



# **South African Water Quality Guidelines**

## **Volume 1 Domestic Use**

**Department of Water Affairs  
and Forestry**

**Second edition  
1996**

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This volume is the first in a series of eight volumes comprising the South African Water Quality Guidelines.

- Volume 1:**            ***South African Water Quality Guidelines -  
Domestic Water Use***
- Volume 2:            South African Water Quality Guidelines -  
Recreational Water Use
- Volume 3:            South African Water Quality Guidelines -  
Industrial Water Use
- Volume 4:            South African Water Quality Guidelines -  
Agricultural Water Use: Irrigation
- Volume 5:            South African Water Quality Guidelines -  
Agricultural Water Use: Livestock Watering
- Volume 6:            South African Water Quality Guidelines -  
Agricultural Water Use: Aquaculture
- Volume 7:            South African Water Quality Guidelines -  
Aquatic Ecosystems
- Volume 8:            South African Water Quality Guidelines -  
Field Guide
-

# Foreword

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The Department of Water Affairs and Forestry is the custodian of South Africa's water resources. Part of its mission is to ensure that the quality of water resources remains fit for recognised water uses and that the viability of aquatic ecosystems are maintained and protected. These goals are achieved through complex water quality management systems which involve role players from several tiers of government, from the private sector and from civil society.

A common basis from which to derive water quality objectives is an essential requirement that enables all role players involved in such a complex system to act in harmony in order to achieve the overarching goal of maintaining the fitness of water for specific uses and to protect the health of aquatic ecosystems. For these reasons the Department initiated the development of the *South African Water Quality Guidelines*, of which this is the second edition. The *South African Water Quality Guidelines* serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems.

The process that followed and the wide variety of organizations and individuals involved in the development of these guidelines ensured the acceptance and use of these guidelines by all significant role players, as the *South African Water Quality Guidelines*. These guidelines are technical documents aimed at users with a basic level of expertise concerning water quality management. However, the role players involved in the different water use sectors are expected to use these guidelines as a basis for developing material to inform water users in specific sectors about water quality and to empower them to effectively participate in processes aimed at determining and meeting their water quality requirements.

The Department recognises that water quality guidelines are not static and will therefore update and modify the guidelines on a regular basis, as determined by ongoing research and review of local and international information on the effects of water quality on water uses and aquatic ecosystems. The process of developing water quality guidelines, and the involvement of key role players, is a continuing one. The second edition is published in a loose leaf, ring binder format to facilitate the regular updating of the guidelines. All those who want to comment on and make suggestions concerning the *South African Water Quality Guidelines* are invited to do so at any time by contacting the Director: Water Quality Management, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001.

Finally I wish to express my sincere appreciation to all those who have been involved in the development of these guidelines. I also look forward to their continued involvement in maintaining one of the cornerstones of the water quality management system in South Africa.

Professor Kader Asmal **MP**  
Minister Of Water Affairs and Forestry

May 1996



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# **Chapter 1**

## **Introduction**

# Introduction

## Scope and Purpose of the Water Quality Guidelines

**Scope**                    *The South African Water Quality Guidelines for Domestic Water Use* are essentially a user needs specification of the quality of water required for different domestic uses. The document is intended to provide the information required to make judgements as to the fitness of water to be used for domestic purposes, primarily for human consumption but also for bathing and other household uses.

The guidelines are applicable to any water that is used for domestic purposes, irrespective of its source (municipal supply, borehole, river, etc.) or whether or not it has been treated.

The guidelines do not address:

- ! water which is sold as a beverage in bottles;
- ! water in swimming pools.

**Purpose**                    *The South African Water Quality Guidelines* are used by the Department of Water Affairs and Forestry as its primary source of information and decision-support to judge the fitness of water for use and for other water quality management purposes.

*The South African Water Quality Guidelines* contain similar information to what is available in the international literature. However, the information here is more detailed, and not only provides information on the ideal water quality for water uses but in addition provides background information to help users of the guidelines make informed judgements about the fitness of water for use.

**Users of the Guidelines**                    *The South African Water Quality Guidelines* are being developed as an important information resource, primarily for water quality managers. Nevertheless, educators and other interested and affected members of the general public are likely to find them a valuable source of information for many aspects of water quality and its management.

**Ongoing Review**                    *The South African Water Quality Guidelines* will be periodically reviewed. The purpose of the reviews is to:

- ! Add guidelines for constituents not yet included;
- ! Update the guidelines for constituents currently included, as relevant new information from international and local sources becomes available on the water quality or support information for a particular constituent.

The loose leaf / ring binder format of the guidelines, as well as the footnotes at the bottom of each page, which clearly indicate the exact version of the guideline, have been designed to facilitate regular updating.

**Overview**                    *The South African Water Quality Guidelines for Domestic Water Use* is divided into six chapters:

- ! Chapters 1 - 4 provide an introduction to the guidelines, define some important water quality concepts, explain how domestic water use was characterised for the purpose of

developing these guidelines, describe how the guidelines were developed and provide some guidance on how they should be used.

- ! Chapter 5 provides the actual guidelines for the different water quality constituents.
- ! Chapter 6 consists of appendices which provide additional support information to users of the guidelines.

## Water Quality

**Introduction** To apply the *South African Water Quality Guidelines* correctly it is important for users to understand how water quality and some related concepts were defined for the purpose of developing the guidelines.

**Definition** The term *water quality* describes the physical, chemical, biological and aesthetic properties of water which determine its fitness for a variety of uses and for protecting the health and integrity of aquatic ecosystems. Many of these properties are controlled or influenced by constituents which are either dissolved or suspended in water.

**Constituents** The term *constituent* is used generically in this edition of the *South African Water Quality Guidelines* for any of the properties of water and/or the substances suspended or dissolved in it. In the international and local literature, several other terms are also used to define the properties of water or for the substances dissolved or suspended in it, for example *water quality variable, characteristic* or *determinand*. Examples of constituents which are used to describe water quality are:

- ! The temperature of the water is 20 EC.
- ! The colour of the water is green.
- ! The concentration of calcium is 60 mg Ca/R.
- ! 30 % of the surface of the water body is covered with Water Hyacinth.

Note that none of the statements of water quality in this example says anything about how desirable or acceptable it is for water to have the properties listed. Therefore, in addition to such statements, one also needs to make a judgement about how desirable or acceptable water of such a quality would be for a particular water use or for maintaining the health of aquatic ecosystems before the fitness of water for use can be determined.

**Criteria** *Water quality criteria* are scientific and technical information provided for a particular water quality constituent in the form of numerical data and/or narrative descriptions of its effects on the fitness of water for a particular use or on the health of aquatic ecosystems.

**No Effect Range** For each water quality constituent there is a No Effect Range. This is the range of concentrations or levels at which the presence of that constituent would have no known or anticipated adverse effect on the fitness of water for a particular use or on the protection of aquatic ecosystems. These ranges were determined by assuming long-term continuous use (life-long exposure) and incorporate a margin of safety.

**Target Water Quality Range** As a matter of policy, the Department of Water Affairs and Forestry (DWAF) strives to maintain the quality of South Africa's water resources such that they remain within the No Effect Range. The DWAF encourages all stakeholders concerned with the quality of South Africa's water resources to join forces and aim to maintain water quality within the No

Effect Range where and whenever possible.

For this reason, the No Effect Range in the *South African Water Quality Guidelines* is referred to as the Target Water Quality Range (TWQR). It is included, and highlighted as such in the water quality criteria provided for each of the constituents in the guidelines.

Users of the *South African Water Quality Guidelines* should note that an important implication of setting the Target Water Quality Range equal to the No Effect Range is that it specifies good or ideal water quality instead of water quality that is merely acceptable.

**Water quality guidelines**

A *water quality guideline* is a set of information provided for a specific water quality constituent. It consists of the water quality criteria, including the Target Water Quality Range, for that constituent together with other support information such as the occurrence of the constituent in the aquatic environment, the norms used to assess its effects on water uses, how these effects may be mitigated, possible treatment options, etc.

The *South African Water Quality Guidelines* consists of guidelines for domestic, recreational, industrial and agricultural water uses, guidelines for the protection of aquatic ecosystems as well as guidelines for the protection of the health and integrity of aquatic ecosystems and guidelines for the protection of the marine environment.

## Fitness for use

**Introduction**

The Department of Water Affairs and Forestry (DWAF) is the custodian of South Africa's water resources. Part of its mission is to maintain the fitness for use of water on a sustained basis. The concept of fitness for use is therefore central to water quality management in South Africa and to the development and use of these guidelines.

**Water use**

Four broad categories of water use are recognised in the South African Water Act, namely the use of water for:

- ! domestic purposes;
- ! industrial purposes;
- ! agricultural purposes; and
- ! recreational purposes.

The DWAF's mandate also requires it to protect the health and integrity of aquatic ecosystems. The water quality requirements of these water uses and those for the protection of aquatic ecosystems, form the basis on which the fitness for use of water is judged.

**Characterisation of water uses**

The broad water use categories listed above can each be subdivided into a number of subcategories such as using water for drinking, cooking, bathing, washing of clothes and gardening. The subcategories of a particular water use can have quite different water quality requirements. Hence the need to characterise water uses into subcategories or components and to specify water quality requirements at a subuse.

The characterisation of water uses involves determining and describing those characteristics which will help determine its significance as well as those that dictate its water quality requirements, for example:

- ! The significance of each water use is determined by considering issues such as the volume of water used, the socio-economic benefits and costs associated with the use; the nature of the use, i.e., whether it is consumptive or not, whether it is abstractive or not, etc.
- ! The water quality requirements of a water use are determined by considering:
  - Typical water quality problems associated with a particular water use or the role that water quality plays in sustaining the use;
  - The effects of poor water quality on the use;
  - The norms that are commonly used as yardsticks to measure the effect of water quality on a particular water use;
  - The water quality constituents which are generally of concern;
  - Any other site- or case-specific characteristics of the water use which may influence its water quality requirements.

**Fitness for use** The fitness for use of water is a judgement of how suitable the quality of water is for its intended use or for protecting the health of aquatic ecosystems.

To be able to make judgements about its fitness for use, one needs to:

- ! characterise the water uses and/or a particular aquatic ecosystem from a water quality perspective;
- ! determine the quality requirements of the intended uses and/or that of aquatic ecosystems;
- ! obtain information on the key constituents which determine the fitness of water for its intended uses and/or which affect the health of aquatic ecosystems;
- ! establish how, and how much, the intended use or aquatic ecosystems will be affected by the prevailing water quality;
- ! determine whether the undesirable effects of water quality on a particular use can be mitigated.

The fitness for use of water can range from being completely unfit for use to being 100 % or ideally fit for a specific use. The narrative descriptions commonly used to express judgements about the fitness of water for use are

- ! ideal; 100 % fit for use; desirable water quality; target water quality range (TWQR);
- ! acceptable;
- ! tolerable, usually for a limited time period only;
- ! unacceptable for use;
- ! completely unfit for use.

**Effects and norms** Water quality can affect water uses or the health of aquatic ecosystems in many different ways. For example, it can affect the:

- ! health of an individual drinking the water or swimming in it;
- ! productivity or yield of a crop being irrigated;
- ! cost of treating water before it can be used in an industrial process;
- ! sophistication of technology required to treat water to adequate quality;
- ! biodiversity of aquatic ecosystems.

It is therefore necessary to use different norms, such as: health effects; crop quality; cost of treatment; sophistication of treatment technology; and the effects on biodiversity as

yardsticks when making judgements about the fitness for use of water.

**Sustained use**

It is important for development, and its associated water uses, to be sustainable. The long-term sustainability of water uses was an important consideration in the development of the guidelines. For example, the water quality criteria for domestic use are based on the assumptions of life-long and continuous exposure to water of a given quality.

The assumptions underlying the development of the guidelines must be taken into account, particularly when making judgments about the fitness of water which needs to be used for a short duration only.





## **Chapter 2**

### **Approach to guideline development**

# Approach to Guideline Development

## Rationale, Approach and Methodology

**Rationale** Many different water quality criteria and guidelines have been published in the international and local literature. Different approaches and methodologies have often been used to derive criteria and guidelines, for example, some guidelines specify maximum concentrations for constituents fit for use, whereas others attempt to define the ideal concentration of a constituent, often with the inclusion of safety factors. Therefore, depending on which guideline or criterion is used to establish water quality requirements, one can arrive at answers that sometimes differ by a factor of a hundred or more.

The rationale for developing the *South African Water Quality Guidelines* was to:

- ! Develop a single set of guidelines and criteria that was appropriate for South Africa, based on a consensus of South African experts and other role players in water quality and fitness for use. The intention of this approach was to limit the confusion that often arose from the use of different criteria and guidelines to establish the water quality requirements for a particular water use by the stakeholders of water supply and utilisation in South Africa;
- ! Modify international guidelines in the light of local research and experience.

**Approach** The approach used to develop the *South African Water Quality Guidelines for Domestic Use* was that the guidelines should, as far as is practically possible, serve as a stand-alone source of information and a support base for decisions, so that water resource managers can make judgements about the fitness for use of water for different domestic purposes. It is accepted that in many cases the user will have to consult different sources or obtain expert opinion before reaching a final conclusion as to fitness of water for use. However, in these cases the guidelines should at least indicate to the users what kinds of information to look for.

Therefore, the guidelines consist not only of the water quality criteria for a specific constituent but also include a substantial amount of information to support the user of the guidelines in making judgements about the fitness of water for domestic use.

In order to decide what information to include in the *South African Water Quality Guidelines* an analysis was done of the DWAF's different water quality management processes. Those that required the guidelines to be used as a source of information and/or "decision support" were identified and their typical information needs determined. The product specification of the *South African Water Quality Guidelines*, delineating the information requirements of the guidelines, was provided to the technical teams responsible for guideline development.

**Methodology** The methodology used to develop domestic water quality guidelines for South Africa entailed:

- ! Listing the various purposes for which domestic water is used;
- ! Describing for each water use the water quality-related problems or issues typically experienced in South Africa;

- ! Determining for each water quality problem or issue the appropriate norm to be used as a yardstick for assessing the effects of water quality on the purpose the water is used for;
- ! Determining, for each norm, which water quality constituents in South Africa typically affect the fitness of water for use, and from this information developing a list of constituents for the domestic guidelines;
- ! Accessing international and local sources of information and expertise to develop draft guidelines for each constituent selected;
- ! Through a process of technical and stakeholder review finalising the guidelines as published in the *South African Water Quality Guidelines*.

**Tentative Guidelines**

The information available on the effects of some constituents on water uses is either very limited and/or there are unresolved differences in opinion on the effects these constituents may have on water uses. In these cases the guidelines have been included in the *South African Water Quality Guidelines* as tentative guidelines, and are clearly indicated as such.

During the ongoing review of the guidelines, it is intended that the status of the tentative guidelines eventually change to regular guidelines, when either sufficient information becomes available or sufficient consensus is reached among experts concerning the effects of these constituents on water uses.

## Sources of Information

**Introduction**

Because the *South African Water Quality Guidelines* are primarily aimed at South African water resources managers and water users, a greater emphasis was given to South African source documents. Opinions of a wide range of South African experts in water quality and water treatment, and of domestic water suppliers and users, were used to supplement published sources. International literature was used primarily as background material.

**Sources of Information**

South African experts in water quality and water treatment, as well as domestic water suppliers and users, were consulted during the development of the guidelines. The following criteria and guidelines published in the international literature were used as background and supplementary information in the development of the *South African Water Quality Guidelines for Domestic Use*:

- ! WHO, 1984. *Guidelines for Drinking Water Quality. Volume 2: Health Criteria and Other Supporting Information*. World Health Organisation, Geneva.
- ! WHO, 1993. *Guidelines for Drinking Water Quality. 2nd Edition, Volume 1: Recommendations*. World Health Organisation, Geneva.
- ! Joint Research Centre, 1989. European Community (EC\*) Drinking Water Standards.
- ! Gardiner and Zabel, 1989. *Standards for Water Abstraction to Potable Supply*.
- ! *Australian Water Quality Guidelines for Domestic Supplies* (Hart, 1974; Hart *et al.*, 1992).

