leftrightarrow HOCl + OH^-$$

The relative distribution of hypochlorous acid and hypochlorite ion resulting from these reactions depends on pH and temperature. At 25°C, hypochlorous acid is the predominant species between pH 1 and pH 7.5, and hypochlorite ion predominates at pH values greater than 7.5. Oxidation reactions and the disinfecting properties of chlorine tend to be more effective at low pH values, because of the predominance of hypochlorous acid, which is a stronger oxidant.

Sodium hypochlorite is a base, which will raise the pH of water, whereas chlorine gas produces an acidic reaction that lowers the pH of the solution. The extent of the pH change will depend on the alkalinity of the water.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, sodium hypochlorite is used as a disinfectant. Sodium hypochlorite solution is more expensive than chlorine, but its use is becoming more widespread, because of concerns about the safe transport and handling of hazardous gaseous chlorine in pressurised tanks.

Sodium hypochlorite can be added at various points of the treatment process:

- for oxidation of organics or metals
- for disinfection purposes
- to maintain a chlorine residual in the distribution system (pre-coagulation, intermediate or post-filtration chlorination).

NOTE: Important general information is contained in PART II, Chapter 8

Concentrations can range from 1 to 5 mg/L (as available chlorine), although 2–3 mg/L is typical. The selection of the appropriate chlorine dose should take into account the amount of disinfection byproducts formed, and the required Ct (concentration × contact time) and chlorine residual; the World Health Organization (WHO) recommends 0.5 mg/L for 30 minutes. A free chlorine residual of more than 0.2 mg/L throughout the distribution system is preferred. In some systems, rechlorination is employed within the distribution system, with chlorine added after water has left the treatment plant, to boost chlorine residuals.

Superchlorination (10–50 mg/L as available chlorine) may be used to disinfect or clean tanks or pipelines. It can also be used to temporarily treat taste and odour issues caused by high ammonia levels. The process is usually followed by dechlorination, to chemically remove excess chlorine.

Knowledge of the breakpoint phenomenon (whereby chlorine applied in sufficient doses will oxidise ammonia and eliminate chloramines, resulting in the formation of a free chlorine residual) is necessary when dealing with water containing ammonia.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in sodium hypochlorite:

- chlorate
- iron
- manganese
- mercury
- nickel

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium hypochlorite should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

The use of a disinfectant such as chlorine results in the formation of free chlorine and combined chlorine residuals and disinfection byproducts. Byproducts include trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs), haloketones, chloral hydrate and chloropicrine. Although many specific chlorine disinfection byproducts have been identified, a significant percentage of the total organic halogens have yet to be identified.

Many factors affect the distribution of disinfection byproduct species, including pH, temperature and levels of total organic carbon (TOC), bromide and chlorine. The THMs (chloroform, bromodichloromethane, dibromochloromethane, bromoform) are the best known chlorination byproducts,. Chlorinated THM, HAA and HAN species are generally present in higher concentrations |than brominated species; however, brominated species predominate in high-bromide waters.

STATUS

Sodium hypochlorite was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B300-99. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Connell GF (1996). *The Chlorination/Chloramination Handbook*. Water Disinfection Series, American Water Works Association. Denver, Colorado.

White GC (1992). *Handbook of chlorination and alternative disinfectants*, 3rd edition. Van Nostrand Reinhold, New York.

NOTE: Important general information is contained in PART II, Chapter 8

Sodium silicate

Drinking water treatment chemical

Sodium silicate, in the form of 'activated silica,' is used as a coagulant or a flocculation aid in the treatment of drinking water, in conjunction with a primary coagulant (e.g. alum). Soluble silicates (waterglass) can also be used to inhibit corrosion or sequester metals, and sodium silicate solution can be used to adjust pH in small water systems.

GENERAL DESCRIPTION

Sodium silicate, $Na_2O{\cdot}xSiO_2$, can be in the form of lumps of greenish glass (soluble in steam), white powders of varying degrees of solubility, or as cloudy or clear solutions of varying viscosity.

Soluble silicates can be differentiated by their ratio of silica to sodium oxide (SiO_2:Na_2O). This ratio, which ranges from 1.6 to 3.3 by weight, determines the physical and chemical properties of the product. Liquid silicates with a ratio of 1.6 have a pH of 13.2; whereas, at a ratio of 3.3 the pH is 11.0. The specific gravity of these solutions ranges between 1.4 and 1.6. The colloidal and polymeric properties of liquid silicates increase as the SiO_2:Na_2O ratio increases.

Appropriate materials for handling sodium silicate include cast iron, steel, fibreglass-reinforced plastic and polyethylene, and rubber linings.

CHEMISTRY

Sodium silicate is produced by fusing high purity silica sand with sodium carbonate or potassium carbonate at 1000–1500°C. This results in an amorphous glass, which can be dissolved in water to form silicate solutions or 'waterglass'.

In solution, silica is present in equilibrium between monomeric anionic species. The proportion of silica and alkali in a sodium silicate is usually expressed as the weight ratio of SiO_2 to Na_2O.

In drinking water treatment, solutions of activated or colloidal silica can be used for coagulation. Such solutions can be generated on site by partial or complete neutralisation of a dilute solution of sodium silicate by a mineral acid, an acid salt or chlorine. The activated silica solution obtained can be slightly alkaline or neutral, and is aged for a short time (1–2 hours) before use. The solution is then further diluted with 2–2.5 volumes of water. The activated silica solution has a shelf life of 1–2 days.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

At one time, activated silica was commonly used as a coagulant aid (after a primary coagulant such as alum or ferric chloride), because it forms heavy, tough flocs that settle fast. However, polyacrylamide polymers have now largely replaced activated silica in most water treatment plants.

Soluble silicates are also used to protect metals from the corrosive effects of water by depositing a thin molecular film of silica (SiO_2) on metal surfaces. Silicate treatment is effective for corrosion control of concrete and a variety of metals: lead, copper, cast iron, ferrous metals, steel, galvanised steel, bronze, red and yellow brass, and nickel alloys. The pH and alkalinity of the water determine which silicate is suitable for this application.

Sodium silicate can also be used to sequester iron and manganese. Following metal oxidation, sodium silicate is added to hold oxidised metals in a colloidal suspension.

Concentrations of activated silica used in drinking water treatment can range from 1 to10 mg/L (as SiO_2), and the concentration required varies with water quality, depending on factors such as pH, turbidity, colour, temperature and contaminant level.

NOTE: Important general information is contained in PART II, Chapter 8

The effectiveness of sodium silicate as a corrosion inhibitor depends on water quantities such as pH and bicarbonate concentration. The chemical is more effective under high-velocity flow conditions. Silicate is effective at high pH, and at a dosage over 15–20 mg/L (as SiO_2).

Silicate with a high ratio of Na_2O to SiO_2 will raise pH in weakly buffered waters. For corrosion control, relatively high concentrations (up to 24 mg/L) are required during the first 30–60 days of treatment, to form the initial protective coating. Thereafter, the silicate dosage is reduced incrementally in 30-day periods, until it reaches maintenance doses (4–8 mg/L).

As a metal sequestrant, sodium silicate (as SiO_2) should be added at up to 4–5 times the level of iron or manganese in the water.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. More than 20 elements are present as trace impurities in sodium silicate, including:

- aluminium
- cadmium
- calcium
- chloride
- iron
- magnesium
- manganese
- sulfate

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

Sodium and silicate residues are present in finished water. When employed in drinking water treatment, sodium silicate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

STATUS

Sodium silicate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B404-98. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

Sodium tripolyphosphate

Drinking water treatment chemical

Sodium tripolyphosphate is used in drinking water treatment to control corrosion and soften water; it is also used as a sequestering and descaling agent, and to stabilise or disperse calcium and iron in the water distribution system.

GENERAL DESCRIPTION

Sodium tripolyphosphate, $Na_5P_3O_{10}$, is a white powder or granular solid, and is odourless. A 1% aqueous solution of sodium tripolyphosphate has a pH of 9.8; the pH of a concentrated solution (slurry) is about 10.5.

Appropriate handling materials for sodium tripolyphosphate include cast iron, steel, fibreglass-reinforced plastic, polyethylene and polyvinyl chloride; rubber-lined containers can also be used.

CHEMISTRY

Sodium tripolyphosphate is manufactured by combining soda ash or caustic soda with phosphoric acid. The product is then heated to form crystalline solids.

Low concentrations of polyphosphate inhibit the precipitation of calcium salts, and therefore inhibit scale formation. If phosphate concentrations are increased, then calcium phosphate precipitates. A further increase in concentration results in the sequestration phenomenon, whereby calcium is sequestered, inhibiting scale formation. Sequestering is affected by pH, with a neutral to alkaline pH being more effective.

Sodium tripolyphosphate can be used as a corrosion inhibitor in combination with divalent cations such as calcium (Ca^{2+}). Positively charged colloidal complexes form, migrate to the cathode and create an amorphous polymeric film. This inhibition is most effective at a pH of 6.5–7.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

The chemical is used in drinking water treatment to control corrosion and soften water; it is also used as a sequestering and descaling agent, and to stabilise or disperse calcium and iron in the water distribution system.

Polyphosphates can change the characteristics of corrosion, making it more uniform rather than a pitting type of corrosion. Polyphosphates have also been used to control oxidation of ferrous iron dissolved from pipes, and to reduce the formation of 'red water' (caused by contamination with hydrated iron oxide). When mixed with orthophosphate, polyphosphates may assist in the formation of an orthophosphate film, by complexing calcium or manganese in hard waters that might otherwise cause unwanted orthophosphate precipitates.

Typical doses for protection against scale, corrosion and prevention of 'red water' range from 0.5 to 20 mg/L, although doses of up to 50 mg/L may be used during mains cleaning.

For corrosion control in a cast-iron distribution system, an initial feed of 5–10 mg/L may be applied for several weeks, followed by a maintenance dosage of 1–2 mg/L; or a continuous dosage of 1–5 mg/L may be used.

For sequestration applications, a ratio of 3.4–5 parts sodium tripolyphosphate per water hardness (as $CaCO_3$) is recommended by manufacturers.

Control of post-precipitation in softened water typically requires a dosage of 0.5–2 mg/L.

Laboratory or pilot trials should be undertaken to determine the appropriate doses.

NOTE: Important general information is contained in PART II, Chapter 8

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product (JECFA):

- arsenic
- fluoride
- iron
- lead
- phosphates

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sodium tripolyphosphate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

Sodium and orthophosphates are present in finished water and can cause problems. For example, phosphates increase biological activity in the distribution system, and polyphosphates both reduce the deposition of protective calcium-containing films and increase the solubility of metals, interfering with the formation of passivating films. Polyphosphates also soften asbestos-cement pipe by accelerating the depletion of calcium and inhibiting the formation of fibre-binding iron or manganese deposits. Similar effects can occur in cement-lined or concrete pipes.