- ! *Canadian Drinking Water Guidelines* (Canadian Guidelines, 1987).
- ! *USA Quality Criteria for Domestic Water Supplies* (NAS/NAE, 1973; US EPA, 1986).
- \* The European Community is referred to as the EC when discussed as an economical/political entity. It is referred to as the European Economic Community (EEC) when citing a Directive promulgated before the formal 1992 change from EEC to EC.

The following criteria and guidelines published in the South African literature were used in the development of the *South African Water Quality Guidelines for Domestic Use*:

- ! South African Bureau of Standards (SABS), 1984. *Specification for Water for Domestic Supplies*.
- ! Kempster and Smith, 1985. National Institute for Water Research (now Division of Water Technology) Proposed Drinking Water Criteria and Department of National Health and Population Development Criteria for Drinking Water Quality (Aucamp and Vivier, 1990);
- ! Kempster and Van Vliet, 1991. Department of Water Affairs and Forestry Internal Discussion Document on Draft Fitness-for-use Curves for Domestic Water Use.



## **Chapter 3**

# **Characterisation of Domestic Water Use**





# Characterisation of Domestic Water Use

**Introduction** The use of water in the domestic environment is common to all consumers and probably provides the widest direct experience of the effects of water quality. The term “domestic water”, as used in these guidelines, refers to water which is used in the domestic environment and refers to all uses water can be put to in this environment. This includes water for:

- ! drinking
- ! food and beverage preparation
- ! hot water systems
- ! bathing and personal hygiene
- ! washing, for example, dishes
- ! laundry
- ! gardening which may include water for fish ponds

**Sources of water** As domestic water is used for a wide variety of activities, it follows that the types of quality requirements for such water represent a synthesis of the needs for the various activities and a wide spectrum of problems may be encountered where water does not meet requirements. Drinking water is often assumed to be the water use with the most stringent quality requirements but other domestic uses such as laundry can dominate quality requirements in some instances. Quality requirements for watering of gardens and animal care (for example, fish ponds) may be derived by consulting guidelines for agriculture (Volume 4) and aquatic ecosystems (Volume 5).

Water supplies to domestic users can originate from impoundments such as dams, from rivers and streams, or from ground water via boreholes. Domestic water supply in South Africa spans a wide range. In cities, consumers generally receive a constant supply of conventionally treated water of high quality. Water in rural areas often receives only partial or minimal treatment, while isolated communities and villages without access to electricity or other amenities often use water directly from rivers or streams without treatment. In the latter cases, both water quantity and quality may be affected by seasonal droughts or floods. Ground water, too, is frequently used with little or no treatment. Water quality problems can also arise when water for domestic supply is obtained from a communal supply and is transported and stored in the home.

Domestic water users can experience a range of impacts as a result of changes in water quality. These may be categorised as follows:

- ! health impacts (short term and long term)
- ! aesthetic impacts, which can include
  - changes in water taste, odour or colour
  - staining of laundry or household fittings and fixtures
- ! economic impacts, which may include
  - increased cost of treatment
  - increased cost of distribution due to scaling, corrosion or deposition of sediments in the distributing system
  - scaling or corrosion of household pipes, fittings and appliances.

**Water Quality Problems** The water quality problems and issues listed above can be identified with the constituents which cause them. Frequently, water quality problems are associated not only with the presence of a constituent, but with the interactions between constituents.

**Constituents** Therefore certain constituents, such as dissolved organic carbon, total hardness and corrosion represent aggregates of constituents which interact to cause a particular water quality effect.

Some constituents are used to characterise a water source, such as those that play a role in causing water quality-related problems, whereas other constituents are associated with site-specific water quality problems.

**Acutely Toxic Constituents** The constituents cadmium, chromium(VI), lead, mercury and vanadium can have either acute and/or irreversible effects on human health, even at very low concentrations. As a precautionary measure, it is **not** advisable to use, for potable purposes, water containing these constituents, at concentrations above the TWQR. To emphasise this warning, a statement cautioning users of the *South African Water Quality Guidelines* is included in the criteria for these constituents.

# **Chapter 4**

## **Information Contained in the Guidelines**

# Information Contained in the Guidelines

## Introduction

The information contained in a guideline for a particular constituent is organised in three sections, namely:

- ! Background information. This section contains most of the support information required to make judgements about the fitness of water for use.
- ! Information on the effects of the constituent, including the criteria, on domestic water uses.
- ! Additional sources of information.

The information in each section of a guideline for a constituent is organised under a series of labels in the left hand margin which identifies the type of information and can assist users of the guidelines to quickly locate the information they require.

## Background Information

**Introduction** The introduction to the guideline for each constituent includes a brief description of the constituent as well as a brief statement of its significance for domestic water uses.

**Occurrence** Information on the fate and occurrence of a constituent in the aquatic environment, as well as the natural and manmade sources thereof are provided as background to help the user determine how widely and in what form and under what circumstances the constituent is likely to occur.

**Interactions** The effects of a water quality constituent on the fitness of water for use can sometimes be significantly modified by synergistic or antagonistic effects caused by the presence or absence of other constituents in the water. These effects, if any, are described in the guideline and should be considered when making judgements about the fitness of water for use.

**Measurement** The effects of many constituents on water use depend on the state (dissolved or particulate) and the chemical species (such as oxidised or reduced; inorganic or organic, etc.) in which they occur. It is important for users of the guidelines to understand how measurement of the concentrations of constituents in water is obtained and which methodologies to use.

**Data Interpretation** The types of effects of constituents on water uses vary from acute to chronic. It is important that the appropriate statistics, depending on the type of effect that is likely, are estimated from datasets and used to make judgements about the fitness of water for use.

For example, if the type of effect is acute then statistics which estimate extreme values, such as the maximum or the 95th percentile, should be used to compare against the water quality criteria provided, whereas if the effects are mostly chronic then estimates of the average situation, such as the median value, should be used.

## **Treatment Options**

There is a wide variety of options, or combinations of options, to:

- ! Improve, with the use of various treatments, the quality of raw water supplied to water users;
- ! Improve, with the use of various treatments, the quality of water on site by the users themselves. For example, to boil raw water drawn from a river before drinking it.

The cost of and the ease with which management interventions can be implemented are important factors that can influence judgements about the fitness of water for use. The feasibility of such interventions depends on

- ! feasibility and availability of technological solutions;
- ! social acceptability;
- ! scale of the intervention required;
- ! institutional capacity to implement and sustain interventions;
- ! availability of suitably qualified people to implement and maintain the intervention;
- ! capital and operating costs of implementing the intervention.

The information on treatment provided in the guidelines is very general and provided simply to give the user of the guidelines a first indication of whether management intervention in the form of treatment is possible. It is expected that if that option is pursued the user would obtain expert advice on water treatment.

## **Effects and Criteria**

### **Norms**

The norms used as yardsticks for assessing the effects of a particular water quality constituent on the fitness for use of water are described in this section of the guideline.

### **Effects**

Water quality has different types of effects on specific water uses. These effects can range from

- ! acute to chronic;
- ! reversible to irreversible;
- ! recoverable to irrecoverable.

To make informed judgements on the fitness of water for use it is important that users of the guidelines take into account the information on what types of effects can be expected.

As a result of the hydrological characteristics of South African rivers, flow and consequently water quality, can be highly variable. The effects of water quality on water uses often depend on the duration of exposure to water of a given quality. Therefore, users of the guidelines must also consider information on the likely duration of the exposure to water of particular quality when judging the fitness of water for use.

The effect of a given water quality on its fitness for use can be significantly enhanced or suppressed by other factors, such as:

- ! Adaptation of organisms, including people, to water of a certain quality;
- ! The diet of the people, animals and organisms using water;

! The effects of climate, for example, on water intake by animals and people;

Users of the guidelines need to take into account the information provided on environmental factors and interactions with other constituents when deciding on the fitness of water for use.

### **Mitigation**

The undesirable effects of water quality on its fitness for a specific use can often be prevented or mitigated through management interventions during use or at the point of use. These interventions can, for example, include the addition of chemicals to water during use to reduce staining, scaling, corrosion, etc. or taking measures to reduce the consumption of water of poor quality in order to minimise possible negative effects.

The user of the guidelines is provided with relevant information on the availability of options for intervention and the feasibility of implementing such interventions.

The information on mitigation provided in the guidelines is very general and is provided simply to give the user of the guidelines a first indication of whether management intervention in the form of mitigation is possible. It is expected that if that option is to be pursued that the user would obtain expert advice on the different mitigation options.

### **Criteria**

In the guidelines for domestic water use, the water quality criteria for most of the constituents is provided in the form of a table in which the effects of increasing concentrations of the constituent are described using the appropriate norms. The no-effect range, designated in the *South African Water Quality Guidelines* as the Target Water Quality Range, is highlighted. The target water quality describes what is considered good or ideal water quality and therefore water quality outside of this range may, under certain circumstances, still be acceptable.

### **Modifications**

There are many site- and case-specific factors which modify the effects of water quality on specific water uses. Examples of such site and/or case factors are:

- ! People working underground in deep mines drink very large volumes of water and could therefore experience effects from poor water quality.
- ! Some chemical forms of a constituent may be much more toxic than others, for example, organic mercury is five to 10 times more toxic than inorganic forms.

It is therefore important that the information on site- or case-specific modification of the guidelines be considered when making judgements about the fitness of water for use.

The information on modification provided in the guidelines is very general and is provided simply to give the user of the guidelines a first indication of whether the criteria for a constituent could or should in certain cases be modified. It is expected that if it appears that the criteria should be modified in a particular case, that the user of the guidelines would obtain expert advice on this issue.

## **Sources of Information**

It was not possible to include in these guidelines all the constituents which may possibly affect the fitness of water for domestic use, or to include all the relevant information on the

constituents for which guidelines were developed.

The user is therefore referred to additional sources on information on a particular constituent. These same sources of information can in some cases also provide information on constituents which are not yet included in the *South African Water Quality Guidelines*.

Should the user of these guidelines require additional information it must be remembered that, besides the publications referenced in the guidelines, there is also a wealth of unpublished information available from a number of organisations and individuals in South Africa. The people and organisations who participated in the development of these guidelines are acknowledged in a list at the front of these guidelines, and this is a good starting point for accessing this information.

# **Chapter 5**

## **Water Quality Constituents**



# Algae

## Background Information

**Introduction** Algae is a term referring collectively to a wide range of pigmented, oxygen-producing, photosynthetic organisms usually present in surface waters. Virtually all aquatic vegetation without true roots, stems and leaves is regarded as algae. Algae range from microscopically small unicellular forms, the size of bacteria, to larger filamentous forms which can be metres in length. Like other plants, algae are primary producers requiring light, carbon dioxide, water, nutrients such as nitrate and phosphate, and trace elements for growth. Algae are common inhabitants of surfaces water exposed to sunlight.

Algae play an important role in the natural purification of surface waters through the assimilation of nitrogen species (ammonia and nitrate) during photosynthesis. Algal photosynthesis also releases oxygen as a by-product into the aquatic environment. Algae often form the basis for aquatic food webs. Algal overgrowths or the presence of noxious algal species can, however, become a nuisance and interfere with the desirable uses of a water body. This can be a natural phenomenon, but is often the result of accelerated eutrophication (nutrient enrichment) caused by human activities.

**Occurrence** Algae can loosely be grouped into three types, *free floating algae* (phytoplankton), *attached filamentous algae* and *algae that coat rocks, plants and sediments* (periphyton).

The classification of algae is extremely complex. However, for the purposes of this guideline, the following groups are important:

- ! **Blue-green algae:** These typically dominate highly nutrient-enriched waters and are sometimes referred to as cyanobacteria.
- ! **Green algae:** These are common summer residents of less enriched water bodies.
- ! **Euglena:** These are flagellate unicellular algae, typical of organically-enriched water.
- ! **Diatoms:** These are flagellate unicellular algae surrounded by a silica coating. This group often dominates winter algal populations.

There are several types of algae which produce toxins, of which two types appear to be the most common. In marine waters some dinoflagellates are responsible for toxic red tides. In fresh waters, the blue-green algae are often responsible for the occurrence of toxic algal blooms. In South Africa the most common bloom-forming toxic species are *Microcystis spp* and *Anabaena spp*, although a number of other species may also produce toxins on occasion.

Blue-green algae produce a variety of neuro-, hepato- and lipopolysaccharide toxins. These toxins have been associated with a number of livestock and game deaths, and with widespread gastroenteritis in human populations. Skin irritations have also been reported in swimmers. These toxins have been known to penetrate standard water treatment processes, but recent work has shown that chlorination which ensures a 0.5 mg/R chlorine residual after 30 minutes contact time is sufficient to destroy the toxins. This process may, however, give rise to by-products which are also potentially toxic.

Chlorophyll *a* concentrations vary from less than 1 µg/R in clear waters to well over 50 µg/R in severe nuisance conditions. In extreme cases concentrations in excess of 1 000 µg/R have been recorded. Cell counts can range from less than 50 cells/mR in clear waters to many thousands of cells/mR in the case of algal blooms.

**Interactions** The amount of algae in surface waters is usually limited by the concentration of nutrients, in particular nitrogen and phosphorus. In turbid waters light availability and other physical conditions can influence the growth of algae. Photosynthetic uptake of CO<sub>2</sub> by day and release of CO<sub>2</sub> by night can cause pH fluctuations, particularly in poorly buffered water. Dense algal growth and the resultant collapse of algal populations may lead to oxygen depletion, often responsible for fish-kills and the death of other aquatic organisms. Algae and their extracellular products constitute a major part of the organic matter that are precursors for the formation of **trihalomethanes** (THMs) during chlorination.

**Measurement** Measurement of algal biomass is usually by means of the chlorophyll *a* concentrations, even though the percentage of chlorophyll *a* varies between species or during the lifecycle of a species. Concentrations are expressed as Fg/R chlorophyll *a*. Chlorophyll *a*, which is present in all algae (except the so-called colourless algae), constitutes approximately one to two percent of the dry weight of organic material in all planktonic algae and is the most convenient indicator of algal biomass estimates. All available analytical methods require pigment extraction as a preliminary step.

The density of algae in water can also be measured in terms of algal cell or colony counts. This method, while more labour intensive, may provide a more accurate measure of the amount of algae present, as well as providing an indication of the species of algae. Counting is usually preceded by preserving and staining of the cells, and counting is normally done using an inverted microscope fitted with a micrometer grating. Counting may also be preceded by disruption of the colonial forms. Blue-green algae, particularly the colonial or filamentous forms, can be enumerated by counting the number of blue-green units (a single colony or filament) detected in a two-minute scan of 0.5 mL of water under x 200 magnification. This is the simplest and most rapid method of assessing the density of blue-green algae present and hence the risk of toxicity, but the method does not account for the difference in colony size.

**Data Interpretation** Seasonal fluctuations in algal numbers and chlorophyll concentrations can be considerable, and are not always accurately represented by a single sample or median value. Infrequent algal blooms can lead to high concentrations, which may result in severe treatment difficulties. If annual mean values are used, the results tend to be biased toward occasional very high values. Therefore analysis of the distribution of algal cell counts or chlorophyll *a* concentrations from routine samples may indicate the incidence of temporal problems. This is particularly important when evaluating the chronic risks associated with the algal toxins.

Waters prone to algal blooms are typically dominated by one or two species. The species present may also provide an indication of the problems that are likely to be encountered. For example, diatom algae are known to block filter apparatus, while many of the *Euglenophytes* can penetrate standard sand filtration systems. Blooms of blue-green algae increase the risk of toxin penetration of the treatment process, and *Anabeana spp.* can result in taste and odour problems even when present in very low numbers.

**Treatment Options** Effective removal of algae in the treatment process depends on the species present. In general removal requires coagulation, flocculation and/or sedimentation. Some species, for example *Microcystis spp.*, are buoyant and therefore lend themselves to dissolved air floatation. Coagulants like aluminium sulphate or ferric chloride are conventionally used, with the addition of small doses of polyelectrolytes to assist flocculation, followed by deep bed or multimedia filtration. The use of activated carbon, in particular granular activated carbon (GAC), is an effective means of removing the algal toxins and other algal by-products from treated water. In the absence of activated carbon treatment (which is

expensive), care should be taken to remove whole cells before treatment with an oxidant, since oxidants cause cell lysis, and the release of toxins and other intracellular products. However, it has recently been indicated that a chlorine residual of 0.5 mg/l after 30 minutes contact time is sufficient to destroy acute toxicity of the hepatotoxins. Chlorination may, however, produce other potentially toxic by-products.

## The Effects of Algae

**Norms** The norms used in the guideline for algae are human health and aesthetic effects.

**Effects** Treatment of water containing algae can result in the breakdown of algal cells giving rise to tastes and odours, which render the water less acceptable for domestic use. The presence of algal cells in the reticulation system may also contribute to bacterial regrowth in the distribution system and can give the treated water a greenish colour.

Ingestion of the hepatotoxins in sufficient quantities can lead to endotoxic shock and liver haemorrhage. Severe gastroenteritis, vomiting and liver function impairment in populations supplied from water bodies dominated by blue-green algae have been noted. There is also limited evidence of an increased incidence of liver cancer in populations exposed to low concentrations of hepatotoxins in untreated surface water over an extended period.

Incidences of neurotoxic poisoning from red tides are common in many coastal cities, but no incidence of widespread human diseases associated with freshwater algal neurotoxins have been noted. Neurotoxic poisoning in other mammals has been recorded, and is typified by muscular tremors, paralysis and convulsions. Death is by respiratory arrest.

During chlorination, algae and their extracellular products can serve as precursors for the formation of THMs. Long-term ingestion of excessive levels of THMs is associated with a small risk of developing gastrointestinal cancer.

**Mitigation** The treatment of human toxicosis from freshwater algal toxins has not been extensively studied, and no known antidotes to the toxins are available. However, treatment after ingestion of whole cells or toxins should be symptomatic.

Water treatment options should be designed to limit the risk of post-treatment toxin activity, and the production of THMs.

**Criteria** Two separate tables of criteria are provided. One assesses the aesthetic effects of chlorophyll *a* concentrations on domestic waters, and the other assesses the potential human health effects of blue-green algae in the domestic supply. The impact of algae on treatment processes is not considered.

### ! Effects of Chlorophyll *a* on Aesthetics

Algae Range (Fg/l chl <i>a</i> )	Effects
Target Water Quality Range 0 - 1	Negligible risk of taste and odours

1 - 15	A slight green colouration to the water at concentrations < 7 µg/R. Above this the water has a noticeably murky appearance and taste and odour problems can occur, particularly with blue-green algae. May promote the growth of bacteria in the distribution system
> 10	Water has a distinct murky appearance, becoming increasingly green in colour. Significant taste and odour problems. Secondary growth of bacteria in the distribution system

### ! Effects of Blue-green Cell Numbers on Human Health

Algae Range (cells/mR)	Effects
<i>Target Water Quality Range</i> 0 - 50	<i>No health effects expected with any of the blue-green algal species and no aesthetic effects likely</i>
50 - 14 000	Possible chronic effects associated with the long-term ingestion of blue-green algae at this concentration. No acute health effects expected. Possible acute neurotoxic effects associated with the ingestion of particularly <i>Anabeana spp.</i> Taste and odour problems likely with this species over 1 000 cells/mR
14 000 - 42 000	Possible acute hepatotoxic effects associated with the ingestion of <i>Microcystis spp</i> in children (10 kg) drinking one litre of water/day. Taste and odour problems likely
> 42 000	Significant risk of acute and chronic effects associated with the ingestion of the algae

**Note:** The above criteria are tentative and based on limited data.

Recent work in Australia has suggested drinking water guidelines for the microcystins (the most common form of hepatotoxins). Criteria for these are provided below.

### ! Effects of Microcystins on Human Health

Microcystin Range (µg/R)	Effects
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<b>Target Water Quality Range</b> 0 - 0.8	<b>No health effects expected</b>
0.8 - 1	Possible chronic effects associated with the long-term ingestion of microcystins in the drinking water. No acute health effects expected
> 1	Possible acute hepatotoxic effects

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# Aluminium

## Tentative Guideline

### Background Information

**Introduction** Pure aluminium is a silvery-white, soft, light metal resistant to corrosion by the formation of a thin protective layer of the oxide of aluminium. Aluminium does not appear to be an essential nutrient for humans and is for all practical purposes non-toxic at near-neutral pH values in unpolluted environments. Aluminium salts are not normally absorbed from food and water, but are complexed with phosphate and excreted in the faeces. The dietary intake of aluminium can be as much as 10 mg/day.

**Occurrence** Aluminium is the most common metal in the earth's crust, having an abundance of 81 g/kg. Aluminium does not occur in the elemental form, but its minerals, particularly the silicates of aluminium, are widespread. Some important minerals containing aluminium are bauxite (hydrated aluminium oxide), spinel (magnesium aluminium oxide) and the kaolins (various aluminium silicates).

Aluminium occurs in water in two main phases, either as suspended aluminium minerals or as dissolved aluminium species. Where aluminium occurs as a hydrated Al(III) cation, it hydrolyses and precipitates as insoluble aluminium hydroxide around neutral pH. The concentration of dissolved aluminium in unpolluted water at neutral pH is 0.005 mg/l or less. In acidic waters, or where soluble aluminium complexes are present, the dissolved aluminium concentration can rise to high mg/l values.

**Interactions** Aluminium oxide and hydroxide are amphoteric, that is, they are insoluble in water around neutral pH, but dissolve under strongly acidic or strongly alkaline conditions. As such, the interactions of aluminium are strongly influenced by **pH**, the chemistry of the aluminium hydroxide and the nature of available organic and inorganic complexing ligands. For example, **fluoride** can keep aluminium in solution at neutral pH.

**Measurement** The criteria refer to the dissolved aluminium concentration, i.e. aluminium which passes through a 0.45 µm membrane filter. The reference method for determining the concentration of aluminium is atomic absorption spectrometry using a nitrous oxide flame and addition of potassium as an ionisation suppressant. If other methods are used, such as colorimetric methods, their characteristics relative to the reference method should be known.

If total aluminium (the dissolved plus suspended fraction) is measured, the sample should be acidified before filtration. A vigorous digestion step is required since the acidification step will only dissolve species such as aluminium hydroxide and not aluminium silicate minerals.

**Data Interpretation** Mean values should be used in interpreting the criteria given. The pH value, as well as the fluoride concentration, should also be taken into account, since fluoride tends to form complexes with aluminium, and may keep aluminium in solution at neutral pH, where it would otherwise precipitate.

**Treatment Options** The technologies available for removing aluminium from water include:

- ! The formation and precipitation of insoluble aluminium salts. Aluminium ions will react with alkalinity in the water to form aluminium hydroxide which is insoluble in the pH range 6.7 - 7.6. The particles formed may be very light and difficult to settle without the addition of a polyelectrolyte to flocculate and increase the specific gravity of the particles. However, if the water has a high concentration of suspended clay particles, settlement is fairly fast and the addition of polyelectrolytes is unnecessary. Light particles can also be settled out in properly designed sedimentation tanks without polyelectrolytes.

An alternative is to dose with a phosphate solution and remove the aluminium as insoluble aluminium phosphate.

- ! Exchange of sodium by aluminium in a cation exchange column along with calcium and magnesium.
- ! Removal of aluminium together with other dissolved components using desalination techniques such as demineralisation by ion exchange, membrane processes or distillation methods.

All of the methods described require skilled monitoring and control, and generate a concentrated waste stream that may cause disposal difficulties.

## The Effects of Aluminium

**Norms** The norms used in the guideline are based on human health and aesthetic effects. The major adverse effects of aluminium in water used for domestic purposes are aesthetic, although chronic human health effects at high concentrations can occur.

**Effects** The main effects of aluminium in domestic water are aesthetic, relating to discolouration in the presence of iron or manganese. Aluminium is also used in water treatment processes, which may result in increased concentrations of aluminium in the final water.

Prolonged exposure to aluminium has been implicated in chronic neurological disorders such as *dialysis dementia* and Alzheimer's disease. It is, however, not clear whether the presence of aluminium causes such conditions or is an indicator of other factors. **Therefore, the link between aluminium in water and adverse effects on human health remains to be conclusively identified.**

Although not strictly related to consumption of drinking water, the consumption of large quantities of aluminium hydroxide in the form of proprietary "antacids" for the relief of minor stomach discomforts can lead to excessive loss of phosphate.

**Mitigation** Measures to mitigate against the effects of aluminium ingestion are unnecessary since aluminium is rapidly eliminated as aluminium phosphate through faeces and in urine.

**Criteria** **Effects of Aluminium on Aesthetics and Human Health**



Aluminium Range (mg/R)	Effects
<i>Target Water Quality Range</i> 0 - 0.15	<i>No acute or chronic health effects occur. Intake from water is &lt; 5 % of the total dietary intake of aluminium. Generally, no adverse aesthetic effects occur. Very slight discolouration of water may become apparent when iron or manganese is present in association with aluminium at the upper limit of the range</i>
0.15 - 0.5	Intake from water may exceed 5 % of the total dietary intake, but no effects on health are expected. Noticeable adverse aesthetic effects (colour) occur when aluminium is present in association with iron or manganese
> 0.5	Intake from water exceeds 5 % of the total daily intake, but no acute health effects are expected except at very high concentrations. There may be long-term neurotoxic effects. <b><i>This relationship has not been conclusively demonstrated.</i></b> Severe aesthetic effects (discolouration) occur in the presence of iron or manganese

**Modifications** Where water is used for renal dialysis or for the preparation of intravenous fluids, the TWQR for aluminium should be 50 times less than what is indicated above, that is, a TWQR of 0 - 0.003 mg/R should be applied.

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# Ammonia

## Background Information

- Introduction** Ammonia (NH<sub>3</sub>), where the nitrogen atom is in the III oxidation state, can readily take up an additional (hydrogen ion) to form the ammonium ion (NH<sub>4</sub><sup>+</sup>). In solution ammonia occurs in equilibrium with the ammonium ion and the position of equilibrium is governed by pH and temperature. Ammonia is not toxic to man at the concentrations likely to be found in drinking water but does exert other effects. For example, elevated concentrations of ammonia can compromise the disinfection of water and give rise to nitrite formation in distribution systems, which may result in taste and odour problems.
- Occurrence** At high pH, ammonia exists predominantly as a gas in solution, and can be released to the atmosphere from water. At low and neutral pH, ammonia is found predominantly as the ammonium ion. Ammonia can also be microbiologically oxidised to nitrates.
- Surface waters which are not contaminated with organic wastes, generally have a low ammonia nitrogen concentration, typically less than 0.2 mg/R. Concentrations exceeding 10 mg/R are found in raw untreated sewage; ammonia concentrations tend to be elevated in waters where organic decomposition under anaerobic conditions takes place. Ammonia is found in runoff from agricultural lands, where ammonium salts have been used for fertilizers.
- Interactions** The chemical reactions and toxicity effects of ammonia are closely correlated to **pH**. Ammonia is more toxic under alkaline than neutral conditions, but has a very low toxicity under acidic conditions. Ammonia can also form complexes with many of the transition metals, notably **copper**.
- Measurement** The criteria are based on the free ammonia nitrogen concentration. This is the sum of the NH<sub>3</sub> and NH<sub>4</sub> nitrogen concentrations, and is given in units of mg/R. The reference method for the determination of ammonia is the phenate colorimetric method, where an intensely blue compound, indophenol, is formed from the reaction of ammonia, phenol, and hypochlorite, under catalysis by Mn(II). Where other methods are used, their characteristics relative to the reference method should be known.
- Data Interpretation** Mean values should be used to compare with the criteria given.
- Treatment Options** At near-neutral pH, the non-toxic ammonium ion predominates while the toxic-free ammonia form predominates as the pH increases to approximately 11. The volatile nature of the free ammonia form provides a useful treatment technique to remove ammonia from water supplies. The pH of the water can be increased to greater than 11.0 by the addition of a strong alkali such as sodium hydroxide, to convert all the ammonia to the volatile free form.
- Treatment involves spraying water in droplet form down through a vertical stripping tower, through which air is blown countercurrent to the water flow. This strips the volatile ammonia from solution into the atmosphere with the air stream, leaving ammonia residuals of less than 1.0 mg/R. Air stripping of ammonia may, however, cause a local smell nuisance

if the ammonia concentrations are significantly high.

The water is then made usable by re-adjusting the pH to approximately 7. Any residual ammonia is likely to exist as the non-toxic ammonium ion. If total removal of ammonia is required the water can be passed through commercially available ion exchange resins which have an affinity for ammonia.

Ammonia removal systems are not suited to treating domestic water on a household scale.

## The Effects of Ammonia

**Norms** The norms used in the guideline for ammonia are primarily based on aesthetic effects, although indirect health effects associated with the possible formation of nitrite in distribution systems have been taken into account.

**Effects** The chemistry of ammonia is very complex, especially where transition metals are present in water, and while ammonia itself is of relatively low toxicity, this is not necessarily the case for some of its organometallic complexes.

Taste and odour complaints are likely to occur if the ammonia concentration exceeds 1.5 mg/R. High concentrations of ammonia can also give rise to nitrite, which is potentially toxic, especially to infants.

**Mitigation** Investigate the causes of associated taste and odour problems and implement measures designed to control eutrophication.

**Criteria** **Effects of Ammonia on Aesthetics and Human Health**

Ammonia Range (mg/RN)	Effects
<i>Target Water Quality Range</i> <i>0 - 1.0</i>	<i>No health or aesthetic effects</i>
1.0 - 2.0	Possibility of taste and odour complaints from consumers
2.0 - 10.0	Consumer complaints of objectionable taste and odours likely. Disinfection by chlorine can be compromised
> 10.0	Unacceptable in domestic water. Danger of formation of nitrite. Likelihood of fish deaths in aquaria. Chlorination is severely compromised

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# Arsenic

## Background Information

**Introduction** Arsenic is a greyish semi-metal and occurs in three oxidation states, namely, (0), (III) and (V). In solution arsenic can exist as arsenite, As(III); arsenate, As(V); and as various organic complexes. Inorganic arsenates form arsenate salts with cations of calcium or iron. Soluble arsenic compounds are readily taken up by living organisms and at elevated concentrations can exert toxic effects. Once absorbed by living organisms, arsenic is excreted slowly, and hence accumulation easily occurs. Ingestion of arsenic in drinking water is most likely to lead to chronic effects, principally different types of skin lesions.

**Occurrence** Arsenic is fairly widespread in the environment, the average concentration in the earth's crust being approximately 2 mg/kg. It is found as arsenates, with sulphides and in association with many other metallic ores, and occasionally in the elemental form.

Typically, the concentration of arsenic in fresh water is less than 1 Fg/l and in sea water, approximately 4 Fg/l. Elevated concentrations of arsenic occur where there is pollution from industrial sources, or where geological outcrops of arsenic minerals occur. For example, new borehole water supplies in areas where arsenic minerals occur, should be tested for arsenic.