The use of sodium tripolyphosphate in the water supply adds to the phosphorous load at the sewage treatment plant. Its use should therefore be considered in consultation with the manager of the plant.

STATUS

Sodium tripolyphosphate was endorsed by the NHMRC for use as a drinking water treatment chemical in 2005.

REFERENCES

ANSI (American National Standards Institute) / AWWA (American Water and Wastewater Association) Standard no B503-01. AWWA CD-ROM (April 2003). Available at <www.awwa.org>

Clesceri LS, Greenberg AE and Eaton AD (eds) (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th edition. American Public Health Association, Washington, DC.

JECFA (Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Joint Expert Committee on Food Additives). *Compendium of Food Additive Specifications*. FAO Food and Nutrition Papers 52 (two volumes). Available at <www.fao.org/es/esn/jecfa/database/cover.htm>

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Sulfuric acid

Drinking water treatment chemical

Sulfuric acid is used to correct pH in coagulation, water softening, corrosion control, prevention of post-precipitation and activation of silica.

GENERAL DESCRIPTION

Sulfuric acid (H_2SO_4) is a strongly corrosive, dense, oily liquid. It is colourless to dark brown, depending on purity, and is miscible with water. Sulfuric acid is generally available in concentrations of 28.5–98.5%, with corresponding specific gravity of 1.2–1.85 at 20°C. The acid is very reactive and dissolves most metals; the concentrated acid oxidises, dehydrates or sulfonates most organic compounds, often causing charring.

Sulfuric acid is highly corrosive to most metals and alloys, and is corrosive to mild steel at concentrations below 90%. It can be stored in fibreglass-reinforced plastic with acid resistant resins, polyethylene, porcelain, glass and rubber linings.

CHEMISTRY

Sulfuric acid is usually produced using the Contact process: sulphur dioxide is catalytically converted to sulphur trioxide, which is then dissolved in sulfuric acid and water.

Sulfuric acid disassociates in water to produce a strong acid:

$$H_2SO_4 \Leftrightarrow 2H^+ + SO_4^{2-}$$

Sulfuric acid is added to lime–soda softened waters to prevent post-precipitation of calcium carbonate and magnesium hydroxides in filters or in water distribution systems. These water usually have pH values of approximately 10.4, and are supersaturated with calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$). Sulfuric acid is therefore used to reduce excessive pH values and alkalinities as follows:

$$H_2SO_4 + 2CaCO_3(s) \Leftrightarrow Ca(HCO_3)_2 + CaSO_4$$

$$H_2SO_4 + Ca(OH)_2 \Leftrightarrow CaSO_4 + 2H_2O$$

Sulfuric acid is used to fortify hydrolysing metal salts (aluminium and iron). The typical acid-fortified alum product, also called acidulated alum or acid alum, contains 5–20% (weight basis) of sulfuric acid. For a given amount of metal ion added to the water, strong acid-fortified products react with more alkalinity and depress the pH to a greater extent than nonfortified metal salt solutions.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, sulfuric acid is used to correct pH in coagulation, water softening, corrosion control, prevention of post-precipitation and activation of silica.

Handling and adding concentrated sulfuric acid to water requires extreme caution, because it can cause severe burns and eye damage. Also, sulfuric acid has an exothermic reaction with water that may cause violent splattering. Careful design is required in dilution systems for sulfuric acid, because the significant heating that may occur could damage pipework.

Concentrations of sulfuric acid required vary widely, depending on the alkalinity of the water and the pH required. Low concentrations (1–30 mg/L) are usually adequate to adjust pH for coagulation; higher doses may be required for water softening.

CONTAMINANTS

NOTE: Important general information is contained in PART II, Chapter 8

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product (JECFA):

- antimony
- arsenic
- cadmium
- chloride
- chromium
- copper
- fluoride
- iron
- lead
- manganese
- mercury
- selenium
- sulfate
- sulfur dioxide
- zinc

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, sulfuric acid should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

STATUS

Sulfuric acid was endorsed by the NHMRC for use as a drinking water treatment chemical in 1983. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

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Zinc orthophosphate

Drinking water treatment chemical

Zinc orthophosphate is used to inhibit corrosion of lead, copper and iron, and to prevent the release of asbestos or cement from water pipes.

GENERAL DESCRIPTION

Zinc orthophosphate, $Zn_3(PO_4)_2$, solution is a clear odourless liquid that is soluble in water; it is available in various ratios of phosphate to zinc.

Appropriate materials for handling zinc orthophosphate include cast iron, steel, fibreglass-reinforced plastic, polyethylene and polyvinyl chloride; rubber-lined containers can also be used.

CHEMISTRY

Zinc orthophosphate is manufactured using zinc salts (chloride or sulfate) and orthophosphate.

Zinc orthophosphate limits the release of lead, copper and iron from metal surfaces by forming a microscopic protective film on these surfaces, and by electrochemical passivation. Water with a high pH (> 8.1) should not be treated with zinc orthophosphate because of zinc hydroxide precipitation. Reactions between orthophosphate and lead in water result in the formation of several solids that are less soluble than basic lead carbonate over a wide range of pH values. The most likely solid phase formed is hydroxypyromorphite ($Pb_5(PO_4)_3OH$). Tertiary lead orthophosphate ($Pb_3(PO_4)_2$) is another solid formed. The formation of lead orthophosphate films depends on the concentration of dissolved inorganic carbon (DIC; e.g. carbonates), acidity, temperature and orthophosphate content. These phosphate films may not form as rapidly as the basic lead carbonate solids. Carbonate competes with orthophosphate for control of lead solubility. Hence, lead orthophosphate films can be formed in water with low levels of carbonate or DIC (these two characteristics are often found together), in which case the effectiveness of a phosphate control program may need to be evaluated over a longer time.

TYPICAL USE IN AUSTRALIAN DRINKING WATER TREATMENT

In drinking water treatment, zinc orthophosphate is used to inhibit corrosion. It is particularly effective at inhibiting lead corrosion, because it reduces lead solubility in waters with both low and high alkalinity. The chemical is used to treat waters that are soft and corrosive. Zinc orthophosphate suppresses corrosion of carbon steel, and the release of asbestos fibres from asbestos–cement (A–C) pipe. It also inhibits corrosion of cast iron, and mildly inhibits corrosion of copper.

A few milligrams per litre of orthophosphate are sufficient at pH values in the 7–9 range.

CONTAMINANTS

The purity of chemicals used in Australia for the treatment of drinking water varies, depending on the manufacturing process. The following chemical contaminants may be present in this product:

- chloride
- sulfate

RESIDUAL AND BYPRODUCT FORMATION IN DRINKING WATER

When employed in drinking water treatment, zinc orthophosphate should be used in such a way that any contaminant or byproduct formed by the use of the chemical does not exceed guideline values in the *Australian Drinking Water Guidelines*.

NOTE: Important general information is contained in PART II, Chapter 8

STATUS

Zinc orthophosphate was endorsed by the NHMRC for use as a drinking water treatment chemical in 1987. The revision undertaken in 2003 did not change the status of this chemical for the treatment of drinking water.

REFERENCES

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Appendix

Appendix: Additional guidance on elements 2 and 3 of the Framework for management of drinking water quality

This appendix provides additional guidance on *Assessment of the drinking water supply system* (element 2) and *Preventive measures for drinking water quality management* (element 3) of the Framework for management of drinking water quality (the Framework). This appendix should be read in conjunction with Chapter 3, which provides a more comprehensive overview of these elements.

Users are also encouraged to draw on the numerous sources providing detailed technical guidance, a number of which have been listed in Section A9.

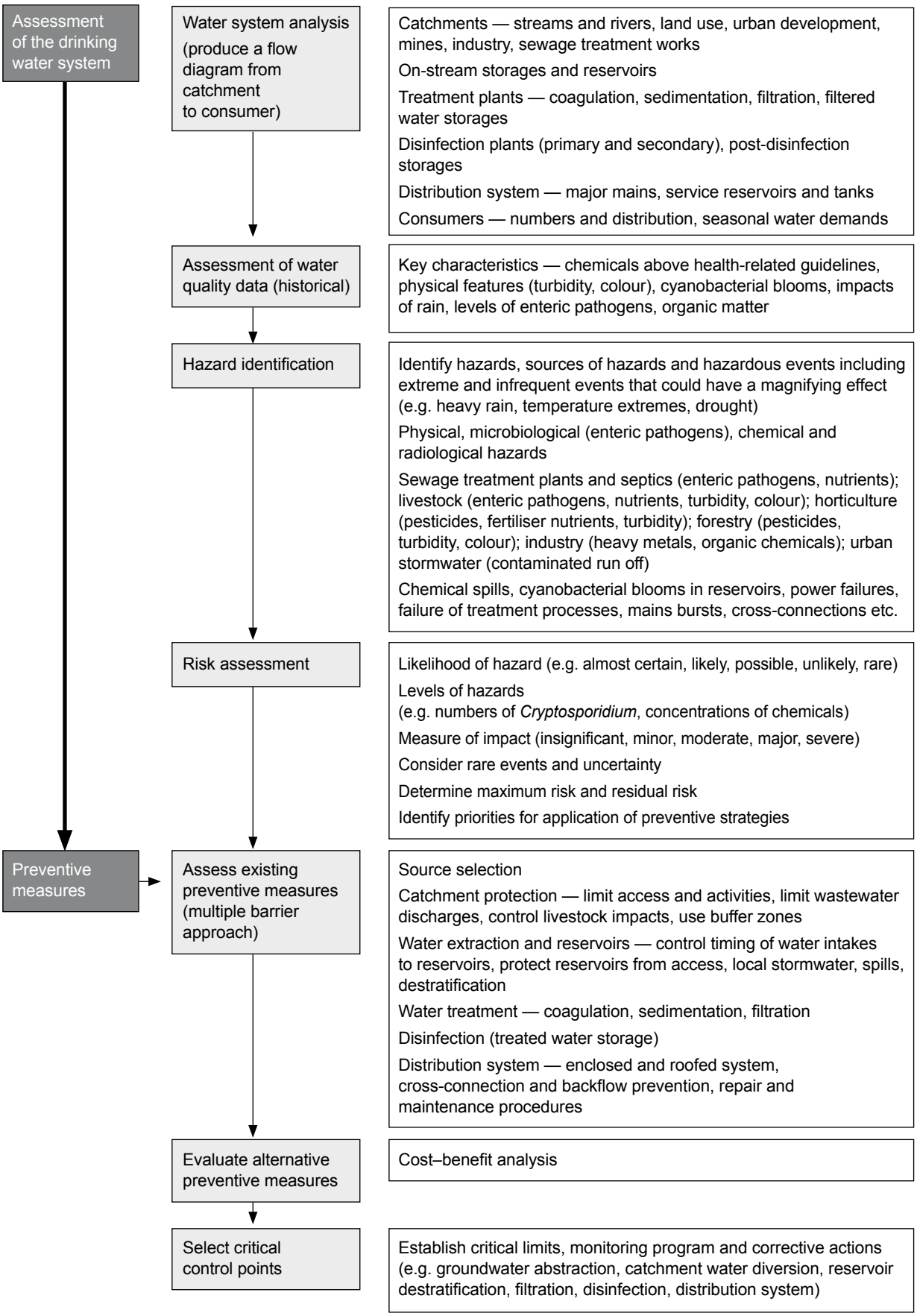
A1 Introduction

Effective management of drinking water quality requires appropriate attention to system analysis and system management. The objectives are to increase understanding of:

- the entire water supply system from catchment to consumer
- the hazards, sources and events that can compromise drinking water quality
- the preventive measures needed to effectively control hazards, including the application of multiple barriers and the establishment of critical control points to reduce exposure to hazards.