Arsenic is used in metallurgy, in the manufacture of glassware and ceramics, and as a pesticide and wood preservative.

**Interactions** To a large extent **pH** and redox potential determine the inorganic arsenic species present in water. Metabolically, arsenic interacts with many elements, among them **selenium** and iodine.

**Measurement** The reference method for the determination of arsenic is atomic absorption spectrometry with hydride generation. The various forms of arsenic are converted to As(V) in an acid digestion and then reduced to As(III), prior to the generation of arsine gas with borohydride. If other methods are used to measure arsenic, their characteristics relative to the reference method should be known.

**Data Interpretation** Once absorbed, arsenic is not readily lost and accumulates in the body. Therefore a single, once-off exposure to a high concentration of arsenic can have serious effects. The criteria given should be interpreted as maximum values not to be exceeded. If mean values are used they must be **five times** less than the non-exceedance values.

**Treatment Options** Arsenic is most effectively removed from water in its pentavalent form. Trivalent arsenic is first converted to the pentavalent form using an appropriate oxidising agent such as chlorine or potassium permanganate. Pentavalent arsenic is effectively removed from water using conventional coagulation and flocculation processes followed by settlement and filtration. Suitable coagulants include aluminium sulphate, ferric salts and lime.

The process requires monitoring to ensure the arsenic is effectively removed. The process will also generate a watery sludge rich in arsenic, that may present disposal problems.

## The Effects of Arsenic

- Norms** The norm used in the guideline for arsenic is human health.
- Effects** Arsenic is slowly excreted from the body, hence it can easily accumulate. Poisoning can be both chronic and acute. Chronic poisoning is characterised by skin lesions including hyperpigmentation and cancer, while acute poisoning can result in death from upper respiratory, pulmonary, gastrointestinal and cardiovascular failure. Nerve damage, characterised initially by sensory loss in the peripheral nervous system, is a primary symptom of arsenic poisoning.
- Mitigation** The chronic effects of ingesting arsenic, excluding cancer, may be reversed by discontinuing exposure. Acute effects may be reversed by administering chelation therapy using 2,3-dimercaptopropanol (British Anti-Lewisite). If arsenic poisoning is suspected medical advice should be sought immediately.

**Criteria** **Effects of Arsenic on Human Health**

<b>Arsenic Range (Fg/R)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 10</i>	<i>No health effects expected; ideal concentration range</i>
10 - 200	Tolerable concentration, but low risk of skin cancer in highly sensitive individuals over long term
200 - 300	Increasing possibility of mild skin lesions over long term. Slight possibility of induction of skin cancer over long term
300 - 600	Possible adverse, chronic effects in sensitive individuals; brief exposure has no effect; skin lesions, including hyperpigmentation, will begin to appear on long-term exposure
600 - 1 000	Symptoms of chronic poisoning such as skin lesions, including hyperpigmentation, will appear on long-term exposure
1 000 - 10 000	Cancer or death will result from chronic poisoning
> 10 000	Death will result from acute poisoning

**Note: It is recommended that the concentration of arsenic in potable water should never exceed 200 Fg/R, but ideally should not exceed the TWQR.**

**HUMAN HEALTH IS SERIOUSLY AT RISK IF 200 F/R IS EXCEEDED.**

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# Asbestos

## Tentative Guideline

### Background Information

**Introduction** Asbestos is a fibrous silicate mineral which is chemically relatively inert, but is hazardous when inhaled. Asbestos fibres in water are of concern, and epidemiological evidence indicates that occupational exposure to asbestos gives rise to a higher incidence of lung and gastrointestinal tract cancers. In particular, mesothelioma, a specific type of cancer, is directly associated with asbestos damage in lung tissue.

**Occurrence** Asbestos minerals are the fibrous amphiboles and serpentines. Through weathering, mining and industrial use, asbestos fibres are released into the environment where they tend to accumulate in soils and sediments, sometimes reaching high fibre counts. Raw waters can contain up to  $2 \times 10^9$  fibres/R.

Asbestos has many industrial uses and applications. It is used in the manufacture of asbestos cement pipes and products, and as a heat insulating material.

**Interactions** Asbestos fibres, by virtue of their inertness, do not interact significantly with other constituents in water.

**Measurement** The criteria refer to total asbestos fibre counts/R. Asbestos fibres are counted using electron microscopy techniques.

**Data Interpretation** Single-sample maximal values should be used to compare with the criteria given and should be interpreted as non-exceedance values. Asbestos fibre counts of less than  $1 \times 10^6$ /R are not considered significant. Any possible health hazard is an indirect one, as the principal danger presented by asbestos fibres is through inhalation.

**Treatment Options** Since asbestos fibres in water are difficult to count, they are usually measured as turbidity. General practice is to assume that the asbestos fibre content is acceptable if the turbidity of the water does not exceed 0.2 NTU. Treatment is aimed at reducing the turbidity of the water, to 0.1 NTU. See **turbidity**.

Treatment of water to remove asbestos depends on the concentration of fibres and their length. The longer fibres (two to 100 Fm) in concentrations greater than  $10^{14}$  fibres/mR can be removed (up to 80 % removal) by conventional sedimentation. Further removal is normally achieved by coagulation and filtration. Suitable coagulants or flocculants, such as aluminium sulphate or polyelectrolytes are used. Filtration through mixed media filters or diatomite (diatomaceous earth) will usually bring about a reduction in fibre concentration of 99 % - 99.9 %, provided coagulants have been optimally dosed.

The fibres are removed in a concentrated stream, either as the sedimentation tank underflow or the backwash stream from filters. Careful consideration needs to be given to safe and responsible disposal of the concentrate stream.

## The Effects of Asbestos

- Norms** The norm used in the guideline for asbestos is human health.
- Effects** The criteria are based on epidemiological studies which indicate that the risk of developing cancer is insignificant for asbestos fibre counts in drinking water of  $1 \times 10^6$  fibres/R.
- Asbestos in drinking water *per se* does not present a cancer risk. It is only indirectly, by inhalation, that a risk is thought to exist. Epidemiological studies indicate that inhalation of asbestos fibres rather than ingestion of fibres in water or food poses an increased risk of developing an associated cancer. The chief hazard is from the inhalation of fibres that have been deposited on clothing after the washing thereof in water containing asbestos fibres.
- Mitigation** Asbestos fibre counts can be considerably reduced through coagulation and filtration processes, and where turbidity is reduced to less than 0.1 NTU, it can be assumed that the asbestos fibre count will be within the TWQR.

**Criteria** **Effects of Asbestos on Human Health**

Asbestos Fibre Count Range (Fibres/R)	Effects
<i>Target Water Quality Range</i> <i>0 to <math>1 \times 10^6</math></i>	<i>No adverse health effect expected</i>
$1 \times 10^6 - 1 \times 10^7$	Minimal health risk in drinking water, insignificant risk of cancer on inhalation
$> 1 \times 10^7$	Increasing risk of cancer, but only after <i>inhalation</i> of the fibres in the water

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# Atrazine

## Tentative Guideline

## Background Information

<b>Introduction</b>	Atrazine is a synthetic organic chemical classified as a triazine herbicide. It is used to suppress weed growth in edible crop production. The presence of atrazine residues in domestic water is of concern since there is evidence that atrazine may be carcinogenic in some animal species; this may indicate potentially carcinogenicity in humans. The total tolerable dietary intake for atrazine is 0.5 Fg/kg of body weight (BW)/day.
<b>Occurrence</b>	Atrazine occurs in the environment as a consequence of its persistence after application in agricultural usage. Atrazine residues can remain in soils and water for long periods because they are only slowly hydrolysed under neutral pH conditions. The typical half-life in soil is 60 - 150 days, and, residues may be detectable for several years after use. Atrazine, being lipid soluble, is readily taken up by living organisms, where it concentrates predominantly in the fatty tissues. On uptake in plants, atrazine can be metabolised into other compounds.
<b>Interactions</b>	Microbiological activity and <b>pH</b> play a significant role in the breakdown rate of atrazine in soils and water. Atrazine is also broken down by sunlight.
<b>Measurement</b>	The criteria are given in terms of the total extractable atrazine concentration, in units of Fg/R. The reference method for the determination of atrazine is by gas chromatography after solvent extraction and clarification.
<b>Data Interpretation</b>	Mean values should be used in the interpretation of the criteria given.
<b>Treatment Options</b>	Atrazine, together with the more commonly used pesticides, can be effectively removed from water by passing it through a granular activated carbon column. The filtered water requires monitoring to ensure that removal is complete. Breakthrough of contaminants from activated carbon filters may occur without warning. Alternative methods currently being investigated use ozone or peroxone for the oxidative destruction of atrazine or compounds thereof.

## The Effects of Atrazine

<b>Norms</b>	The norm used in the guideline for atrazine is human health.
<b>Effects</b>	The oral toxicity of atrazine to mammals is low. The LD <sub>50</sub> is approximately 22 000 mg/kg. Chronic exposure can result in an increased cancer risk.
<b>Mitigation</b>	There are no known means of mitigating against the effects of atrazine intake.

### Criteria **Effects of Atrazine on Human Health**

<b>Atrazine Range (Fg/R)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 2</i>	<i>No health effects for lifetime exposure</i>

2 - 20	No health effects for an exposure period not exceeding seven years. Exposure longer than seven years carries a potential risk of cancer incidence
> 20	Possibility of a long-term risk of cancer induction

**Note:**

The criteria are based on those given by the WHO, 1993. The No Adverse Effect Level (NOAEL) for a rate of 0.5 mg/kg is divided by 1 000 to account for intra and interspecies uncertainty and potential carcinogenicity, to arrive at a safe daily intake for man (lifetime exposure), of 0.5 µg/kg. Taking the water contribution as 10 % of the total dietary atrazine exposure, gives a concentration of 2 µg/l for water for a lifetime exposure. Where the exposure is only for a limited period, (seven years, or one tenth of the average life span), then a level of 20 µg/l is considered acceptable.

**Since the criteria given above are based on interspecies risk calculations, there is a degree of uncertainty in the derived values. Further research into the effects of atrazine on mammals and humans is required.**

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# Cadmium

## Tentative Guideline

### Background Information

**Introduction** Cadmium is a soft, bluish-white metal, chemically similar to zinc and highly toxic to living organisms. The presence of cadmium in the aquatic environment and in drinking water is of concern because it bioaccumulates. Cadmium has a low solubility under conditions of neutral or alkaline pH and is highly soluble under acidic conditions, where toxic concentrations can easily arise from the dissolution of cadmium from cadmium-plated materials.

**Occurrence** Cadmium occurs in association with zinc ores and is also found as the mineral Greenockite (cadmium sulphide). Cadmium sulphide, carbonate and hydroxide salts are insoluble in water, whereas cadmium chloride, nitrate and sulphate salts are highly soluble in water. Cadmium binds strongly to sulphhydryl groups, hence, the pronounced tendency of cadmium to bioaccumulate in the food chain. Cadmium is not usually found in water at concentrations greater than 1 Fg/R, unless the water has been subject to pollution from cadmium containing industrial effluents.

Cadmium is used in electroplating, in alloys, in certain solders and in nickel-cadmium batteries. Salts of cadmium are used in photography, pottery, the electronics industry and as pigments in many different applications.

**Interactions** Cadmium interacts strongly with **zinc** due to the chemical similarity of the two metals. Adequate zinc intake tends to provide partial protection against the toxic effects of cadmium. Cadmium also interacts with **selenium**.

**Measurement** The criteria are given in terms of the total cadmium concentration, in units of Fg/R. The reference method for the measurement of cadmium is atomic absorption spectrometry. If other methods of analysis are used, their characteristics relative to the reference method should be known.

**Data Interpretation** Since cadmium tends to accumulate, single-sample values should be used to compare with the criteria given, and should be interpreted as non-exceedance values. Cadmium concentrations should also be interpreted in relation to associated zinc concentrations.

**Treatment Options** Cadmium in water supplies is most conveniently removed by raising the pH and precipitating the insoluble cadmium salts after the addition of lime or iron salts in the pH range of 8.5 - 11.5. Precipitation is followed by settlement and filtration as in conventional water treatment. The precipitation process requires careful monitoring to ensure that removal is complete. To achieve very low residuals, it may be necessary to pass the stream through an ion exchange column charged with the appropriate resin.

A watery cadmium-rich sludge or concentrate stream is generated in the processes, that may present disposal difficulties.

## The Effects of Cadmium

<b>Norms</b>	The norm used in the guideline for cadmium is human health.
<b>Effects</b>	<p>At elevated concentrations cadmium is acutely toxic and can cause severe renal damage with renal failure. Cadmium also causes acute gastroenteritis which closely mimics the gastroenteritis caused by micro-organisms. The half-life of cadmium in the body is several decades, hence, it is important to avoid exposure.</p> <p>Smoking is an additional and significant source of cadmium exposure. Most fatal poisonings have been as a result of exposure to cadmium fumes, where cadmium is heated or cadmium alloys are welded. As cadmium vapour has no odour, fatal exposure to the fumes can easily occur.</p>
<b>Mitigation</b>	Cadmium poisoning is very difficult to treat due to rapid and irreversible uptake by the kidneys. Immediate medical attention should be sought if cadmium poisoning is suspected. Zinc and ethylenediamine tetra-acetic acid may be used to ameliorate the effects of cadmium.



**Criteria**

**Effects of Cadmium on Human Health**

Cadmium Range (µg/l)	Effects
<i>Target Water Quality Range</i> 0 - 5	<i>No observable health effects</i>
<b>As a precautionary measure, it is recommended that the TWQR not be exceeded because of the potentially acute and/or irreversible effects of cadmium on human health</b>	
5 - 10	No observable health effects, unless zinc nutritional status is suboptimal, or in smokers, where there is a slight risk of subclinical effects on long-term exposure
10 - 20	Threshold for health damage with continuous exposure. Single incidence of exposure will not have observable effects
20 - 1 000	Danger of kidney damage with long-term exposure. Brief exposure, for less than one week should not cause any noticeable damage. Exposure should not exceed one week
> 1 000	Danger of acute cadmium poisoning, with the possibility of fatalities

**Note:**

In the environment, cadmium occurs in association with zinc, in a zinc to cadmium ratio of approximately 300:1. This association is attributed to the chemical similarity between the two metals and provides a guide for calculating the tolerable cadmium intake. The daily requirement for zinc is approximately 15 mg/day, and hence the tolerable concentration of cadmium is calculated to be approximately 50 µg/day. Similar values are reported by the WHO, 1993, which are based on the "safe" level of cadmium in the renal cortex. This should not exceed 50 mg/kg, to give a tolerable daily cadmium intake of not more than 1 µg/kg (BW)/day. This gives a tolerable cadmium intake of not more than 70 µg/day for a 70 kg human. The criteria are based on the assumption that not more than 20 % of the total dietary intake of cadmium is from water. Intake via smoking was not taken into account for the calculation of the above criteria.

**Modifications**

Where the zinc nutritional status is suboptimal the mean cadmium concentration should not exceed 5 Fg/l. If the zinc nutritional status is adequate, a mean cadmium concentration of double this value is quite safe.

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# Calcium

## Background Information

<b>Introduction</b>	Calcium is an alkaline earth metal and exists as the doubly positively-charged ion, Ca(II). Calcium occurs naturally in varying concentrations in most waters and, together with magnesium, is one of the main components of water hardness. <i>Soft</i> waters contain low, while <i>hard</i> waters contain high concentrations of calcium; see <b>total hardness</b> . Calcium is an essential element for all living organisms and is an important constituent of the bony skeleton of mammals, which consists of phosphates of calcium.
<b>Occurrence</b>	<p>Mineral deposits of calcium are common, usually as calcium carbonate, phosphate or sulphate. Calcium bicarbonate, chloride and nitrate are very soluble in water, calcium sulphate is moderately soluble and calcium carbonate and phosphate are insoluble. Typically, the concentration of calcium in:</p> <ul style="list-style-type: none"><li>! fresh water is 15 mg/R; and</li><li>! in sea water is approximately 400 mg/R.</li></ul> <p>On heating water containing calcium bicarbonate, carbon dioxide is lost and calcium carbonate precipitates; this causes scaling in hot water systems.</p>
<b>Interactions</b>	The solubility of calcium in water is usually governed by the carbonate/bicarbonate equilibrium and is thus strongly influenced by <b>pH</b> and temperature. Metabolically, calcium interacts with cations, especially those of <b>magnesium</b> , and with both inorganic anions (bicarbonate, sulphate and phosphate) and organic anions (acetate and organic acids). Biologically, calcium exerts an influence on the integrity of cell membranes and thereby strongly influences the absorption and toxicity of heavy metals.
<b>Measurement</b>	The criteria refer to the dissolved calcium concentration, in units of mg (Ca)/R. The reference method for the determination of calcium is atomic absorption spectrometry, using a phosphate interference inhibitor such as lanthanum, and an ionisation suppressant, such as caesium or potassium. If other methods are used to measure calcium, their characteristics relative to the reference method should be known.
<b>Data Interpretation</b>	Mean values should be used to compare with the criteria given. Calcium concentrations should also be interpreted in conjunction with the major associated anion(s), normally bicarbonate, chloride or sulphate, as well as magnesium, sodium and potassium.
<b>Treatment Options</b>	<p>Calcium is commonly removed from water using treatment processes suitable for softening hard water. These include:</p> <ul style="list-style-type: none"><li>! <b>Precipitation</b> of calcium as calcium carbonate by the addition of sodium carbonate. This process will not reduce calcium in solution to less than 40 mg/R;</li><li>! <b>Cation exchange softening</b> is used to replace the calcium (and magnesium if present) in water with sodium in ion exchange columns regenerated with a sodium chloride brine. Ion exchange is a simple technique and can be operated successfully on a household scale. However, on an industrial scale the process usually needs to be closely monitored because the consequences of incomplete calcium removal may be severe;</li></ul>

and

! **Demineralisation** in mixed bed ion exchange columns will remove all calcium ions together with other ions in solution, where a particularly low salinity water is required.

The same result can be obtained using a range of desalination techniques such as membrane treatments or distillation, but these may be subjected to scaling problems, particularly in the presence of carbonate or sulphate ions. On an industrial scale the processes need skilled operation and control. All of the processes produce a concentrated waste stream, that may cause disposal difficulties.

## The Effects of Calcium

**Norms** The norm used in the guideline for calcium is based on aesthetic effects, particularly the undesirability of scaling in domestic appliances and the impairment of soap lathering.

**Effects** Calcium is an important mineral element in the human diet, the total daily dietary intake being in the range of 500 - 1 400 mg/day. Calcium has been reported as exerting a protective action against cardiovascular disease. However, the available data purporting to show an inverse relationship between hardness or the calcium concentration of water, and the occurrence of cardiovascular disease do not demonstrate an unequivocal causal relationship. There is no conclusive evidence to support claims for the increased incidence of human kidney and urinary tract stones (urolithiasis) resulting from the long-term consumption of water with high concentrations of calcium. Calcium is known to mitigate against the toxicity of certain heavy metals.

Scaling, the principal undesirable effect which occurs in water heating appliances such as kettles, urns, geysers, boilers and certain pipes, results in less efficient use of electrical power and any other fuel used for heating purposes, and the partial obstruction of pipes.

High concentrations of calcium impair the lathering of soap by the formation of insoluble calcium salts of long chain fatty acids that precipitate as scums. This results in excessive soap consumption used in personal hygiene and, in rare cases, household cleaning operations. In addition the scums are unaesthetic, leading in the long-term to the marking of enamelled surfaces such as baths and handbasins.

**Mitigation** Household appliances require regular descaling and where practicable, mild acid treatments, for example, dilute acetic acid can be used to remove calcium carbonate. Scum deposits on enamelled surfaces are usually removed using mildly abrasive, alkaline household cleaning agents which prevent staining.

**Criteria****Effects of Calcium on Personal Hygiene, Household Distribution Systems and Water Heating Appliances**

Calcium Range (mg/R as Ca)	Effects
<i>Target Water Quality Range</i> 0 - 32	<i>No health effects. No scaling evident. Possible corrosive effects &lt; 16 mg/R</i>
32 - 80	No health effects. Increased scaling problems Lathering of soap impaired
> 80	No health effects. Severe scaling problems Lathering of soap severely impaired

**Modifications**

*To convert values given as mg/R of Ca in the above table to mg/R of CaCO<sub>3</sub>, multiply by a conversion factor of 2.5, that is, mg/R Ca x 2.5 = mg/R CaCO<sub>3</sub>*

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# Chloride

## Background Information

**Introduction** Chloride is the anion of the element chlorine. Chlorine does not occur in nature, but is found only as chloride. The chlorides of sodium, potassium, calcium and magnesium are all highly soluble in water.

Chloride is of concern in domestic water supplies because elevated concentrations impart a salty taste to water and accelerate the corrosion rate of metals. High concentrations of chloride can also be detrimental to chloride-sensitive garden plants.

**Occurrence** Chloride is a common constituent in water, is highly soluble, and once in solution tends to accumulate. Typically, concentrations of chloride in fresh water range from a few to several hundred mg/R. In sea water the concentration is approximately 19 800 mg/R. Chloride inputs to surface waters can arise from irrigation return flows, sewage effluent discharges and various industrial processes. Chloride can only be removed from water by energy-intensive processes or ion exchange.

**Interactions** The taste threshold and the corrosion acceleration threshold of chloride are dependent on the action of other water quality constituents such as associated cations, the **pH** and the calcium carbonate concentration.

**Measurement** The criteria are given in terms of the dissolved chloride concentration, in units of mg/R. The reference method for the determination of dissolved chloride is colorimetry, with ferricyanide. If other methods are used, their characteristics relative to the reference method should be known.

**Data Interpretation** Mean values should be used to compare with the criteria given. Chloride concentrations should also be interpreted in conjunction with the major cations and anions.

**Treatment Options** Chlorides are highly soluble and cannot be precipitated at concentrations usually present in water. Chloride can be removed from water by **electrolysis** to form chlorine gas, liberated at the anode. Electrolysis is not effective where the conductivity and the chloride concentration are low.

More commonly, chloride is removed together with other ions using:

- ! **anion exchange resin beds**, in which all significant anions will be removed; and
- ! **desalination techniques** such as reverse osmosis and electrodialysis.

The concentrated waste streams generated from ion exchange and desalination processes may cause disposal difficulties. Desalination techniques require skilled operation, control and maintenance; capital and operating costs are typically high.

## The Effects of Chloride

**Norms** The norms used in the guideline for chloride are based principally on aesthetic effects and on the influence of corrosion rates in domestic appliances. Human health is a secondary norm; effects are only observed at very high concentrations.

**Effects** Chloride is only detectable by taste at concentrations exceeding approximately 200 mg/R. A salty taste becomes quite distinctive at 400 mg/R and objectionable at greater than 600 mg/R. At chloride concentrations greater than 2 000 mg/R nausea may occur, while at 10 000 mg/R vomiting and dehydration may be induced.

Chloride accelerates the corrosion rate of iron and certain other metals well below the concentration at which it is detectable by taste. The threshold for an increased corrosion rate is approximately 50 mg/R. At chloride concentrations greater than 200 mg/R, there is likely to be a significant shortening of the lifetime of domestic appliances as a result of corrosion.

**Mitigation** Non-renewable, disposable anodes can be used to mitigate against corrosion of domestic appliances.

**Criteria** **Effects of Chloride on Aesthetics, Household Distribution Systems and Appliances and Human Health**

Chloride Range (mg/R)	Effects
<i>Target Water Quality Range</i> 0 - 100	<i>No aesthetic or health effects. The threshold for corrosion acceleration in domestic appliances is at 50 mg/R</i>
100 - 200	No aesthetic or health effects. Possible increase in the corrosion rate in domestic appliances
200 - 600	Water has a distinctly salty taste, but no health effects Likelihood of noticeable increase in corrosion rates in domestic appliances
600 - 1 200	Water has objectionable salty taste and will not slake thirst Likelihood of rapid corrosion in domestic appliances
> 1 200	Water unacceptably salty. Nausea and disturbance of the electrolyte balance can occur, especially in infants, where fatalities due to dehydration may occur



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# Chromium(VI)

## Tentative Guideline

### Background Information

**Introduction** Chromium(VI) is a highly oxidised state of metallic chromium. It occurs as the yellow-coloured dichromate salt under neutral or alkaline conditions and as the orange-coloured chromate salt under acidic conditions. Chromium(VI) is highly water soluble at all pH values. The reduced forms of chromium, namely, chromium(II) and chromium(III), are less soluble than chromium(VI), have much lower toxicity indices than chromium(VI), and do not constitute as serious a health hazard.

**Occurrence** The most common ore of chromium is chromite, in which chromium occurs in the trivalent state. Minerals containing chromium(VI) do occur, but are not common. Elevated concentrations of chromium(VI) found in the environment are due to industrial pollution. Because chromium(VI) is highly water soluble, it is very mobile in the environment and readily moves through the soil profile, resulting in contamination of ground water supplies. Chromium(VI) can be reduced to chromium(III) under suitable pH and reducing conditions. However, chromium(III) can also be re-oxidised to chromium(VI) under oxidising conditions. Chromium(VI) is not normally found in water at concentrations greater than 0.01 mg/R. Higher concentrations potentially occur wherever industrial activities using chromium(VI) compounds are located.

In water, chromium(II) and chromium(III) are not usually found at near-neutral pH, since the hydroxides of these two oxidation states are insoluble. However, they may occur in water under acidic conditions.

Chromic acid or hexavalent chromium salts are used in alloys in the metal pickling and plating industry, in the leather industry and in the manufacture of paints, dyes, explosives, ceramics and paper.

**Interactions** The equilibrium between chromium(VI) and its reduced forms is strongly influenced by **pH** and redox potential. The presence of oxidisable organic matter and **iron(II)** salts encourages the conversion of chromium(VI) to the lower, less toxic oxidation states.

**Measurement** The reference method for the determination of chromium(VI) is diphenyl carbazide spectrophotometry. When chromium(VI) is measured, the total chromium concentration should also be determined to establish whether chromium(III) is also present, or whether all the chromium is in the VI state. Where other methods are used, their characteristics relative to the reference method should be known.

**Data Interpretation** The criteria given should be interpreted as maximal allowable values and should not be exceeded.

**Treatment Options** Chromium(VI) is the most soluble of the chromium species and removal thereof requires pretreatment of chromium(VI) to a more easily precipitable species. Therefore, removal of chromium(VI) from water requires the reduction of chromium(VI) to the trivalent form with ferrous sulphate, or by reaction with oxidisable organic matter. The trivalent chromium can then be removed by various processes, including:

! **Precipitation and flocculation** as chromium(III) hydroxide with lime and alum or ferric salts, followed by settlement and filtration. The process needs careful monitoring to ensure effective removal of chromium; and

! Removal with **reverse osmosis** or **ion exchange**.

Alternative methods are available for adsorbing chromium(VI) onto ferric hydroxide precipitates. However, these are not as efficient as methods which rely on the reduction of chromium(VI), followed by precipitation of chromium(III) or chromium(II) hydroxides when the pH is raised.

All processes produce a watery sludge or concentrate stream that may be rich in chromium, and present disposal difficulties.

## The Effects of Chromium(VI)

**Norms** The norm used in the guideline for chromium(VI) is based on human health.

**Effects** Occupational exposure to chromium(VI) is associated with the occurrence of nasal septum and skin ulcers, as well as with the occurrence of lung cancer. Chromium(VI) when ingested is associated with taste effects and nausea when the concentration exceeds 1 mg/R. Definitive evidence of carcinogenesis via the oral route is equivocal, and chromium(VI) has also been implicated in the cause of gastrointestinal cancer.

Chromium(II) and chromium(III) have much lower toxicities than chromium(VI).

**Mitigation** Reduction of chromium(VI) to the less toxic chromium(III) or chromium(II) forms using an appropriate reducing agent significantly reduces the toxicity of chromium(VI).

**Criteria** **Effects of Chromium(VI) on Human Health**

<b>Chromium(VI) Range (mg/R)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 0.050</i>	<i>Risk of cancer induction insignificant No toxic or aesthetic effects</i>
<b>As a precautionary measure it is recommended that the TWQR not be exceeded due to the potentially acute and/or irreversible effects of chromium(VI) on human health</b>	
0.05 - 1.0	Possible risk of induction of gastrointestinal cancer following long-term exposure
1.0 - 5.0	Undesirable taste, slight nausea, and increasing risk of cancer induction
> 5.0	Risk of acute toxicity

**Note:** The criteria given above are tentative due to the lack of sufficient experimental evidence to determine risk levels following oral ingestion of chromium(VI). While it is

certain that chromium(VI) results in serious health effects on occupational exposure to high concentrations of chromium(VI), the threshold limit for significant risk following oral exposure is uncertain.

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# Colour

## Background Information

**Introduction** *True colour* is the colour of a water sample from which the turbidity has been removed. *Apparent colour* includes the colour and appearance of suspended matter. *True colour* is described by the dominant wavelength or hue together with the degree of brightness or luminance and the saturation or purity of the colour. Colour in domestic water may be due to natural sources of coloured organic matter like humic and fulvic acids. Colour is strongly influenced by the presence of iron, manganese and certain other metals either as natural impurities or corrosion products.

**Occurrence** Colour in water can be of natural mineral or origin or it may be as an industrial result of effluents containing soluble coloured materials (discharges from pulp and paper, and textile industries). The presence of iron and manganese can cause a natural brown discolouration in water. Iron and manganese are also found in association with humic acids or lignins. Colloidal matter present in water is often associated with colour. The persistence of colour in water depends on the causative substance(s). The reddish-brown colour from dissolved iron complexes is generally readily removed in conventional water treatment processes. Colour from dissolved organic dyes may be more persistent.

**Interactions** The *apparent colour* of water is strongly related to **turbidity**. Most natural causes of colour are associated with the presence of dissolved organic matter, and **iron** and **manganese** compounds. Other metal ions may on occasion give rise to colour in water.

**Measurement** Colour may be measured either in Pt-Co colour units, using the visual colour comparison method, or by spectrophotometric methods, where the colour characteristics are reported as:

- ! Dominant wavelength (nm)
- ! Hue (colour)
- ! Luminance (%)
- ! Purity (%)

**Data Interpretation** Mean values should be used to compare with the criteria given.

**Treatment Options** Colour in water supplies is caused by a variety of agents. Different methods may therefore be required to remove colour. These include:

- ! Filtration of the water through a slow sand filter. The biologically active surface layer on the filter removes colour by metabolising the organic material in the water.
- ! Some forms of colour in water are amenable to removal by coagulation, flocculation, clarification (by settlement or flotation) and filtration. A further activated carbon filtration step may be beneficial.
- ! Some forms of colour in water are readily removed by strong oxidising agents such as ozone.

In many cases a combination of treatment processes will be required to achieve the water quality required. Some improvement in the colour of household water can be achieved by filtering it through a disposable activated carbon cartridge.