Figure A1 provides a suggested roadmap to assist in the application of these aspects of the Framework. Further guidance on implementing these aspects is offered in the following text.

Figure A1 *Application of Framework elements 2 and 3*



A2 Water supply system analysis

Assessment of the drinking water system provides an important information base and is a prerequisite for subsequent steps in which strategies for prevention and control of hazards are planned and implemented. The purpose of this element is to develop a broad overview and basic understanding of the water supply system. It is not intended to be an extensive data collection exercise; rather, it is the characterisation of the system at an appropriate level of detail to provide a useful information base from which to make effective decisions.

Summary of actions

- Assemble a team with appropriate knowledge and expertise.
- Construct a flow diagram of the water supply system from catchment to consumer.
- Assemble pertinent information and document key characteristics of the water supply system to be considered (see Table A1).
- Periodically review the water supply system analysis.

Characterisation of the water supply system should be fully documented and should be a collaborative effort between relevant agencies. Characterisations will be specific for each system but should include, where appropriate, consideration of the catchment area, source water, groundwater system, reservoirs and raw water transport, treatment systems, distribution system and consumers.

Table A1 provides examples of some key characteristics to be considered in assessing drinking water supply systems from catchment to consumer. Seasonal characteristics, as well as extreme and infrequent events such as droughts or floods, should also be considered.

Much of the necessary information may be available in existing documentation from studies carried out previously or from external agencies. Sources of useful information can include:

- land use surveys and catchment maps
- s anitary surveys
- surveys of major streams and rivers
- research and investigative monitoring
- inspections and field audits
- employee knowledge
- records from local authorities (e.g. locations of septic tanks, animal feedlots, sewage treatment plants)
- community surveys
- public and consumer complaints.

Geographic information systems (GIS) can provide a useful means of displaying, cataloguing and interpreting data.

Table A1 *Key characteristics of the drinking water supply system*

Catchments

- Geology and soils
- Topography and drainage patterns (hydrology)
- Streams and rivers
- Meteorology and weather patterns (climatic and seasonal variations)
- Riparian conditions
- Vegetative cover
- General catchment and river health
- Wildlife (e.g. native and feral animals)
- Historical contaminated sites
- Competing water uses
- Land irrigation practices
- Nature and intensity of development and land-use activities:
  - agricultural, dairy and animal husbandry
  - land clearing
  - forestry
  - mining
  - industrial
  - rural and urban development / residential
  - sewage treatment works and septic tanks
  - recreational activity
- Intermittent or seasonal use practices
- Future planning activities
- Development and planning restrictions

Source water

- Surface water (river, reservoir, dam)
- Groundwater
- Flow and reliability of source water
- Seasonal and event changes (including infrequent events such as droughts or floods)
- Spatial variations
- General and unique constituents (physical, chemical, microbial):
  - major ions and pH
  - salinity, hardness
  - turbidity
  - bacteria, viruses and protozoa
  - naturally occurring organics
  - volatile and nonvolatile synthetic organics
  - metals and radionuclides

Groundwater systems

- Geology, homogeneity
- Confined or unconfined aquifer
- Depth to water table
- Flow rate and direction
- Dilution characteristics
- Recharge area
- Well-head protection
- Depth of casing

Storage reservoirs and intakes

- Detention times
- Reservoir design:
  - size
  - materials
  - storage capacity
  - depth of storage
- Seasonal variations:
  - stratification
  - algal blooms
- Treatment efficiencies (microbial removal)
- Protection (e.g. covers, enclosures, access)
- Recreational or human activity
- Intake location and operation
- Bulk transport:
  - pipeline material
  - length
  - flow rate and changes in flow rate
  - cleaning systems

Table A1 *Key characteristics of the drinking water supply system (Continued)*

Treatment Systems

- Treatment processes (including optional processes)
- Treatment configuration
- Equipment design:
  - size
  - materials
  - peak flow rates
  - process change control
  - backup systems
- Monitoring equipment and automation
- Water treatment chemicals used:
  - flocculant/coagulant
  - filtration aids
  - fluoride
  - powdered activated carbon
  - disinfectant
- Treatment efficiencies
- Disinfection log removals of pathogens
- Disinfection residual and contact period

Service reservoirs and distribution systems

- Reservoir design:
  - size
  - materials
  - storage capacity
  - depth of storage
- Detention times
- Seasonal variations:
  - stratification
- Protection (e.g. covers, enclosures, access)
- Distribution system design:
  - size
  - network
  - pipe materials
  - pipe age
- Hydraulic conditions (e.g. detention times, flows)
- Backflow protection
- Secondary disinfection practices
- Disinfectant residuals
- Disinfection byproducts

Consumers

- Consumer distribution (industry, bodies corporate, general community)
- Vulnerable groups (hospitals, nursing homes)
- Water demand and patterns of drinking water consumption (diurnal and seasonal variations)
- Internal plumbing

A3 Assessment of water quality data

A review of historical data from source waters, treatment plants and finished water supplied to consumers can assist in understanding drinking water system characteristics and the identification of hazards.

Summary of actions

- Assemble historical data from source waters, treatment plants and finished water supplied to consumers (over time and following specific events).
- Assess data using tools such as control charts and trends analysis to identify trends and potential problems.

Water quality data should be reviewed both over time and following specific events (e.g. heavy rainfall) to identify those aspects of the system that require improvement. Water quality parameters that can provide useful information include:

- turbidity or particle counts
- microbial quality
- chemical quality
- algal counts
- naturally occurring organic matter
- colour
- pH
- disinfectant residuals
- disinfection byproducts.

Tools that may be useful in assessing data include control charts and modelling methods (e.g. using temporal overlays of water quality records and climatic information). In some cases, awareness of potential problems or hazards can be difficult because events occur gradually or result from cumulative effects. Trends analysis can be a valuable tool for recognising the accumulation of gradual changes and for predicting where things may be going wrong.

A4 Hazard identification

Adoption of a risk-based approach that includes the identification of hazards from catchment to consumer and the assessment of the potential impact on drinking water quality and human health (i.e. risk) is essential to effective system management. Hazard identification and risk assessment are useful for understanding the vulnerability of a drinking water supply and planning effective risk management strategies to assure drinking water quality and safety.

The purpose of this element is to identify and document all potential hazards and the hazardous events and sources that might give rise to the presence of these hazards.

Summary of actions

- Define the approach and methodology to be used for hazard identification. Devise an evaluation team with appropriate representatives.
- Review hazardous agents in drinking water and ensure that their link to public health is understood (see Section V – Fact Sheets).
- Identify and document hazards, sources and hazardous events for each component of the water supply system (see Tables A2 and A3).
- Periodically review and update the hazard identification to incorporate any new hazards.

A structured approach is important to ensure that significant issues are not overlooked and that areas of greatest risk are identified. There is no single right way to perform these activities; however, the process should involve a structured and comprehensive evaluation of the water supply system.

For each component of the water supply system, all hazards and hazardous events and sources that might affect drinking water quality and safety (what can happen and how) should be identified and documented. Table A2 provides examples of various pollution sources and the potential hazards they produce.

All potential hazards, hazardous events and sources should be included in the assessment, regardless of whether or not they are under the direct control of the drinking water supplier. Continuous, intermittent or seasonal pollution patterns should also be considered as well as extreme and infrequent events such as droughts or floods. Table A3 provides examples of potential sources and hazardous events, from catchment to consumer, to be considered.

Table A2 *Examples of sources and potential hazards*[a]

Potential sources	Potential hazard
Septic tanks	Pathogens,[b] nitrates/nitrites
Sewage treatment plants	Pathogens, nutrients[c]
Animal husbandry	Pathogens, nutrients[c], turbidity[c], colour[c]
Horticulture	Pesticides, fertiliser nutrients[c], turbidity[c], colour[c]
Rural stormwater	Pathogens, turbidity[c], colour[c]
Forestry	Pesticides, turbidity[c], colour[c]
Industry	Heavy metals, organic chemicals including halogenated organics; specific industries can be associated with specific types of contaminants (e.g. arsenic and copper associated with wood preserving, cadmium and chromium with electroplating and chromium with leather tanning)
Mining	Acid mine wastes from pyrites tailings can release and transport metals such as aluminium, iron and manganese; other naturally occurring metals such as cadmium and copper can also be leached; arsenic can be associated with old goldfield areas
Urban stormwater	Lead and zinc from roads, turbidity[c], colour[c], petrol/oil products, microorganisms from pets (lower range of pathogens than from humans or livestock waste)
Stormwater/sewer overflows	Pathogens, nutrients[c], turbidity[c], colour[c]

a – Human and animal waste represent the largest sources of potential hazards in drinking water. Both can include high numbers of enteric pathogens and large amounts of nutrients. Due to the scale of primary production in Australia, the total amount of livestock waste would greatly exceed the amount of human waste.

b – The potential range of pathogens present will vary according to the type of waste involved. Many enteric pathogens, and in particular viruses and protozoa, infect only one species. In general, human enteric viruses are only carried and excreted by humans. Human infectious *Cryptosporidium parvum* can be carried by humans and livestock, but the current state of knowledge suggests that the species of *Cryptosporidium* that infect birds do not infect humans.

c – Potential indirect hazards.