## The Effects of Colour

<b>Norms</b>	The norm used in the guideline for colour is aesthetic effects.
<b>Effects</b>	No direct health effects result from the presence of colour in drinking water except when colourants are toxic. Aesthetic effects are mainly visual but some colourants may stain or otherwise affect household appliances, for example, iron or manganese.
<b>Mitigation</b>	For drinking purposes, small amounts of water can be treated using domestic water purifiers / filters.
<b>Criteria</b>	<b>A Target Water Quality Range 15 Pt-Co units is recommended for drinking water.</b>

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# Copper

## Background Information

**Introduction** Copper is an essential trace element to plants, animals and humans. Copper occurs in three oxidation states, namely metallic copper(0), cuprous copper(I) and cupric copper(II). A significant source of copper in domestic water arises from the dissolution of copper from plumbing systems in areas with soft or low pH waters; see **total hardness** and **pH**. High concentrations of copper impart a disagreeable taste to water, and consumption of such water is therefore highly unlikely.

**Occurrence** Many minerals containing copper are known, some of which are important semi-precious minerals, such as malachite, azurite and turquoise. Copper is also sometimes found in the elemental state. Copper(II) carbonate, hydroxide and sulphide are insoluble in water, while copper sulphate, nitrate and chloride are soluble. Ammonium complexes of copper are also soluble in water. At neutral and alkaline pH, the concentration of copper in surface waters is usually low, typically, 0.003 mg/R, whereas in acidic waters, copper readily dissolves, and substantially higher concentrations may occur. The concentration of copper in sea water is approximately 0.0003 mg/R. Copper is readily adsorbed and precipitated in sediments at alkaline pH. Re-mobilisation of copper to underlying water occurs on acidification. Copper also bioaccumulates in certain plants.

Copper has excellent conducting properties. One of the most important industrial uses of copper is in the electrical industry.

**Interactions** The oxidation state of copper in water depends strongly on **pH** and the concentration of associated anions such as **sulphate**, **chloride** and **nitrate**. Metabolically, copper interacts with zinc, iron, molybdenum, arsenic, selenium and sulphur.

**Measurement** The criteria are given in terms of the total copper concentration, in units of mg/R. Total copper is measured after acidification of the water sample. The reference method for the determination of copper is atomic absorption spectrometry. If other methods are used for measuring copper, their characteristics relative to the reference method should be known.

**Data Interpretation** Single maximal values should be used to compare with the criteria given. Copper concentrations should also be interpreted in relation to pH and the concentration of ammonia; ammonia can solubilise copper at alkaline pH and facilitate the uptake thereof.

**Treatment Options** Copper in solution is most conveniently removed from water by either:

- ! Flocculation with alum or ferric salts at pH 6 - 7; this reduces the soluble copper concentration to a low level; or
- ! Raising the pH and precipitating the insoluble copper carbonate and hydroxide complexes with lime treatment. The precipitation is followed by settlement and filtration as in conventional water treatment.

The precipitation process requires careful monitoring to ensure complete removal. A watery copper-rich sludge is generated in the process; this may present disposal difficulties.

## The Effects of Copper

**Norms** The norms used in the guideline for copper are health and aesthetic effects. Aesthetic effects predominate at concentrations usually encountered in drinking water.

**Effects** At relatively low concentrations copper imparts a strongly astringent taste to water and can also give rise to staining of laundry and plumbing fittings. At higher concentrations these effects become progressively more severe. Ingestion of high concentrations of copper results in gastrointestinal disturbances and possible liver, kidney and red blood cell damage. However, owing to the extremely disagreeable taste of water with high copper concentrations, it is unlikely that such water would be consumed.

**Mitigation** Mitigatory measures to counteract the effects of having ingested excessive amounts of copper are usually unnecessary since, even at the threshold concentration for health effects, nausea and consequent vomiting result, which rid the body of copper. Ingestion of massive doses of copper requires hospitalisation and liver failure may occur.

**Criteria** **Effects of Copper on Aesthetics and Human Health**

Copper Range (mg/l)	Effects
<i>Target Water Quality Range</i> 0 - 1	<i>No health or aesthetic effects</i>
1 - 3	No health effects. Astringent taste and staining of laundry and plumbing fixtures start appearing
3 - 30	No health effects. Severe taste and staining problems
30 - 200	Gastrointestinal irritation, nausea and vomiting. Severe taste and staining problems
> 200	Severe poisoning with possible fatalities. Severe taste and staining problems

**Note:** It is recommended that the concentration of copper in potable water should not exceed 30 mg/l, as this is the threshold for acute poisoning with nausea and vomiting.

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# Corrosion

## Background Information

**Introduction** The equilibrium saturation point of water for calcium carbonate and other salts is described by various indices which provide an indication of the scale-forming or corrosive potential of the water. If water is supersaturated, it is *scale forming*, whereas if it is undersaturated, it is non-scale forming or *corrosive*.

The distribution system is the most expensive component in a supply of potable water and maintenance and replacement of corroded or scaled-up components imposes unnecessary costs on the water supplier and ultimately on the domestic consumer. The application of appropriate water treatment practices can minimise the adverse effects of scaling and corrosion. Ideally, potable water that is *stable*, that is, non-corrosive and non-scaling, should be distributed to consumers.

**Occurrence** Corrosion can be a problem in distribution systems and appliances with metallic structures in contact with water. The following types of water are corrosive:

- ! Soft waters with little or no dissolved calcium bicarbonate, for example, rain water.
- ! Waters with high concentrations of chloride or sulphate.
- ! Waters with low or acidic pH values.

In order to quantitate the corrosivity or scaling tendency of water it is necessary to calculate various indices. The corrosive/scaling properties of water can be manipulated during water treatment by the addition of chemicals.

**Interactions** The corrosive properties of water are not only influenced by the chemical composition of the water. Other determining factors include the bacteriological activity in the water, the presence of electrical fields, the conjunction of dissimilar metals, and the constituent properties accounted for in the derivation of corrosion indices.

**Measurement** Tables and formulas relating to the most well-known corrosion/scaling indices are given below:

! ***Langelier index***

The Langelier index is based on the calculation of the saturation pH ( $pH_s$ ) of water with respect to calcium carbonate. The Langelier index (LI) describes the difference between the measured (or actual) pH of the water ( $pH_a$ ) and the hypothetical pH ( $pH_s$ ) of the water if it were in equilibrium with solid  $CaCO_3$  at the actual concentrations of the bicarbonate ion and the calcium ion present:

$$LI = pH_a - pH_s$$

A positive Langelier index indicates scale-forming tendency and a negative Langelier index indicates a scale-dissolving tendency, with the possibility of corrosion. Calculation of  $pH_s$  is derived from the alkalinity, calcium, pH, the dissolved salts concentration and the temperature of the water.

! ***Ryznar index***

The Ryznar index (RI) is defined as:

$$RI = 2pH_s - pH_a, \text{ where } pH_s \text{ is the saturation pH as given by the Langelier method, and } pH_a \text{ is the actual pH.}$$

An alternate formula for the Ryznar index is:

$$RI = pH_a - 2LI, \text{ where LI is the Langelier index.}$$

Interpretation of the Ryznar index is as follows:

Ryznar index	Water property
< 6.5	scale-forming tendency
> 6.5	corrosive tendency

! **Corrosion ratio**

The corrosion ratio (R) is used to estimate the corrosive tendency of chloride and sulphate ions and is given by:

$$R = \{ \text{me/R}(\text{Cl}^- + \text{SO}_4^{2-}) \} / \{ \text{me/R alkalinity as CaCO}_3 \}$$

A ratio less than 0.1 indicates general freedom from corrosion in neutral to slightly alkaline oxygenated waters. Higher ratios indicate a tendency towards progressive corrosion, that is, aggressive waters.

! **Aggressiveness index**

The aggressiveness index (AI) formulated for evaluating corrosion in an asbestos cement pipe, is defined as:

$$AI = pH + \log_{10}(AH), \text{ where;} \\ A = \text{total alkalinity in mg/R CaCO}_3; \text{ and} \\ H = \text{calcium hardness as mg/R CaCO}_3$$

Interpretation of the aggressiveness index is as follows:

Aggressiveness index (AI)	Water property
\$ 12	Non-aggressive
10.0 to 11.9	Moderately aggressive
# 10	Highly aggressive

**Data Interpretation**

Data interpretation depends on the index used. Generally, mean values can be used.

**Treatment Options**

The tendency of a water to form a scaling film on plumbing fixtures and particularly in hot water systems can be reduced by manipulating of the chemical composition of the water. Scaling is commonly reduced by removal of alkalinity and calcium hardness from the water until it becomes slightly undersaturated with respect to the calcium carbonate

concentration, and consequently slightly aggressive. Alkalinity can be reduced by adding a weak acid solution, while calcium hardness is reduced by base exchange softening. Conversely, an aggressive water which tends to attack unprotected concrete structures can be stabilised by increasing its alkalinity or pH and calcium content. Poorly controlled additions may result in a scaling water.

A water which is corrosive to metal fittings can usually be rendered less corrosive by increasing its alkalinity or pH, and reducing the sulphate and chloride content. Alkalinity addition is the more simple procedure since removal of sulphate and chloride would necessitate using a desalination technique.

The modifications necessary to achieve acceptably stable waters may be very complex, requiring strong treatment skills and sophisticated analytical facilities.

## The Effects of Corrosion

**Norms** The norms used in the guideline for corrosion are based on economic considerations and aesthetic and health effects.

**Effects** For the domestic user a corrosive or aggressive water may necessitate premature replacement of plumbing, tanks, geysers and household appliances. A scaling water may result in impaired water flow rates, especially in hot water systems, necessitate premature replacement of hot water plumbing, result in increased power consumption and require frequent replacement of heating elements as a result of poor heat transfer across the scale layer.

The presence of oxidised iron as a result of corrosion can give rise to a red discolouration of the water and impact negatively on the aesthetic quality thereof. Possible health risks associated with bacterial regrowth as a result of corrosion, may also exist.

**Mitigation** ! **Scaling**

As with chemical corrosion, scaling is best prevented by proper stabilisation of the water. Electromagnetic anti-scaling devices are available on the market but have not been proven or widely accepted. Scaling due to hard water may be alleviated by lowering of pH and/or water softening processes, for example, lime softening. Scale is extremely difficult to remove and even with the use of the stabilised acid wash procedure, removal is seldom effective.

! **Chemical corrosion**

Chemical corrosion can be eliminated or alleviated by using corrosion-resistant coatings or materials for all elements of the water supply system which come into direct contact with the water. Normally, the proper stabilisation of the water during treatment through the addition of pH and alkalinity-adjusting chemicals (for example, soda ash) should be adequate to prevent chemical corrosion and scaling by treated potable water. Phosphates or silicates can also be used as layer-forming materials. The amount and type of chemicals to be added can be determined by graphical methods using manual calculations or the computer software, Stasoft III.

The use of asbestos cement pipes or commercially available coatings for steel piping is suitable for water of lower corrosivity but is not recommended where proper

stabilisation is a practicable alternative. For example, cement-lined and coated steel pipes are used extensively in the Western Cape, where water is stabilised to protect the cement.

Cathodic protection may be required in some instances, for example, where pipelines run close to electrical cables or close to electric railway lines.

**! Biological corrosion**

Biological corrosion is best prevented by commencing with a clean, sediment-free system, that is maintained as such. The organic content of the water and especially the Assimilable Organic Carbon (AOC) content should be kept as low as possible in order to deprive micro-organisms of nutrition. This in turn limits the amount of post-disinfection required. However, post-disinfection using chlorination or chloramination is imperative at high AOC concentrations and/or in distribution systems with long retention times. Multiple re-chlorination may be required in order to ensure the presence of an adequate chlorine residual in all parts of the distribution system.

**Criteria**

**! Scaling**

Stabilise the water during treatment to the acknowledged standards for a stable water, using either manual calculations or the Stasoft III software. Heated appliances such as geysers and kettles should be taken into account.

**! Chemical Corrosion**

Because of the large number of possible effects, the following general criteria are recommended:

- Stabilise the water during treatment to the acknowledged standards for a stable water, using either manual calculations or the Stasoft III software;
- Avoid having different metals in contact with one another in the water distribution system;
- Use the correct materials for construction and coating;
- Do not lay pipelines close to electric cables;
- Limit sulphate and chloride concentrations in the water; and
- Prevent any bacterial growth or other biological activity.

**! Biological Corrosion**

The following general criteria should be adhered to:

- Keep the organic content of the water, especially the AOC content, as low as possible;
- Practise adequate post-disinfection of the treated water, especially where a treated water has a high organic content and/or where retention times in the distribution system are long. Chlorination or chloramination should be used for post-disinfection and rechlorination in multiple steps may be required in order to ensure the presence of adequate free chlorine residuals in all parts of the distribution system; and
- Prevent or flush out any sediments in any part of the distribution system. New parts of the distribution system should be thoroughly cleaned before commissioning in order to commence with a clean system.



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# Dissolved Organic Carbon

## Background Information

**Introduction** Dissolved organic carbon (DOC) is the organic carbon present in water in the dissolved form, able to pass through a 0.45 µm membrane filter. The DOC content of water includes both low molecular weight volatile organic compounds and moderate to high molecular weight organic compounds.

The presence of DOC can have adverse aesthetic implications (taste, odour and colour), which may be associated with both naturally-occurring organic carbon and organic carbon originating from domestic or industrial effluent discharges.

**Occurrence** The origin of the DOC source in water largely determines the effect it has in the water system, and can range from harmless to highly toxic. For example, DOC from natural humic acids of soil origin are not usually toxic and only of aesthetic concern. However, if the DOC content includes synthetic organic compounds, usually found in agricultural runoff after pesticide application, it may be associated with significant toxicity. Industrial effluents and domestic runoff entering the water also affect the character of the DOC. The DOC concentration in unpolluted water is typically less than 5 mg/R, but in waters receiving organic wastes from runoff, significantly higher concentrations may be encountered.

The rate of breakdown of organic carbon compounds varies and depends on the intrinsic stability of the compound and associated environmental conditions. Low molecular weight organic carbon compounds may be released into the atmosphere, whereas high molecular weight compounds tend to be associated with suspended solids and ultimately accumulate in sediments.

**Interactions** Water quality constituents and properties which are related to the DOC content include the:

- ! Chemical oxygen demand (COD), a measure of the oxygen requirement of organic matter;
- ! Biological oxygen demand (BOD), a measure of the biochemically-mediated oxygen demand of water that is indicative of that portion of the organic carbon which is relatively easily oxidised by micro-organisms; and
- ! Total organic carbon (TOC), a measure of the organic carbon found in solution and in suspended matter.

COD and BOD determinations are normally carried out on unfiltered water samples and thus are measures of both dissolved and suspended organic matter. The TOC is the sum of both the dissolved and suspended organic carbon.

Certain DOC compounds can be precursors of **trihalomethanes** (THMs); these are undesirable in water due to their carcinogenic potential. However, no direct correlation between the DOC, TOC, COD or BOD concentrations and the occurrence of THMs or taste and odour problems can be made since the specific organic compounds making up the DOC content differ vastly in their potential reactions and effects.

**Measurement** The criteria for the DOC concentration are given in units of mg/R. The reference methods for the determination of the:

- ! DOC, is persulphate-ultraviolet oxidation;

- ! TOC, is combustion-infrared;
- ! COD, is dichromate sulphuric acid digestion.
- ! BOD, for the five-day water sample, is given in **Standard Methods**.

Where other methods of measurement are used, their characteristics relative to the reference methods should be known.

**Data Interpretation** Mean values should be used to compare with the criteria given. Where the DOC concentration is elevated, the possible origin of the DOC should be sought and if necessary, the presence of known undesirable organic compounds should be tested for.

**Treatment Options** Removal of organic carbon from domestic water supplies can be achieved by a number of techniques. Assuming the residual concentrations are only marginally above acceptable levels, the treatment methods include:

- ! Filtration of the water through a slow sand filter. In time the filter develops a biofilm which metabolises the organic carbonaceous material in the water, effecting measurable purification;
- ! Some forms of organic carbon are amenable to removal by coagulation, flocculation, clarification (settlement or flotation) and filtration. An activated carbon filtration step may be beneficial; and
- ! Organic carbon is readily oxidised by strong oxidising agents such as hydrogen peroxide, ozone or Peroxone.

In many cases, a combination of treatment processes is necessary to achieve the water quality required. Some improvement in the organic quality of household water can be achieved by filtering through disposable activated carbon cartridges. The strong oxidising agents mentioned above are hazardous if handled carelessly.

## The Effects of Dissolved Organic Carbon

**Norms** The norms used in the guideline for DOC are based on human health and aesthetic effects and apply mainly to treated domestic water supplies.

**Effects** The DOC concentration in water *per se* has no direct health implications but, is an indicator of the organic material content of the water. Such material may pass through the water treatment process to the disinfection stage. If disinfection by chlorination is practised, the DOC concentration and content is a tentative indication of the potential for the formation of THMs by halogenation of dissolved organic precursors. Chloroform, dichlorobromomethane, dibromochloromethane and bromoform are some of the principal THMs which may be formed.

Chloroform has been implicated as a probable cause of drinking water-related cancer in laboratory animals. However, a quantitative link between the DOC concentration and either trihalomethane formation or human health effects has not been established and studies of drinking waters throughout South Africa thus far, have found no causal relationship between THM concentrations and cancer incidence and/or mortality. Further, it should also be noted that intake of THMs from other sources, for example food, far exceeds the intake

from other environmental sources such as drinking water.

**Mitigation** Mitigation against effects of having consumed water with high concentrations of DOC is not an issue unless toxic organic substances or sewage are ingested, in which case, medical help should be sought if acute symptoms become evident.

Prolonged ingestion of water high in THMs should be avoided if possible.

**Criteria** **Effects of Dissolved Organic Carbon and Human Health**

<b>Dissolved Organic Carbon Range (mg C/l)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 5</i>	<i>No effect on health, aesthetics (taste, odour, colour) or THM formation during chlorination</i>
5 - 10	Slight risk of health effects, depending on the DOC composition. Slight aesthetic effects (taste, odour, colour). Some THM formation during chlorination
10 - 20	Risk of health effects, depending on the DOC composition. Significant aesthetic effects (taste, odour, colour). THMs formed during chlorination
> 20	Aesthetic effects (taste, odour, colour) and formation of THMs during chlorination. Marked health effects, depending on the composition of the DOC

**Note:**

No ranges for concern regarding chronic and acute health effects are indicated due to lack of quantitative evidence linking DOC concentration to health effects.

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# Fluoride

## Background Information

**Introduction** Fluoride is the most electronegative member of the halogens. It has a strong affinity for positive ions and readily forms complexes with many metals. In its elemental form, fluorine is a greenish-yellow gas which readily dissolves in water to form hydrofluoric acid. Fluorine is highly reactive and will attack most materials, including glass. Apart from the alkali metal fluorides, most fluorides are insoluble in water. Many soluble complexes are formed with silicates and the transition metals.

The presence of fluoride in drinking water reduces the occurrence of dental caries in adults and children. A small amount of fluoride is necessary for proper hardening of dental enamel and to increase resistance to attack on tooth enamel by bacterial acids. In humans and animals, fluoride accumulates in the skeleton.

**Occurrence** Common fluoride minerals are fluor-spar ( $\text{CaF}_2$ ) and fluor-apatite, a calcium fluorophosphate. Others of importance include various fluoro-silicates and mixed fluoride salts, such as cryolite ( $\text{Na}_3\text{AlF}_6$ ).

Typically the concentration of fluoride in:

- ! unpolluted surface water, is approximately 0.1 mg/R;
- ! ground water, is commonly up to 3 mg/R, but as a consequence of leaching from fluoride containing minerals to ground water supplies, a range of 3 - 12 mg/R may be found;
- ! sea water, is approximately 1.4 mg/R.

Fluoride is present in many foods, and water is not the only source thereof. Drinking water is estimated to contribute between 50 % - 75 % of the total dietary fluoride intake in adults. In domestic water supplies as well as industrial supplies used in the food and beverage industries, the fluoride concentration in the water should not exceed approximately 0.7 mg/R.

In industry, fluorine and fluorides are used in the isotopic enrichment of uranium, in the manufacture of various fluorochemicals such as fluoro-chlorohydrocarbon refrigerants and in the etching of glass.

**Interactions** Due to the very pronounced electron affinity of the fluoride atom, fluoride is capable of interacting with almost every element in the periodic table. In natural waters it is thought to be one of the main ions that allows for the solubilisation of beryllium, scandium, niobium, tantalum and tin. Fluoride reacts readily with **calcium** to form calcium fluoride, which is reasonably insoluble and can be found in sediments. Where phosphate is present, an even more insoluble apatite or hydroxy apatite may form. Fluoride also reacts very readily with **aluminium**, a property which is made use of in the removal of fluoride from water.

Absorption of fluoride complexes depends on their lipid solubility, the ease with which dissociation from the complexes occurs under acidic conditions and on the ion size and charge. Fluoride is readily absorbed in the free fluoride ion form if ingested.

**Measurement** The criteria are given in terms of the dissolved fluoride concentration, in units of mg/R. The reference method for the determination of fluoride is the SPADNS colorimetric method. The SPADNS method is based on the formation of a red colour between the fluoride ion and a zirconium dye lake and relies on the tendency of fluoride to complex strongly to the

zirconium ion. Where other methods are used, such as use of a fluoride-specific electrode or ion chromatography, their characteristics relative to the reference method should be known.

**Data Interpretation** Mean values should be used to compare with the criteria given. If, however, a single sample value exceeds 8 mg/R, it should be treated as a maximum non-exceedance value. The concentration of fluoride should always be interpreted in conjunction with temperature and the concentrations of calcium, aluminium and silicate.

**Treatment Options** Fluoride is a relatively stable anion which is difficult to remove from water to the required concentration range. Although calcium fluoride is relatively insoluble, its solubility is an order of magnitude higher than the levels which need to be achieved by treatment. The methods for the removal of fluoride include:

- ! Adsorption in a bed of activated alumina;
- ! Removal in ion exchange columns along with other anions; and
- ! Removal in membrane processes such as reverse osmosis and electrodialysis together with virtually all other ions.

Regeneration of the activated alumina or ion exchange bed produces a high fluoride stream which may pose disposal difficulties. A concentrated reject stream is also produced from reverse osmosis and electrodialysis, hence possible disposal problems.

The techniques used are sophisticated and relatively expensive both in capital and operating costs. High levels of skill are needed in the design, operation and maintenance of the equipment.

## The Effects of Fluoride

**Norms** The norms used in the guideline for fluoride are primarily based on human health effects. Fluoride does not affect the aesthetic quality of domestic water.

**Effects** If fluoride is ingested, it is almost completely absorbed, whereafter it is distributed throughout the body. Most of the fluoride is retained in the skeleton and a small proportion in the teeth. Fluoride accumulates most rapidly in the bones of the young, but continues to accumulate up to the age of 55. It is excreted primarily in urine. The rate of fluoride retention decreases with age, and most adults are considered to maintain a steady state whereby accumulation of toxic amounts of fluoride is avoided by a balance between skeletal sequestration and renal excretion.

The difference between concentrations of fluoride that protect tooth enamel and those that cause discolouration is marginal. Discolouration of dental enamel and mottling occurs at concentrations in the range of 1.5 - 2.0 mg/R in persons whose teeth are undergoing mineralisation. Generally, children up to seven years of age are susceptible.

High doses of fluoride interfere with carbohydrate, lipid, protein, vitamin, enzyme and mineral metabolism. Skeletal fluorosis may occur when concentrations of fluoride in water exceed 3 - 6 mg/R and becomes crippling at intakes of 20 - 40 mg/day. This is equivalent to a fluoride concentration of 10 - 20 mg/R, for a mean daily water intake of two litres. Systemic toxicity and interference with bone formation and metabolism occur at high



concentrations.

Chronic effects on the kidneys have been observed in persons with renal disorders and rarer problems, including effects on the thyroid gland, which may occur with long-term exposure to high fluoride concentrations. Acute toxic effects at high fluoride doses include haemorrhagic gastroenteritis, acute toxic nephritis and injury to the liver and heart- muscle tissues. Many symptoms of acute fluoride toxicity are associated with the ability of fluoride to bind to calcium. Initial symptoms of fluoride toxicity include vomiting, abdominal pain, nausea, diarrhoea and convulsions.

### **Mitigation**

Drinking water is often considered an important dietary source of fluoride. Pharmacists provide information on regions in South Africa where concentrations of fluoride in the drinking water are low; if this is the case dietary fluoride supplements are recommended.

Fluorosis is less severe when drinking water is hard, rather than soft, since the occurrence of calcium together with fluoride limits fluoride toxicity. However, there is no way of mitigating against the effects of long-term ingestion of higher than recommended concentrations of fluoride.

**Criteria**

**Effects of Fluoride on Aesthetics and Human Health**

Fluoride Range (mg/R)	Effects
<i>Target Water Quality Range</i> 0 - 1.0	<i>The concentration in water necessary to meet requirements for healthy tooth structure is a function of daily water intake and hence varies with annual maximum daily air temperature. A concentration of approximately 0.75 mg/R corresponds to a maximum daily temperature of approximately 26 EC - 28 EC. No adverse health effects or tooth damage occurs</i>
1.0 - 1.5	Slight mottling of dental enamel may occur in sensitive individuals. No other health effects are expected
1.5 - 3.5	<i>The threshold for marked dental mottling with associated tooth damage due to softening of enamel is 1.5 mg/R</i> Above this, mottling and tooth damage will probably be noticeable in most continuous users of the water. No other health effects occur
3.5 - 4.0	Severe tooth damage especially to infants' temporary and permanent teeth; softening of the enamel and dentine will occur on continuous use of water. <b>Threshold for chronic effects of fluoride exposure</b> , manifested as skeletal effects. Effects at this concentration are detected mainly by radiological examination, rather than overt
4.0 - 6.0	Severe tooth damage especially to the temporary and permanent teeth of infants; softening of the enamel and dentine will occur on continuous use of water. Skeletal fluorosis occurs on long-term exposure
6.0 - 8.0	Severe tooth damage as above. Pronounced skeletal fluorosis occurs on long-term exposure
> 8.0	Severe tooth damage as above. Crippling skeletal fluorosis is likely to appear on long-term exposure
> 100	Threshold for onset of acute fluoride poisoning, marked by vomiting and diarrhoea
> 2 000	The lethal concentration of fluoride is approximately 2 000 mg/R

**Note:**

**It is recommended that the concentration of fluoride in potable water never exceed 4.0 mg/R, due to the likelihood of skeletal fluorosis with crippling, as well as the loss of teeth.**

**Modifications**

Ambient air temperature strongly influences the total water intake of humans and animals, and hence indirectly, susceptibility to the detrimental effects of fluoride. Generally, the hotter it is, the greater is the water consumption. Calcium and particularly aluminium

concentrations influence the absorption of fluoride. The criteria have taken into account the effects of these variables at the values likely to be encountered in a "typical" water sample.

The European Union recognises two maximum admissible concentrations for fluoride, namely, 1.5 mg/R at 8 - 12 EC and 0.7 mg/R at 25 - 30 EC. Under South African conditions this is probably in the region of 0.75 mg/R, equivalent to approximately 26 - 28 EC maximum temperature. The relationship between air temperature and recommended fluoride concentrations is indicated below.

Maximum Daily Air Temperature (EC)	Optimum Fluoride Concentration (mg/R)
16	1.0
20	0.9
24	0.8
29	0.7
34	0.6*
40	0.5*

\* Extrapolated Values

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# Indicator Organisms

## Background Information

**Introduction** A wide variety of pathogenic viruses, protozoa and bacteria may be transmitted by water. These micro-organisms cause diseases such as gastroenteritis, giardiasis, hepatitis, typhoid fever, cholera, salmonellosis, dysentery and eye, ear, nose and skin infections, which have worldwide been associated with polluted water. Infections are generally contracted by drinking contaminated water, recreational exposure to contaminated water, inhaling contaminated aerosols or the consumption of raw food (that is, irrigated vegetables and shellfish) exposed to polluted water.

Most waterborne diseases are caused by pathogens typically transmitted by the faecal-oral route. However, pathogens excreted into water from healthy skin or hair, wounds, pustules, urine, mucus, saliva and sputum can also be transmitted, particularly by recreational body-exposure and inhalation of aerosols. Some waterborne pathogens are excreted by healthy carriers or infected persons, in many cases children, who show no clinical symptoms of disease. The minimal infectious dose of intestinal bacteria tends to be relatively high, approximately 10 - 1 000 or more, while that of intestinal protozoa and viruses can be as low as a single viable unit.

Assessment of the safety of water by tests for the many pathogens which may be present would be impractical for technical and economic reasons. Indicator organisms are, therefore, generally used for routine monitoring of the potential presence of pathogens in water. Indicator organisms should ideally fulfil the following criteria:

- ! be suitable for all types of water;
- ! be present in sewage and polluted waters whenever pathogens are present;
- ! be present in numbers that correlate with the degree of pollution;
- ! be present in numbers higher than those of pathogens;
- ! not multiply in the aquatic environment;
- ! survive in the environment for at least as long as pathogens;
- ! be absent from unpolluted water;
- ! be detectable by practical and reliable methods; and
- ! not be pathogenic and should be safe to work with in the laboratory.

There is no single indicator organism that meets all these requirements. The wide variety of indicators used all have their own advantages and disadvantages. It is, therefore, generally recommended that routine quality surveillance programmes include appropriate combinations of indicators and, as far as possible, test for at least those pathogens of major importance, in order to obtain the most reliable indication of potential risks of infection. There are no universal guidelines for combinations of indicators and the frequency of testing. Each situation has to be considered in its own right. The selection of individual indicators, combination of indicators, inclusion of tests for pathogens and sampling frequency has to be formulated on the basis of considerations including risks of infection as indicated by sanitary surveys, potential sources of pollution and bather densities, as well as financial resources and the availability of laboratory facilities and expertise. Sanitary surveys are a fundamental component of safety monitoring programmes and are particularly important when microbiological testing is restricted and infrequent.

Since the waterborne diseases of prime importance are those caused by enteric pathogens transmitted by the faecal-oral route, indicators of faecal pollution are generally included in

water quality monitoring programmes, particularly those for drinking water.

Indicators generally recommended for assessment of the microbiological safety of domestic water, include:

- ! **Total coliform bacteria:** Primarily used as a practical indicator of the general hygienic quality of water; mainly used in routine monitoring of drinking water supplies;
- ! **Faecal coliform bacteria:** Primarily used as a practical indicator of faecal pollution; more specific for faecal pollution than total coliforms; mainly used for assessment of faecal pollution of wastewater, raw water supplies and natural water environments used for recreational purposes;
- ! ***Escherichia coli*:** Highly specific indicator of faecal pollution which originates from humans and warm-blooded animals;
- ! **Enterococci (faecal streptococci):** Relatively specific indicators of faecal pollution which tend to survive longer in water environments than coliform bacteria; and
- ! **Bacteriophages:** The survival and incidence of bacterial viruses (phages) in water environments resembles that of human viruses more closely than most other indicators commonly used. The application of coliphages (bacteriophages which infect *E. coli* and certain related species) in water quality assessment is rapidly gaining ground. Somatic coliphages occur in large numbers in sewage and polluted water environments and are easy to detect, but they may be replicated by host bacteria in certain water environments. Male-specific (F-RNA) coliphages are highly specific for sewage pollution and cannot be replicated in water environments, but detection methods are more complicated.