Table A3 *Examples of hazardous events and their potential sources*

Catchments and groundwater systems

- Rapid variations in raw water quality
- Sewage and septic system discharges
- Industrial discharges
- Chemical use in catchment areas (e.g. use of fertilisers and agricultural pesticides)
- Major spills and accidental spillage
- Public roads
- Human access (recreational activity)
- Wildlife (native and feral)
- Unrestricted livestock
- Inadequate buffer zones
- Surrounding land use (e.g. animal husbandry, agriculture, forestry, industrial area, waste disposal, mining)
- Changes in surrounding land use
- Poorly vegetated riparian zones, failure of sediment traps and soil erosion
- Stormwater flows and discharges
- Existing or historical waste-disposal or mining sites / contaminated sites and hazardous wastes
- Unconfined and shallow aquifers
- Groundwater under direct influence of surface water
- Inadequate well-head protection and unhygienic practices
- Uncased or inadequately cased bores
- Saline intrusion of coastal aquifers
- Contaminated aquifers
- Climatic and seasonal variations (e.g. heavy rainfalls, droughts)
- Bushfires, natural disasters, sabotage

Table A3 *Examples of hazardous events and their potential sources (Continued)*

Storage reservoirs and intakes

- Open reservoirs and aqueducts, uncovered storages
- Human access / absence of exclusion areas around shorelines
- Animal access including birds and vermin
- Short-circuiting of reservoir
- Depletion of reservoir storage
- No selective withdrawal
- No alternative water sources
- Unsuitable intake location
- Cyanobacterial blooms
- Stratification
- Soil erosion
- Inadequate buffer zones and vegetation
- Climatic and seasonal variations (e.g. heavy rainfalls, droughts)
- Public roads / accidental spillage
- Failure of alarms and monitoring equipment
- Bushfires and natural disasters
- Sabotage

Treatment systems

- Significant flow variations through water treatment system
- Incapable equipment or unit processes
- Inadequate backup
- Inappropriate treatment processes
- Process control incapability or operational inflexibility
- Use of unapproved or contaminated water treatment chemicals and materials
- Chemical dosing failures
- Inadequate mixing
- Failure of dosing equipment
- Inadequate filter operation and backwash recycling
- Ineffective disinfection
- Equipment malfunctions
- Poor reliability of processes
- Failure of alarms and monitoring equipment
- Power failures
- Sabotage and natural disasters
- Formation of disinfection byproducts

Service reservoirs and distribution systems

- Open reservoirs and aqueducts / uncovered storages and unprotected pipe system
- Human access, absence of exclusion areas around shorelines
- Animal access including birds and vermin
- Short-circuiting of reservoir, stagnation zones
- Buildup of sediments and slimes
- Inappropriate materials and coatings or material failure
- Aged pipes, infrastructure
- Corrosion of reservoirs and pipe system
- Mixing of different source waters
- Infiltration and ingress of contamination from cross-connections, backflow (soil and groundwater)
- Biofilms, sloughing and resuspension, regrowth
- Pipe bursts or leaks
- Inadequate repair and maintenance, inadequate system flushing and reservoir cleaning
- Commissioning new mains
- Inadequate disinfection after construction, repairs
- Flow variability, inadequate pressures
- Treatment dosing failure
- Inadequate maintenance of chlorine residual
- Formation of disinfection byproducts
- Failure of alarms and monitoring equipment
- Sabotage and natural disasters

Consumers

- Potential consumer misuse
- Leaching of metals
- Inappropriate plumbing and construction materials

A5 Risk assessment

The objective of risk assessment is to distinguish between very high and low risks so that priorities for risk management can be established.

Once potential hazards and their sources and events have been identified, the level of risk associated with each hazard or event needs to be estimated. Not all hazards will require the same degree of attention, and risk estimation assists in directing attention and resources to those hazards that are most threatening.

In some instances, an initial screening-level risk assessment may be useful to identify broad issues and show where to focus efforts for a more detailed assessment.

Summary of actions

- Define a consistent approach to be used for risk assessment.
- Evaluate the major sources of uncertainty associated with each hazard and hazardous event and consider actions to reduce uncertainty.
- Determine significant risks and establish and document priorities for risk management (based on assessment of maximum and residual risk).
- Periodically review and update the risk assessment.

An example of an approach to estimating the level of risk is provided in Tables A4, A5 and A6. These tables have been adapted from AS/NZS 4360:1999 *Risk Management* and can be modified to meet the needs of an organisation.

Using these tables to guide a risk assessment will quickly reveal the need to define the level of detail required and format to be used for classifying events. Events may arise along a continuum from commonly recurring incidents of minor consequence to rarer incidents with more serious consequences. In some cases, variations of the same type of event can appear at both ends of the spectrum. For example, 'loss of disinfectant residual in the distribution system' can have distinctly different meanings. A slight reduction or a loss in parts of a system may be fairly common and have limited health consequences; a total loss of disinfection should be rare but could have potentially severe consequences. There is no set of rules to be followed in using these tables; rather, they are offered as a general guide for the development of a consistent methodology that will be relevant for the water system under study.

Table A4 *Qualitative measures of likelihood*

Level	Descriptor	Example description
A	Almost certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur or should occur at some time
D	Unlikely	Could occur at some time
E	Rare	May occur only in exceptional circumstances

Table A5 *Qualitative measures of consequence or impact*

Level	Descriptor	Example description
1	Insignificant	Insignificant impact, little disruption to normal operation, low increase in normal operation costs
2	Minor	Minor impact for small population, some manageable operation disruption, some increase in operating costs
3	Moderate	Minor impact for large population, significant modification to normal operation but manageable, operation costs increased, increased monitoring
4	Major	Major impact for small population, systems significantly compromised and abnormal operation if at all, high level of monitoring required
5	Catastrophic	Major impact for large population, complete failure of systems

Table A6 *Qualitative risk analysis matrix – level of risk*

Likelihood	Consequences				
	1. Insignificant	2. Minor	3. Moderate	4. Major	5. Catastrophic
A (almost certain)	Moderate	High	Very high	Very high	Very high
B (likely)	Moderate	High	High	Very high	Very high
C (possible)	Low	Moderate	High	Very high	Very high
D (unlikely)	Low	Low	Moderate	High	Very high
E (rare)	Low	Low	Moderate	High	High

Based on the assessment of risk, priorities for risk management should be determined. Maximum risk in the absence of preventive measures should first be determined to identify high-priority risks and provide an indication of worst-case scenarios in the event of failures. Residual risk, determined in conjunction with evaluation of existing preventive measures, should also be assessed to provide information on the effectiveness of existing strategies and the need for improvements.

UNCERTAINTY

The outcome of hazard identification and risk assessment will depend on the level of uncertainty associated with each parameter. Evaluating the major sources and types of uncertainty associated with the hazards can assist in understanding the limitations of the hazard identification and risk assessment as well as how these limitations can be reduced.

Hazard identification and risk assessment need to explicitly consider the sources and types of uncertainty.

Uncertainty can be broadly classified into two types: *variability* and *knowledge uncertainty*. By documenting the major sources of variability and knowledge uncertainty that arise for all risks, insights can be gained into the appropriate actions for reducing the role of uncertainty.

Variability represents the true differences that can occur in the specific values of parameters that contribute to a risk – for example, contaminant concentrations over time and space, flows and number of people exposed. Variability contributes to uncertainty because it usually cannot be described completely, due to incomplete or insufficient monitoring data, and there is no single correct answer that will cover all circumstances. For example, the mean temperature over a defined period of time will not represent the high and low extremes and these may be more important depending on what we are seeking to know. Because there is variability in temperature, a decision will need to be made on which value or values to use from the available data, and this choice will carry with it some uncertainty.

Knowledge uncertainty represents an inadequate state of knowledge that exists in the values of parameters measured. Knowledge uncertainty may be reflected in a lack of assurance that methods are accurately measuring what is intended or in a lack of understanding of how a process works. For example, in using methods to count *Cryptosporidium* oocysts, there may be a degree of uncertainty that the particles being counted are truly *Cryptosporidium* oocysts. Alternatively, while there may be confidence that the method for counting oocysts is accurate, further uncertainty exists about what the measurement means because it is not known if the oocysts are viable and, if viable, whether they are infective.

There is value in being able to distinguish the relative impacts of variability and knowledge uncertainty. Variability cannot be reduced by more accurate measurement. However, by characterising variability more fully, the nature of a hazard (and thereby the dimensions of the risk) can be better understood. Understanding how variability contributes to uncertainty may lead to actions to change a system to reduce its variability (e.g. increasing reservoir storage times to minimise fluctuations in water quality).

In contrast to variability, knowledge uncertainty can be reduced by better measurement and research. The increased understanding from reducing knowledge uncertainty can provide greater assurance that the preventive measures being considered will achieve their intended purpose. This requirement supports the need for a research capability within the water industry.

A6 Preventive measures and multiple barriers

The identification, evaluation and planning of preventive measures should always be based on system-specific hazard identification and risk assessment. The level of protection used to control a hazard should be proportional to the associated risk.

The multiple barrier principle should be employed and preventive measures should be comprehensive from catchment to consumer. Wherever possible, the focus of these measures should be to prevent contamination in the catchment rather than to rely on downstream control. Box A1 provides further information on catchment management and source water protection.

Summary of actions

- Identify existing preventive measures from catchment to consumer for each significant hazard and event.
- Determine the residual risk.
- Evaluate alternative and additional preventive measures where improvement is required.
- Document the preventive measures and strategies addressing each significant risk into a plan.
- Establish mechanisms to ensure cooperation and development of action plans with external agencies.

Examples of preventive measures and management strategies from catchment to consumer are provided in Table A7. An indication of removals of enteric pathogens using the multiple barrier approach is provided in Table A8. Table A9, in the following section, also provides examples of preventive measures for *Giardia* from catchment to consumer for a river system.

Once preventive measures addressing each significant risk have been identified, the strategies should be documented into a plan. Any new preventive measures to be implemented over the longer term, such as covering water storages or the introduction of filtration, should be incorporated into an improvement plan (see Section 3.12.2).

Where responsibility for preventive measures lies outside the direct control of the drinking water supplier (i.e. with external agencies), mechanisms for communication to ensure cooperation and development of action plans should be established (see Section 3.1.3).

Box A1 *Catchment management and source water protection*

Catchment management and source water protection provide the first barrier for the protection of water quality. Catchment management usually involves a coordinated approach to develop short-term and long-term plans to enhance water quality and eliminate or control any potential sources of pollution.

Whether water is drawn from surface catchments or underground sources, it is important that the local catchment or aquifer is understood, and that the activities that could lead to water pollution are identified and managed. Effective catchment management and source water protection include development of a catchment management plan with the commitment of land use planning authorities to prevent inappropriate development and to enforce relevant planning regulations.

Catchment management plans

A comprehensive catchment management plan should be developed and implemented to mitigate any existing and potential future risks, and where practical, aim to improve the quality of water harvested over time. The plan should include, where appropriate, the following elements:

- a policy statement identifying the protection of water quality as an explicit objective of local legislation
- preparation and review of land use planning controls jointly with the planning authority
- establishment of agreed processes and criteria for managing development applications
- a clear statement of responsibilities of different agencies and agreed coordination processes
- identification of water quality hazards, estimation of risks and planning of relevant management strategies
- a monitoring program to identify pollution sources, maintain quality control, and collect long-term data to determine trends
- regular documented inspections to monitor catchment conditions and land use changes
- a community awareness program, including strategies for working with landowners to support the catchment management plan
- agreed and tested emergency response plans with relevant emergency services for responding to major pollution events such as spillages or contamination.

The extent to which catchment pollution can be controlled or remediated is often limited in practical terms wherever there are competing water uses and pressure for increased development in the catchment. In devising catchment management plans, it may be necessary or useful to divide large catchments into smaller, more manageable units (e.g. subcatchments). Where this is done, it is important to ensure that, in combination, the various plans provide an integrated approach across the entire catchment. For large river systems protection may be possible only over limited reaches in the vicinity of the raw water off-take or reservoir inlet.

Planning controls

Well-designed planning regulations are a critical component of sound catchment management and protection of water quality. Where possible, protection of water resources should be included as a principal objective in planning policies.

Planning regulations should address management and control of high-risk development in catchments and aquifer intake areas (e.g. intensive animal feedlots) and should also address the issue of long-term incremental development. Urban development, agroindustry and general industry should be carefully scrutinised to ensure that they will not impact on water resources. On site waste treatment and disposal systems should be permitted only where sites are suitable and there is minimal risk to the water supply. Such systems should be designed, installed and maintained correctly, and inspected regularly. Defects should be reported and rectified.

Responsibility for the development and implementation of planning strategies and regulations is generally shared between state and local government agencies. It is important that drinking water suppliers and environment and health authorities establish strong links with planning agencies and take an active role in:

- the development or amendment of these planning strategies and regulations
- the evaluation of individual development proposals with respect to potential impacts on water quality or quantity.

Where appropriate, formal agreements should be required to ensure approval conditions are complied with and recorded on land titles to alert potential purchasers of the obligations associated with the property.

Box A1 *Catchment management and source water protection (Continued)*

Community awareness

Community awareness programs should be developed to promote the protection of water quality. Support for local landcare and watercare groups is a relatively low-cost opportunity to develop community awareness and reduce pollution risks.

Diffuse sources of pollution arising from agricultural and animal husbandry activities are difficult to manage but their effect on water quality can be minimised by the use of best practice management such as fencing of streams, management of riparian zones and off-stream watering of stock. Landowners can be encouraged to protect stream banks and provide buffer strips through community awareness programs and by subsidising tree planting and fencing works.

Cooperation with landowners and close collaboration with agricultural agencies are essential for the management of point sources such as dairy effluent and stockyard runoff. Demonstration projects that aim to show the benefits of collecting and using this material are useful.

Table A7 *Examples of preventive measures from catchment to consumer*

Source water and catchments	
• Use of an appropriate source water	• Regular inspections of catchment areas
• Ownership and control of catchment area	• Protection of waterways (fencing out livestock, buffer zones, management of riparian zones)
• Designated and limited uses	• Runoff interception
• Registration of chemicals used in catchments	• Use of planning and environmental regulations to regulate potential water polluting developments
• Control of human activities within catchment boundaries	• Use of industry codes of practice and best practice management
• Control of wastewater effluents	
• Involvement in land use planning procedures	
• Participation of community and landowners within the catchment area	

Water extraction and storage systems	
• Control of water extraction	• Prevention of unauthorised access
• Alternate selection of water source	• Destratification of water storage
• Use of available water storage for periods of heavy rainfall	• Diversion of stormwater downstream from intake
• Appropriate location and protection of intake	• Roofed storages and reservoirs with appropriate stormwater collection and drainage
• Proper well construction including casing, sealing and well-head security	• Securing tanks from access by animals
• Proper location of wells in aquifer	• System maintenance – reservoir cleaning or scouring – pipeline flushing – fittings maintenance
• Water storage systems to maximise detention times	
• Infiltration wells	
• Enclosed water storages	

Table A7 *Examples of preventive measures from catchment to consumer (Continued)*

Water treatment system

- Coagulation or flocculation and sedimentation
- Alternative treatment
- Use of approved water treatment chemicals and materials
- Control of water treatment chemicals
- Regular assessment of hazards and risks
- Use of skilled and trained operators
- Process controllability of equipment
- Availability of backup systems
- Water treatment process optimisation, including
  - chemical dosing
  - filter backwashing
  - flow rate
  - minor infrastructure modifications
- Use of tank storage in periods of poor-quality raw water

Distribution systems

- Distribution system maintenance
- Availability of backup systems (power supply)
- Maintaining an adequate disinfectant residual
- Cross-connection and backflow prevention devices implemented
- Fully enclosed distribution system and storages
- Secondary disinfection
- Appropriate repair procedures, including subsequent disinfection of water mains
- Maintaining adequate system pressure

Monitoring

- Quality assurance and validation procedures for sampling and testing
- Calibration and maintenance of equipment

Consumers

- Information dissemination:
  - responsibilities relating to drinking water quality
  - plumbing and appliances
  - backflow prevention
  - point of use devices

Table A8 *Estimated removals of enteric pathogens using multiple barriers*

	Estimated reduction in numbers of enteric pathogens				Estimated overall removal[b]
	Watershed protection	**Reservoir detention**	**Filtration**	**Disinfection**[a]	
Bacteria	0.5–1 log removal	~ 1 log removal per 10 days storage Retention for over 60 days will provide almost complete removal.	0.5–1 log removal	Complete inactivation can be achieved by a range of disinfectants including chlorine, chloramines and UV, provided doses and contact times are sufficient.	Complete removal achievable
Viruses	Complete removal of human enteric viruses if human waste excluded.	1–2 log removal Long-term detention (1–6 months)	Conventional: 2 log removal Direct: 1 log removal Membrane[c]: > 4 log removal	Chlorine, UV light, ozone and chlorine dioxide: 3 log removal	Removal of 5 log achievable
Giardia	0.5–1 log removal	1.5–2.5 log removal Long-term detention (1–6 months)	Conventional: 2.5 log removal Direct: 2 log removal Membrane[c]: > 4 log removal	Chlorine: 1–2 log removal Ozone and chlorine dioxide: 2 log removal	Removal of 5.5–8 log achievable
Cryptosporidium	0.5–1 log removal	1–2 log removal Long-term detention (1–6 months)	Conventional: 2 log removal DAFF: 2 log removal Direct filtration: 2 log removal Membrane[c]: > 4 log removal	Ozone: 0.5–2 log removal Chlorine dioxide: 0.5–1 log removal UV light: 3 log removal Chlorine and chloramines: ineffective	Removal of 3.5–7 log achievable

DAFF = dissolved air flotation and filtration

a – Log removals based on standard doses and minimum contact times of 30 minutes

b – Using standard technology (catchment control, detention, conventional filtration, chlorination)

c – Depending on pore size

A7 Critical control points

Appropriate selection of critical control points is an important consideration, as increased focus in process control (monitoring and documentation) for a water supply system will be directed toward these activities and processes. The identity and number of critical control points is system specific and will be determined by the range and magnitude of potential hazards and associated risks. Identification of critical control points may be aided by the use of a decision tree, as shown in Figure A2.

Critical control points have several operational requirements, including establishing an appropriate monitoring regime specifying specific parameters and critical limits to ensure the process or activity operates effectively. Failure to meet a critical limit represents loss of control of the process and an unacceptable health risk, either directly, through the supply of unsafe water, or indirectly, where multiple critical control points exist, by exceeding the capacity of subsequent processes. Corrective actions must also be available to re-establish process control when criteria have not been met.

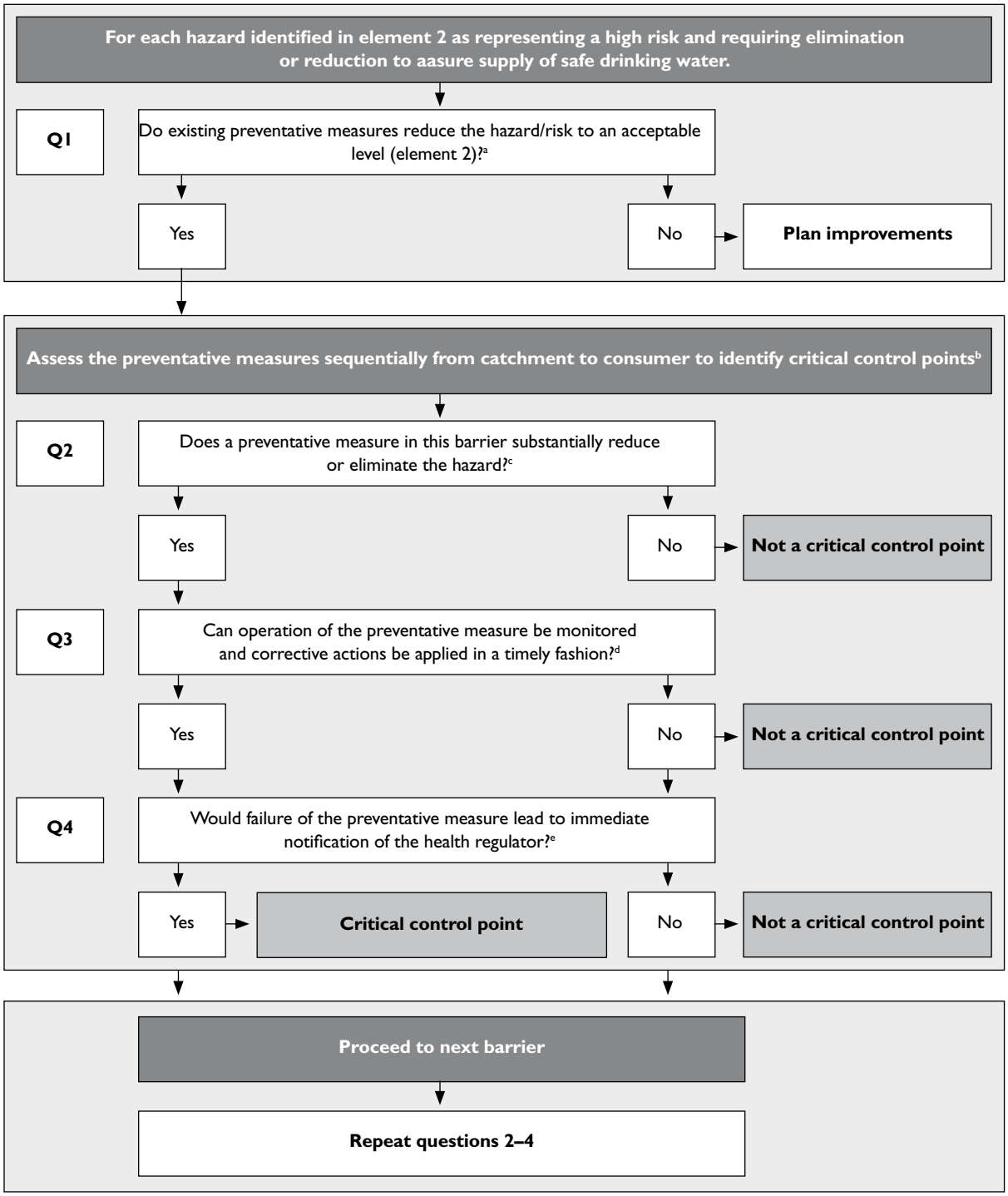
If there is a deviation from a critical limit corrective actions also must be available to reduce the health risk from hazards present in the system.

Summary of actions

- Assess preventive measures from catchment to consumer to identify critical control points.
- Establish mechanisms for operational control (see Section 3.4 *Operational procedures and process control).*
- Document the critical control points and criteria.

Table A9 provides examples of potential sources of *Giardia*, preventive measures and potential critical control points from catchment to consumer for a river system. Table A10 provides further detail on potential critical control points and operational criteria.

Figure A2 *Critical cpntrol point decision tree*



Notes

a – Preventive measures should be applied from catchment to consumer in accordance with the multiple barrier approach. Overall, when considered together, these preventive measures should prevent or reduce the hazard to an acceptable level.

b – Drinking water systems generally include numerous preventive measures and strategies that all contribute to assuring the safety of water supplied to consumers; however, only a limited number are amenable to selection as critical control points. The identification of critical control points is system specific and involves making judgments based on knowledge of the potential hazards and associated risks, and the preventive measures. Each significant hazard identified should have a critical control point. However, there may be more than one critical control point to address the same hazard, and more than one hazard may be prevented or reduced by a specific critical control point. Appropriate selection of critical control points is an important consideration because the focus in process control (monitoring and documentation) will increasingly be directed toward these processes and activities. Too many critical control points may make the system unwieldy and too few may fail to provide adequate assurance of drinking water quality.

c – Important considerations are that the preventive measure is essential for significantly reducing the given hazard and that the effectiveness of the measure has been validated.

d – Operational control must be provided for the preventive measure to assure its ongoing effectiveness. This includes establishing a monitoring regime to ensure the process or activity operates to requirements. Practicalities of monitoring should be considered. Operational parameters and criteria must be monitored with sufficient frequency to guarantee the critical control point is providing protection against targeted hazards and to reveal any failures in a timely fashion. Corrective actions must be available to regain control immediately when criteria have been exceeded or deviated from.

e – Failure means deviation from a critical limit not from a target criterion (see Section 3.3.2 and 3.4.2). The significance of critical control points is that failure of the process or activity represents an out-of-control hazard. A practical consideration is whether failure of the process or activity (i.e. loss of control) will result in a (potentially) unacceptable health risk and require immediate notification of the health regulator.

Table A9 *Example preventive measures and potential critical control points for* Giardia *– river system*

	Potential sources of *Giardia*	**Preventive measures**	**Potential critical control points**[a]
River/weir	Septic tank effluent	Installation, design and maintenance standards	
		Setback distances	
	Livestock waste	Riparian zones	
		Stocking rate controls	
		Stream fences	
		Flow diversion from reservoir of highly contaminated first-flush water following heavy rainfall	Flow diversion
Resevoir	Human or livestock access	Restrict access	
		Fencing	
		Interception drains	
		Detention	
Treatment plant		Coagulation	
		Sedimentation	
		Filtration	Filtration
Disinfection station		Disinfection, automatic dosing and monitoring	Disinfection
Distribution system	Cross-connections / backflows	Booster chlorination	
	Mains breaks / new mains	Cross-connection control	(one or more of the preventive measures)
		Positive pressure	
		Maintenance and repair protocols and procedures	

a – Determined using the critical control point decision tree

Table A10 *Example – potential critical control points and operational criteria*

Activity/process	Hazard(s)	Critical limit	Monitoring	Corrective action
Groundwater abstraction	Enteric bacteria, viruses and protozoa from septic and livestock waste; nitrates	Physical surety of bore and radius of protection zone. Absence of *E. coli.* NO_3 50 mg/L (as nitrate)	Weekly inspection and testing for presence of *E. coli.* 6–monthly monitoring of nitrate	Repair fault in bore Enforce protection zone
Catchment water reception at take off weir prior to reservoir	Higher levels of enteric bacteria, viruses and protozoa from septic and livestock waste following heavy rainfall	Set flow rate and turbidity limits at location upstream of weir	Continuous stream monitoring station	Divert flow away from reservoir intake
Reservoir mixing/ destratification	Cyanotoxins	6500 cells/mL Target value: 1000 cells/mL	Continuous monitoring of temperature and dissolved oxygen through the water column Regular sampling; increase frequency following detection of cyanobacteria or in summer	Dose reservoir with copper sulfate Improve efficiency of mixing Take reservoir out of service
Filtration	Enteric bacteria, viruses and protozoa	Combined filtered water turbidity < 0.5 NTU 95% of time Maximum 5 NTU Target value: < 0.3 NTU at all times	Continuous online monitoring	Identify problem and take action e.g. repair faulty operation Increase coagulant dose Filter backwash
Primary disinfection and storage	Enteric bacteria, viruses and *Giardia*	Free chlorine residual > 1 mg/L Detention >x (to set minimum C.*t*)[a]	Continuous online monitoring and alarms with automatic feedback to chlorine dosing Flow not to exceed x ML per hr	Increase chlorine dose Decrease flows to increase detention time Stop supply
Secondary disinfection	Enteric and free-living bacteria	Free chlorine residual >1 mg/L	Continuous online monitoring and alarms with automatic feedback to chlorine dosing	Increase chlorine dose Stop supply
Distribution of treated water	Enteric bacteria, viruses and protozoa Chemical contaminants	Minimum free chlorine residual of 0.2 mg/L at specified locations Positive pressure at specified locations	Continuous online monitoring Hydraulic pressure	Increase chlorine dose Identify and repair source of pressure loss

C.*t* = contact time; *E. coli* = *Escherichia coli;* NTU = nephelometric turbidity unit

a – see Section A8 Chlorination as an example of a critical control point

A8 Chlorination as an example of a critical control point

Disinfection is designed to kill pathogenic microorganisms, thereby preventing waterborne diseases. Chlorination is the most commonly used process for disinfection; it is effective in killing bacteria and can be reasonably effective in inactivating viruses (depending on type) and most protozoa, including *Giardia*. *Cryptosporidium* is not inactivated by the concentrations of chlorine that can be safely used in drinking water.

Although the microbial quality of drinking water is of primary importance and must never be compromised, chlorine levels and the formation of chlorination byproducts should be controlled to prevent any adverse health effects that may eventually be found to be attributable to disinfection byproducts.

The effectiveness of chlorination depends on several factors, including:

- chlorine dose
- contact time between chlorine and the water
- chlorine demand
- pH
- temperature
- turbidity.

Chlorine demand is important because it is the chlorine residual in the water and not the chlorine dose that determines the efficacy of chlorination. Natural water contains inorganic and organic compounds that react with chlorine. Reactions with naturally occurring organic matter produce chlorination byproducts, the most well known being the trihalomethanes. Chlorine may also react with compounds such as phenols to impart a taste and odour to water.

A sufficient chlorine dose must therefore be added to the water to allow for the chlorine demand reactions to occur, and to ensure that there is an adequate free chlorine residual available to disinfect the water effectively. Turbidity should be reduced as much as possible before the addition of the disinfectant in order to decrease the chlorine demand, limit shielding of microorganisms in particles and reduce the formation potential of chlorination byproducts.

Chlorination fulfils the requirements of a critical control point. The effectiveness of eliminating potentially harmful microorganisms is validated by extensive research and technical literature (e.g. see USEPA 1999). In addition, process control measures are readily available. Chlorination must be functional and effective at all times, as even short periods of sub-optimal performance can represent a serious risk to public health.

Table A11 and the following text provide a summary of the chlorination process as a critical control point.

Table A11 *Chlorination as a critical control point*

Hazards			
Enteric bacteria, viruses and Giardia			
Process controls			
• Chlorine dosing system		• Chlorine cylinder changeover	
• Plant flow rate / operation of clear well storage		• Backup power / duplicate facilities	
• pH adjustment			
Operational monitoring			
Parameter	*Target criteria*	*Critical limits*	*Monitoring methods*
Chlorine residual	> 0.5 mg/L	Specific low chlorine residual set to achieve a minimum C.*t* requirement based on maximum flow and minimum storage times. Time is an important factor in determining the critical limit e.g. if there is a filtered water storage prior to supply to customers an interruption to chlorination of up to several hours may not result in the C.*t* value falling below the minimum limit.	Online, continuous chlorine residual analyser, flow and pH 24-hour monitored alarms on residual monitoring, pH and chlorine dosing equipment. Regular turbidity and temperature monitoring, and chlorine demand calculations. Increase frequency on changing water quality. Appropriate electronic or hard copy monitoring records.
pH	pH 6.5–7.5		
Flow rate	Set to achieve minimum contact time		
Chlorine dose	Set points ± x%		
Turbidity	< 1.0 NTU		
Temperature			

Corrective action

Any breach in critical limits or target criteria should result in any of the following operating procedures as necessary:

- inspect and calibrate equipment
- adjust flow rate
- adjust chlorine dose or feed point
- carry out additional monitoring, increase sampling and testing
- recalculate C.*t* values
- implement unplanned maintenance procedure
- secondary or booster disinfection
- use alternative supply or divert water
- engage backup equipment
- plant automatic shutdown
- implement emergency response
- record actions to be taken and report (internally or externally as required).

Verification

- Calibration and maintenance of equipment
- Drinking water quality monitoring
- Consumer satisfaction
- Evaluation and audit

A8.1 PROCESS CONTROLS

Effective operation of chlorination requires consideration of several associated process control measures. These include:

- **Chlorine dosing system**, ideally with flow-proportional automatic dosing and feedback loops to achieve target chlorine residual and provide rapid responses to any changes in flow and water quality. Flow meters and alarms should be provided on the chlorine feed system to warn of disinfectant loss.
- **Plant flow-rate control** and the design and operation of the clear-well or post-treatment reservoir (whichever is used to provide an adequate contact time). The infrastructure for chlorination should be of sufficient capacity to handle maximum flow rates and should not be hydraulically overloaded or subjected to rapid changes in hydraulic loading, as these conditions will compromise its effectiveness.
- **pH adjustment** for supplies where sudden large changes of pH are known to occur (e.g. due to problems arising from chemical dosing with lime, permanganate, caustic soda etc).
- **Provision of an alarm system** on the chlorine supply, to indicate when the supply is running low, and of a spare or surplus chlorine supply. Chemical suppliers should be evaluated and selected on their ability to supply product in accordance with required specifications.
- **Inspection, calibration and maintenance of equipment** to ensure continuing process capability and accuracy of monitoring results.
- **Emergency measures** such as backup generators, alarms and duplicate facilities (e.g. chlorinator, disinfectant feed system, pumps, monitoring equipment etc) to avoid loss of disinfection if failure occurs.

A8.2 OPERATIONAL MONITORING

Operational parameters

It is essential to monitor residual chlorine concentration, flow rate (contact time), chlorine dose, pH, temperature and turbidity to determine whether water is being disinfected properly. Total coliforms and heterotrophic bacteria can also be used.

For processes such as disinfection, where failure can result in a rapid change in water quality and pose a significant health risk, monitoring should be online and continuous to provide an immediate indication of performance. Flow measurement and chlorine residual can be monitored online and continuously with feedback loops to ensure correct conditions are met. For supplies where sudden changes of pH are known to occur, continuous monitoring of this parameter should also be considered. Alarm systems that are monitored 24 hours a day should be installed to indicate when operational criteria have not been met.

Critical limits and target criteria

Operational criteria for chlorination are normally determined by calculating the C.*t* values required to attain target levels of pathogen inactivation at specified temperatures and pH. C.*t* is the product of residual chlorine concentration in mg/L and the contact time in minutes.

Free chlorine residuals and C.*t* values should be validated for individual water supplies.Tables of C.*t* values for various temperatures and pHs for the inactivation of *Giardia* and viruses by free chlorine and other disinfectants have been published by the United States Environmental Protection Agency (e.g. see Table A12 and USEPA 1999).

Ongoing compliance with minimum C.*t* values should be confirmed.

Table A12 *C.t values for inactivation by free chlorine (mg.min/L)*

		99% (2 log) inactivation		99.9% (3 log) inactivation	
	pH	**10°C**	**20°C**	**10°C**	**20°C**
Giardia[a]	7.0	75	37	112	56
	8.0	108	41	162	81
Viruses	6.0–9.0	3	1	4	2

Source: USEPA (1999). Disinfection Profiling and Benchmarking Guidance Manual, EPA 815-R-99-013.

a – At a free chlorine residual of 1 mg/L

Corrective action

Corrective action taken in response to target criteria or critical limits not being met could include:

- examination of the chlorination process (investigate equipment)
- adjustment of flow rate to increase detention time
- adjustment of pH
- recalculation of C.*t* values
- adjustment of disinfectant dose rates
- variation of the disinfection application point
- verification of chlorine dose solution
- increased sampling, verification of operational monitoring
- inspection and calibration of equipment
- engagement of backup chlorination equipment
- secondary disinfection, spot dose or booster disinfection
- water diversion or reliance on alternate supply (storage)
- shutdown of plant, automatic immediate shutdown
- implementation of an emergency response plan (e.g. issuing advice to boil water).

A8.3 VERIFICATION

The chlorination process should be verified by supplementing with:

- regular calibration and maintenance of the chlorine dose and monitoring equipment to ensure continuing process capability and accuracy of monitoring results. Procedures, schedules, responsibilities and records (maintenance logs) for the calibration and maintenance of equipment should be documented
- routine sampling and testing of *E. coli* (or thermotolerant coliforms) in the distribution system and as supplied to consumers
- monitoring of consumer comments and complaints regarding chlorine taste and odour
- performance evaluation and operational audit to confirm that objectives are being met. This entails the periodic review of operational monitoring, drinking water quality monitoring data and consumer satisfaction, logbook records of planned and unplanned maintenance and calibration, and operating procedures.

A9 Further sources of information on drinking water quality management

A9.1 DRINKING WATER QUALITY MANAGEMENT – GENERAL

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A10 National Water Quality Management Strategy

The Natural Resource Management Ministerial Council (NRMMC) is continuing the development of the National Water Quality Management Strategy (NWQMS). The National Health and Medical Research Council (NHMRC) is involved in aspects of the NWQMS which affect public health.

The NWQMS has three major elements: policies, process and guidelines.

POLICIES

The main objective of the NWQMS is set out in the NWQMS Paper No. 2, *Policies and Principles - a reference document* (ANZECC & ARMCANZ 1994) and is;

- to achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development.

This objective is being pursued through a strategy based on high-status national guidelines with local implementation.

Policies and Principles - a reference document emphasises the importance of:

- Ecologically sustainable development;
- Integrated (or total) catchment management;
- Best management practices, including the use of acceptable modern technology and waste minimisation and utilisation; and
- The role of economic measures, including 'user-pays' and 'polluter-pays' approaches.

PROCESS

The process for water quality management starts with the community working in concert with government to develop a management plan for each catchment, aquifer, estuary, coastal water or other water body. The plan should take account of all existing and proposed activities and developments; it should contain feasible management options that aim to achieve the environmental values that have been agreed for that waterbody. The process is outlined in the NWQMS Paper No. 3, *Implementation Guidelines* (ANZECC & ARMCANZ 1998) and is schematically represented in figure A10.1. The NWQMS envisages use of both regulatory and market-based approaches.

Management of water resources is mainly a state and territory responsibility, but the NWQMS will be implemented in the context of:

- The NWQMS guidelines;
- State and territory water policies;
- Community preferences on the use and values of local waters;
- The current water quality of local waters; and
- The economic and social impacts of maintaining current water quality or of meeting new local water quality goals.

Implementation of the NWQMS should include:

- Catchment, groundwater and coastal water quality management plans;
- An appropriate level of water and sewerage services provided by authorities; and
- Further development of regulatory and market frameworks.

Community views from a crucial part of the NWQMS and public comment is sought during both the development and implementation of the strategy.

Environmental values and water quality (NWQMS) guidelines are described in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000).

NATIONAL GUIDELINES

The national guidelines are technical papers providing guidance on many aspects of the water cycle including ambient and drinking water quality, monitoring, groundwater, rural land and water, urban stormwater, sewerage systems and effluent management for specific industries. The full list of NWQMS documents, with their current status is in table A10.1. The list, together with other information, is also available on the NWQMS web site at http://www.affa.gov.au/nwqms

Figure A10 *Natiional Water Quality Management Strategy*

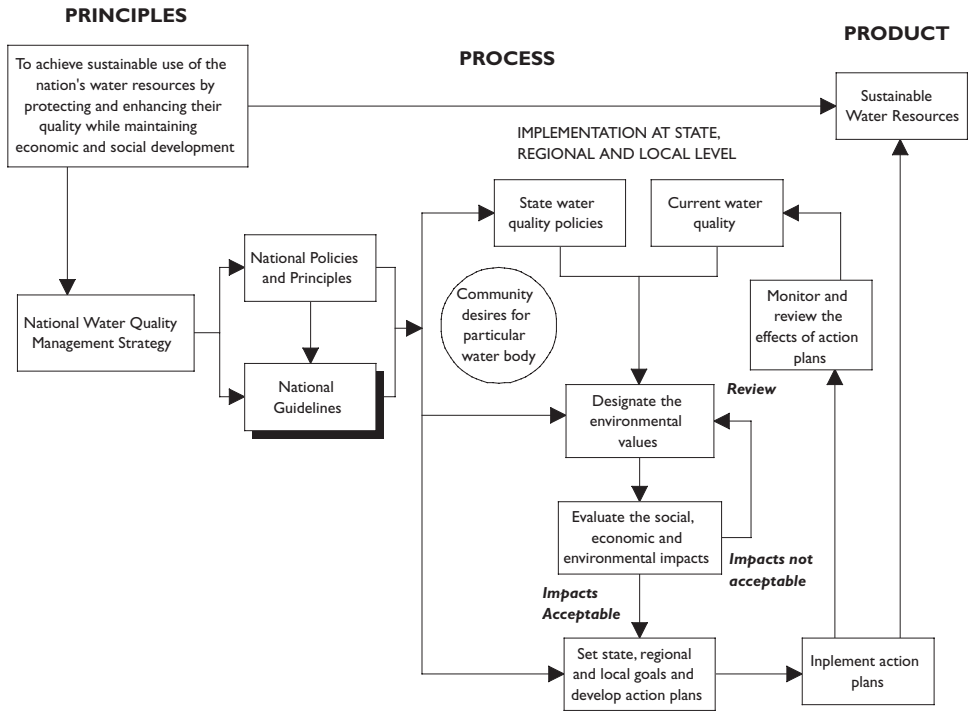

Table A10.1 The technical papers of the National Water Quality Management Strategy, by category

Policies and Process for Water Quality Management	
Paper no.1	*Water Quality Management - an outline of the policies*
Paper no.2	*Policies and Principles - a reference document*
Paper no.3	*Implementation Guidelines*
Water Quality Benchmarks	
Paper no.4	*Australian and New Zealand Guidelines for Fresh and Marine Water Quality*
Paper no.4a	*An Introduction to the Australian and New Zealand Guidelines for Fresh and Marine Water*[S]
Paper no.5	*Australian Drinking Water Guidelines - Summary (withdrawn)*
Paper no.6	*Australian Drinking Water Guidelines*
Paper no.7	*Australian Guidelines for Water Quality Monitoring and Reporting*
Groundwater Management	
Paper no.8	*Guidelines for Groundwater Protection*
Guidelines for Diffuse and Point Sources*	
Paper no.9	*Rural Land Uses and Water Quality - a community resource document*
Paper no.10	*Guidelines for Urban Stormwater Management*
Paper no.11	*Guidelines for Sewerage Systems - Effluent Management*
Paper no.12	*Guidelines for Sewerage Systems - Acceptance of Trade Waste (Industrial)*
Paper no.13	*Guidelines for Sewerage Systems - Sludge (Biosolids) Management*[#]
Paper no.14	*Guidelines for Sewerage Systems - Use of Reclaimed Water*
Paper no.15	*Guidelines for Sewerage Systems - Sewerage System Overflow*[#]
Paper no.16a	*Effluent Management Guidelines for Dairy Sheds*
Paper no.16b	*Effluent Management Guidelines for Dairy Processing Plants*
Paper no.17	*Effluent Management Guidelines for Intensive Piggeries*
Paper no.18	*Effluent Management Guidelines for Aqueous Wool Scouring and Carbonising*
Paper no.19	*Effluent Management Guidelines for Tanning and Related Industries in Australia*
Paper no.20	*Effluent Management Guidelines for Australian Wineries and Distilleries*

* the guidelines for diffuse and point sources are national guidelines that aim to ensure high levels of environmental protection that are broadly consistent across Australia

\# Not yet released in final form

S this document is available with its main document, but not as a separate item.

Glossary

Glossary

ADWG:	Australian Drinking Water Guidelines, published by the National Health and Medical Research Council (NHMRC).
biofilm:	microbial populations that grow on the inside of pipes and other surfaces.
***Campylobacter*:**	a group of bacteria that is a major cause of diarrhoeal illness.
catchment:	area of land that collects rainfall and contributes to surface water (streams, rivers, wetlands) or to groundwater.
chlorination:	use of chlorine as a means of disinfection.
chloramination:	use of chloramines (compounds formed by the reaction of hypochlorous acid or aqueous chlorine with ammonia) as a means of disinfection.
chlorine demand:	the difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and the nature and amount of any impurities in the water.
coagulation:	clumping together of very fine particles into larger particles using chemicals (coagulants) that neutralise the electrical charges of the fine particles and destabilise the particles.
Codex Alimentarius:	a food quality and safety code developed by the Codex Alimentarius Commission of the Food and Agriculture Organization of the United Nations and the World Health Organization.
coliform bacteria:	group of bacteria whose presence in drinking water can be used as an indicator for operational monitoring.
consumer:	an individual or organisation that uses drinking water.
corrective action:	procedures to be followed when monitoring results indicate a deviation occurs from acceptable criteria (adapted from Codex Alimentarius).
critical control point:	a point, step or procedure at which control can be applied and which is essential to prevent or eliminate a hazard or reduce it to an acceptable level (adapted from Codex Alimentarius).
critical limit:	a prescribed tolerance that must be met to ensure that a critical control point effectively controls a potential health hazard; a criterion that separates acceptability from unacceptability (adapted from Codex Alimentarius).
***Cryptosporidium*:**	microorganism commonly found in lakes and rivers that is highly resistant to disinfection. *Cryptosporidium* has caused several large outbreaks of gastrointestinal illness, with symptoms that include diarrhoea, nausea and stomach cramps. People with severely weakened immune systems (i.e. severely immunocompromised people) are likely to have more severe and more persistent symptoms than healthy individuals (adapted from United States Environmental Protection Agency).
C*t*:	the product of residual disinfectant concentration (C) in milligrams per litre determined before or at taps providing water for human consumption, and the corresponding disinfectant contact time *(t)* in minutes.

cyanobacteria:	bacteria containing chlorophyll and phycobilins, commonly known as 'blue-green algae'.
destratification:	agitation of water body to break up and mix otherwise stable layers of water.
disinfectant:	an oxidising agent (e.g. chlorine, chlorine dioxide, chloramines and ozone) that is added to water in any part of the treatment or distribution process and is intended to kill or inactivate pathogenic (disease-causing) microorganisms.
disinfectant residual:	the amount of free and/or available disinfectant remaining after a given contact time under specified conditions.
disinfection:	the process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water treatment.
disinfection byproduct:	products of reactions between disinfectants, particularly chlorine, and naturally occurring organic material.
distribution system:	a network of pipes leading from a treatment plant to customers' plumbing systems.
dose-response:	the quantitative relationship between the dose of an agent and an effect caused by the agent.
drinking water:	water intended primarily for human consumption (but excluding bottled water, for the purposes of these guidelines).
drinking water quality management audit:	the systematic and documented evaluation of activities and processes to confirm that objectives are being met, and which includes an assessment of management system implementation and capability.
drinking water quality monitoring:	the wide-ranging assessment of the quality of water in the distribution system and as supplied to the consumer, which includes the regular sampling and testing performed for assessing conformance with guideline values and compliance with regulatory requirements and agreed levels of service.
drinking water supplier:	an organisation, agency or company that has responsibility and authority for treating and/or supplying drinking water.
drinking water supply system (water supply system):	all aspects from the point of collection of water to the consumer (can include catchments, groundwater systems, source waters, storage reservoirs and intakes, treatment systems, service reservoirs and distribution systems, and consumers).
enteric pathogen:	pathogen found in the gut.
epidemiology:	the study of the distribution and determinants of health/disease states in human populations.
***Escherichia coli*:**	bacterium found in the gut, used as an indicator of faecal contamination of water.
eucaryote:	organism with a defined nucleus (animals, plants and fungi, but not bacteria or cyanobacteria).
eutrophication:	degradation of water quality due to enrichment by nutrients such as nitrogen and phosphorus, resulting in excessive algal growth and decay and often low dissolved oxygen in the water.

exposure:	contact of a chemical, physical or biological agent with the outer boundary of an organism (e.g. through inhalation, ingestion or dermal contact).
exposure assessment:	the estimation (qualitative or quantitative) of the magnitude, frequency, duration, route and extent of exposure to one or more contaminated media.
filtration:	process in which particulate matter in water is removed by passage through porous media.
flocculation:	process in which small particles are agglomerated into larger particles (which can settle more easily) through gentle stirring by hydraulic or mechanical means.
***Giardia lamblia*:**	A protozoan frequently found in rivers and lakes. If water containing infectious cysts of ***Giardia*** is ingested, the protozoan can cause a severe gastrointestinal disease called giardiasis.
grab sample:	single sample collected at a particular time and place that represents the composition of the water only at that time and place.
groundwater:	water contained in rocks or subsoil.
guideline value:	the concentration or measure of a water quality characteristic that, based on present knowledge, either does not result in any significant risk to the health of the consumer (health-related guideline value), or is associated with good quality water (aesthetic guideline value).
hazard:	a biological, chemical, physical or radiological agent that has the potential to cause harm.
hazard analysis critical control point (HACCP) system:	a systematic methodology to control safety hazards in a process by applying a two-part technique: first, an analysis that identifies hazards and their severity and likelihood of occurrence; and second, identification of critical control points and their monitoring criteria to establish controls that will reduce, prevent, or eliminate the identified hazards.
hazard control:	the application or implementation of preventive measures that can be used to control identified hazards.
hazard identification:	the process of recognising that a hazard exists and defining its characteristics (AS/NZS 3931:1998).
hazardous event:	an incident or situation that can lead to the presence of a hazard (what can happen and how).
helminth:	a worm-like invertebrate of the order Helminthes.
heterotrophic bacteria:	bacteria that use organic matter synthesised by other organisms for energy and growth.
heterotrophic plate count (HPC):	the number of colonies of heterotrophic bacteria grown on selected solid media at a given temperature and incubation period, usually expressed in number of bacteria per millilitre of sample.
integrated catchment management:	the coordinated planning, use and management of water, land, vegetation and other natural resources on a river or groundwater catchment, based on cooperation between community groups and government agencies to consider all aspects of catchment management.

ISO 9001:2000 (Quality Management):	an international accredited standard that provides a generic framework for quality management systems. Designed to assure conformance to specified requirements by a supplier at all stages during the design, development, production, installation, and servicing of a product, it sets out the requirements needed to achieve an organisation's aims with respect to guaranteeing a consistent end product.
ISO 14001:1996 (Environmental Management Systems):	an international accredited standard that provides a generic framework for guidance on the development and implementation of an environmental management system to minimise the impacts of business operations on the environment and to foster environmental sustainability.
indicator:	a specific contaminant, group of contaminants or constituent that signals the presence of something else (e.g. *Escherichia coli* indicate the presence of pathogenic bacteria).
indicator organisms:	microorganisms whose presence is indicative of pollution or of more harmful microorganisms.
jar test:	a laboratory procedure used to estimate the minimum or ideal coagulant dose required to achieve certain water quality goals. A jar test simulates a water treatment plant's coagulation and flocculation units with differing chemical doses, and mixing and settling times.
log removal:	used in reference to the physical-chemical treatment of water to remove, kill, or inactivate microorganisms such as bacteria, protozoa and viruses (1-log removal = 90 per cent reduction in density of the target organism, 2-log removal = 99 per cent reduction, 3-log removal = 99.9 per cent reduction, etc).
maximum risk:	risk in the absence of preventive measures.
microorganism:	organism too small to be visible to the naked eye. Bacteria, viruses, protozoa, and some fungi and algae are microorganisms.
multiple barriers:	use of more than one preventive measure as a barrier against hazards.
***Naegleria fowleri*:**	an amoeba that causes a form of meningitis.
nephelometric turbidity unit (NTU):	a measure of turbidity.
operational monitoring:	the planned sequence of measurements and observations used to assess and confirm that individual barriers and preventive strategies for controlling hazards are functioning properly and effectively.
particle count:	the results of a microscopic examination of treated water with a 'particle counter' – an instrument that classifies suspended particles by number and size.
pathogen:	a disease-causing organism (e.g. bacteria, viruses and protozoa).
pH:	an expression of the intensity of the basic or acid condition of a liquid. Natural waters usually have a pH between 6.5 and 8.5.
point-of-use treatment device:	a treatment device applied to a single tap used for the purpose of reducing contaminants in drinking water at that one tap.

preventive measure:	any planned action, activity or process that is used to prevent hazards from occurring or reduce them to acceptable levels.
procaryote:	organism whose nucleus is not clearly defined (bacteria and cyanobacteria but not animals, plants or fungi).
protozoa:	a phylum of single-celled animals.
quality:	the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs; the term 'quality' should not be used to express a degree of excellence (AS/NZS ISO 8402:1994).
quality assurance:	all the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality (AS/NZS ISO 8402:1994).
quality control:	operational techniques and activities that are used to fulfil requirements for quality (AS/NZS ISO 8402:1994).
quality management:	includes both quality control and quality assurance, as well as additional concepts of quality policy, quality planning and quality improvement. Quality management operates throughout the quality system (AS/NZS ISO 8402:1994).
quality system:	organisational structure, procedures, processes and resources needed to implement quality management (AS/NZS ISO 8402:1994).
radionuclide:	an isotope of an element that is unstable and undergoes radioactive decay.
raw water:	water in its natural state, prior to any treatment; or the water entering the first treatment process of a water treatment plant.
representative sample:	a portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.
reservoir:	any natural or artificial holding area used to store, regulate or control water.
residual risk:	the risk remaining after consideration of existing preventive measures.
risk:	the likelihood of a hazard causing harm in exposed populations in a specified time frame, including the magnitude of that harm.
risk assessment:	the overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences (adapted from AS/NZS 4360:1999).
risk management:	the systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.
sanitary survey:	a review of the water sources, facilities, equipment, operation and maintenance of a public water system to evaluate its adequacy for producing and distributing safe drinking water.
service reservoir/tank:	a storage for drinking water, generally within the distribution system, used to meet fluctuating demands, accommodate emergency requirements and/or equalise operating pressures.
source water:	water in its natural state, before any treatment to make it suitable for drinking.

storage reservoir:	a natural or artificial impoundment used to hold water before its treatment and/or distribution.
stratification:	the formation of separate layers (of temperature, plant or animal life) in a lake or reservoir. Each layer has similar characteristics (e.g. all water in the layer has the same temperature).
surface water:	all water naturally open to the atmosphere (e.g. rivers, streams, lakes and reservoirs).
surrogate:	see indicator.
symbiont:	an organism that lives in a mutually beneficial close association with another organism.
target criteria:	quantitative or qualitative parameters established for preventive measures to indicate performance; performance goals.
thermotolerant coliforms:	see coliform bacteria.
total coliforms:	see coliform bacteria.
total quality management:	adds to the concepts of quality management a long-term global management strategy and the participation of all members of the organisation for the benefit of the organisation itself, its members, its customers and society as a whole (AS/NZS ISO 8402:1994).
toxicology:	study of poisons, their effects, antidotes and detection.
turbidity:	the cloudiness of water caused by the presence of fine suspended matter.
validation of processes:	the substantiation by scientific evidence (investigative or experimental studies) of existing or new processes and the operational criteria to ensure capability to effectively control hazards.
verification of drinking water quality:	an assessment of the overall performance of the water supply system and the ultimate quality of drinking water being supplied to consumers; incorporates both drinking water quality monitoring and monitoring of consumer satisfaction.
virus:	molecules of nucleic acid (RNA or DNA) that can enter cells and replicate in them.

Index of Information sheets and fact sheets

INFORMATION SHEETS (PART IV)

FACT SHEETS (PART V)

Microorganisms

Physical and Chemical