### Occurrence

Commonly used indicators are excreted or released consistently by virtually all humans because they are members of the normal microbial flora of humans. Some of the indicators are also consistently excreted by warm-blooded animals. Faecal indicators are, therefore, always present in sewage-polluted water and their numbers are in relatively close correlation with levels of faecal pollution and the time since pollution has taken place. Incidentally, this valuable feature also represents one of the shortcomings of indicators because pathogens are not excreted by all individuals and their numbers in water environments are highly variable depending on factors such as disease outbreaks.

Several natural processes in aquatic systems such as sedimentation, adsorption, coagulation and flocculation may remove micro-organisms from water without inactivation and may even protect the organisms against inactivation. These processes are significant since subsequent release may cause an apparent increase in numbers of the organisms.

### Interactions

Many physical, chemical, biological and biochemical factors play a role in the survival and removal of micro-organisms in water environments. These factors include exposure to sunlight, temperature, pH, turbidity, nutrients, toxic substances, predation and competition. Some indicators may even multiply in waters with sufficient nutrients and suitable temperature. Increased survival of micro-organisms in sediments may be due to protection against predation, sunlight and other causes of inactivation.

### Data Interpretation

#### ! Application

Strictly speaking faecal indicators (that is, bacteria or phages) only indicate faecal pollution,

which implies the potential presence of waterborne pathogens. Faecal pollution does, of course, also have aesthetic implications for drinking and recreational waters. Despite shortcomings, commonly-used faecal indicators have proved to be of major value in water quality assessment and control.

Bacterial indicators of faecal pollution recommended in this guideline (coliforms and enterococci) have shortcomings, particularly with regard to protozoan parasites and viruses. Although somatic and F-RNA phages overcome some of the shortcomings regarding viruses; these indicators are not yet widely used, particularly by laboratories in South Africa. There is a need for more information on the value of phage indicators and transfer of the technology.

A logarithmic distribution is commonly used in determining the measure of central tendency of bacterial counts. For such a distribution the median is, in principle, the same as the log or geometric mean, although random differences can be expected in practice, depending on the number of samples and the sampling frequency. Organisations concerned with water quality management and research in South Africa tend to use either the median or the geometric mean as the measure of central tendency in microbial data sets.

### **! Sample Frequencies**

It is not possible to recommend universal sampling frequencies or indicator organisms for monitoring the microbiological safety of water. As mentioned earlier, too many variables are involved.

### **Treatment Options**

Several conventional water purification processes, including sedimentation, absorption, coagulation and flocculation will all result in the partial removal of micro-organisms in water. These processes, however, do not necessarily inactivate the micro-organisms and additional disinfection processes need to be applied. Chlorine disinfection is often practised. Disinfection, however, requires careful process control of the disinfection species, dosage and contact time.

In situations where no conventional treatment is practised, micro-organisms can be destroyed by boiling the water before use.

## Recommended Indicator Bacteria, Their Detection and Uses in Water Quality Management

Indicator	Detection and use in water quality management
Total coliform bacteria (total coliforms)	Refers to all bacteria which produce colonies with a typical metallic sheen within 20 - 24 hours of incubation at 35 EC on m-Endo agar. Gives an indication of the general sanitary quality of water since this group includes bacteria of faecal origin. However, many of the bacteria in this group may originate from growth in the aquatic environment. Used to evaluate the general sanitary quality of drinking water and related waters, for example, swimming pool water
Faecal coliform bacteria (faecal coliforms)	Refers to all bacteria which produce typical blue colonies on m-FC agar within 20 - 24 hours of incubation at 44.5 EC and comprises members of the total coliform group which are capable of growth at elevated temperature. Indicator of probable faecal pollution of water since this group is much more closely associated with faecal pollution than the broader total coliform group. Some faecal coliforms may not be of faecal origin. Used to evaluate the quality of wastewater effluents, river water, sea water at bathing beaches, raw water for drinking water supply, recreational waters as well as water used for irrigation, livestock watering and aquaculture
<i>Escherichia coli</i> ( <i>E. coli</i> )	Refers to faecal coliforms which test indole-positive at 44.5 EC and generally consists only of <i>E. coli</i> which is almost definitely of faecal origin. Used to evaluate the possible faecal origin of total and faecal coliforms, usually when these are isolated from drinking water
Enterococci (faecal streptococci)	Refers to bacteria which produce typical reddish colonies on m-Enterococcus agar after 48 hours incubation at 35 EC. These bacteria often appear in human and animal faeces, but in lower numbers than total or faecal coliforms and are more resistant than coliform bacteria. Not all faecal streptococci are of faecal origin, resulting in taxonomic regrouping of this group in recent years. Enterococci comprises a sub-group of faecal streptococci, being considered to include predominantly faecal streptococci of proven faecal origin. Used in evaluation of treatment processes and recreational waters
Somatic coliphages	A diverse group of phages which infect <i>E. coli</i> and certain closely related bacteria. These phages occur in large numbers in sewage, and are detectable by relatively simple, economic and rapid techniques. Their numbers may increase in certain water environments suitable for the growth of host bacteria. Somatic coliphages indicate faecal pollution, and their incidence and survival in water environments would seem to more closely resemble that of human viruses than faecal bacteria
F-RNA coliphages	A restricted group of coliphages (also known as male-specific coliphages) which only infect <i>E. coli</i> and related hosts which produce fertility fimbriae during the logarithmic growth phase at temperatures > 30 EC. These phages can, therefore, not be replicated in natural water environments which implies that they are highly specific indicators of faecal pollution. Their numbers in sewage are generally lower than those of somatic coliphages, and their behaviour and incidence in water environments would seem to resemble that of human viruses even closer than somatic coliphages. Detection methods for F-RNA phages are more complicated than those for somatic coliphages



The guidelines include information on the following indicator organisms:

Heterotrophic bacteria  
Total Coliforms  
Faecal Coliforms  
Coliphages

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# Indicator Organisms

## *Heterotrophic Bacteria*

### Background Information

**Introduction** Heterotrophic bacterial counts are used to indicate the general microbial quality of water. They are used to assess the efficiency of water treatment and disinfection processes, to test the integrity of distribution systems for after-growth and to determine the quality of water used in industrial processes.

Heterotrophic plate counts do not indicate possible faecal pollution nor do they represent the total number of bacteria present in the water; only those bacteria able to grow under the specific conditions of the test are counted. Various methods and media exist to perform this analysis and it is also referred to as a standard plate count or colony count.

**Occurrence** Heterotrophic plate counts detect a wide range of bacteria which are omnipresent in nature. Pollution of water can give rise to conditions conducive to bacterial growth, such as high nutrient concentrations and high turbidity and can result in a substantial increase of these naturally-occurring organisms.

**Interactions** The activities of heterotrophic bacteria are dependent on the physical, chemical and biological interactions of the aquatic environment, which determine their growth rate and survival. See **indicator organisms**.

**Measurement** Heterotrophic plate counts are usually reported as counts (number of colonies)/mℓ. Three alternative methods for determining the heterotrophic plate count in a water sample have been approved by the American Standard Methods Committee, namely pour plates, spread plates and membrane filtration methods. Various media are used which could result in variation in the results. Results are obtained after incubation at 35°C for 48 hours. This temperature and period of incubation favours the detection of faecal organisms.

**Data Interpretation** Mean values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. Variations in growth media, incubation periods and temperature may result in the enumeration of different heterotrophic bacterial populations. Hence, data collected using different methods is not directly comparable.

**Treatment Options** See **indicator organisms**.

### The Effects of Heterotrophic Bacteria

**Norms** The norm used in the guideline for heterotrophic bacteria is human health.

**Effects** Heterotrophic plate counts are used to assess the general bacterial content of water but do not necessarily represent the total bacterial population present. High heterotrophic plate counts in treated water indicate inadequate treatment of the water, post-treatment contamination or bacterial aftergrowth in the distribution system. Therefore, pathogenic micro-organisms, bacteria, viruses or parasites could possibly be present in the water and

pose a health risk when the water is used for domestic consumption.

**Mitigation** A person who has contracted a water-related, infectious disease should receive medical attention.

**Criteria** **Effects of Heterotrophic Plate Counts on Human Health**

<b>Heterotrophic Plate Count Range (counts/1 mℓ)</b>	<b>Effects</b>
<i>Target Water Quality Range</i> <i>0 - 100</i>	<i>Negligible risk of microbial infection</i>
100 - 1 000	Indicative of inadequate treatment, post-treatment contamination or aftergrowth in the water distribution system. Slight risk of microbial infection
> 1 000	Indicative of poor treatment, post-treatment contamination or definite after-growth in the water distribution system. Increased risk of infectious disease transmission

## Sources of Information

See **indicator organisms**.

# Indicator Organisms

## *Total Coliforms*

### Background Information

<b>Introduction</b>	Total coliform bacteria are frequently used to assess the general hygienic quality of water and to evaluate the efficiency of drinking water treatment and the integrity of the distribution system. They should not be detectable in treated water supplies. If found, they suggest inadequate treatment, post-treatment contamination and/or aftergrowth or an excessive concentration of nutrients. In some instances they may indicate the presence of pathogens responsible for the transmission of infectious diseases.
<b>Occurrence</b>	Total coliforms comprise a heterogeneous group which include bacteria from the genera <i>Escherichia</i> , <i>Citrobacter</i> , <i>Enterobacter</i> , <i>Klebsiella</i> , <i>Serratia</i> and <i>Rahnella</i> . Although most of these bacteria are of faecal origin, some bacteria classified as coliforms are not of faecal origin.
<b>Interactions</b>	The activities of coliform bacteria are dependent on all the physical, chemical and biological interactions of the aquatic environment, which determine their growth rate and survival. See <b>indicator organisms</b> .
<b>Measurement</b>	Total coliforms are usually enumerated as counts (number of colonies)/100 mL. Samples must be refrigerated immediately after collection and should be analysed within six hours. Prior to analysis, domestic water samples containing residual chlorine must be dechlorinated, usually with sodium thiosulphate. Analysis may be by membrane filtration (0.45 µm diameter pore size), pour plates or by multiple tube fermentation techniques. The total coliform bacteria are all bacteria which produce colonies with a typical metallic sheen within 20 - 24 hours of incubation at 35 °C on m-Endo agar.
<b>Data Interpretation</b>	Mean values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. See <b>indicator organisms</b> .
<b>Treatment Options</b>	See <b>indicator organisms</b> .

### The Effects of Total Coliforms

<b>Norms</b>	The norm used in the guideline for total coliforms is human health.
<b>Effects</b>	<p>Total coliform counts are primarily used in the evaluation of water treatment processes. They indicate microbial growth in the distribution system or post-treatment contamination of drinking water.</p> <p>The total coliform group includes bacteria of faecal origin and indicates the possible presence of bacterial pathogens such as <i>Salmonella spp.</i>, <i>Shigella spp.</i>, <i>Vibrio cholerae</i>, <i>Campylobacter jejuni</i>, <i>C. coli</i>, <i>Yersinia enterocolitica</i> and pathogenic <i>E. coli</i>, especially when detected in conjunction with other faecal coliforms. These organisms can cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever.</p>

**Mitigation** A person who has contracted a water-related infectious disease should receive medical attention.

**Criteria** **Effects of Total Coliforms on Human Health**

<b>Total Coliform Range (counts/100 mL)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 5</i>	<i>Negligible risk of microbial infection</i>
5 - 100	Indicative of inadequate treatment, post-treatment contamination or growth in the distribution system. Risk of infectious disease transmission with continuous exposure and a slight risk with occasional exposure
> 100	Indicative of poor treatment, post-treatment contamination or definite growth in the water distribution system. Significant and increasing risk of infectious disease transmission

**Sources of Information**

See **indicator organisms**.

# Indicator Organisms

## *Faecal Coliforms*

### Background Information

<b>Introduction</b>	Faecal coliforms, and more specifically <i>Escherichia coli</i> ( <i>E.coli</i> ), are the most commonly used bacterial indicators of faecal pollution. This indicator group is used to evaluate the quality of wastewater effluents, river water, sea water at bathing beaches, raw water for drinking water supply, treated drinking water, water used for irrigation and aquaculture and recreational waters. The presence of <i>Escherichia coli</i> is used to confirm the presence of faecal pollution by warm-blooded animals (often interpreted as human faecal pollution). Some organisms detected as faecal coliforms may not be of human faecal origin but are almost definitely from warm-blooded animals.
<b>Occurrence</b>	Faecal coliforms have been shown to represent 93 % - 99 % of coliform bacteria in faeces from humans, poultry, cats, dogs and rodents. Some faecal coliform tests also enumerate <i>Klebsiella spp.</i> , which can originate from non-faecal sources and a few other bacterial strains also of non-faecal origin. <i>Escherichia coli</i> usually comprises approximately 97 % of coliform bacteria in human faeces. The remainder include <i>Klebsiella spp.</i> , <i>Enterobacter spp.</i> and <i>Citrobacter spp.</i>
<b>Interactions</b>	The activities of micro-organisms are dependent on all physical, chemical, and biological interactions of the aquatic environment, which determine their growth rate and survival. See <b>indicator organisms</b> .
<b>Measurement</b>	Faecal coliforms are usually enumerated as counts (number of colonies)/100 mℓ of water. Water samples must be refrigerated immediately after collection and should be analysed within six hours. Prior to analysis, domestic water samples containing residual chlorine must be dechlorinated, usually with sodium thiosulphate. Analysis may be by membrane filtration (0.45 μm diameter pore size), pour plates or by multiple tube fermentation techniques. Faecal coliform bacteria are all bacteria which produce typical blue colonies on m-FC agar within 20 - 24 hours of incubation at 44.5 EC. <i>Escherichia coli</i> are considered to be all the faecal coliforms which test indole-positive at 44.5 EC.
<b>Data Interpretation</b>	Mean values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. See <b>indicator organisms</b> .
<b>Treatment Options</b>	See <b>indicator organisms</b> .

### The Effects of Faecal Coliforms

<b>Norms</b>	The norm used in the guideline for faecal coliforms is human health.
<b>Effects</b>	Faecal coliforms are primarily used to indicate the presence of bacterial pathogens such as <i>Salmonella spp.</i> , <i>Shigella spp.</i> , <i>Vibrio cholerae</i> , <i>Campylobacter jejuni</i> , <i>Campylobacter coli</i> , <i>Yersinia enterocolitica</i> and pathogenic <i>E. coli</i> . These organisms can be transmitted via the faecal/oral route by contaminated or poorly-treated drinking water and may cause

diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever.

The risk of being infected by microbial pathogens correlates with the level of contamination of the water and the amount of contaminated water consumed. Higher concentrations of faecal coliforms in water will indicate a higher risk of contracting waterborne disease, even if small amounts of water are consumed.

**Mitigation**

A person who is suspected of having contracted a water-related infectious disease should receive medical attention.

**Criteria**

**Effects of Faecal Coliforms on Human Health**

Faecal Coliform Range (counts/100 mL)	Effects
<i>Target Water Quality Range</i> 0	<i>Negligible risk of microbial infection</i>
0 - 10	Slight risk of microbial infection with continuous exposure; negligible effects with occasional or short-term exposure
10 - 20	Risk of infectious disease transmission with continuous exposure; slight risk with occasional exposure
> 20	Significant and increasing risk of infectious disease transmission. As faecal coliform levels increase, the amount of water ingested required to cause infection decreases

**Sources of Information**

See **indicator organisms**.



# Indicator Organisms

## Coliphages

### Background Information

**Introduction** Coliphages are bacterial viruses which infect and replicate in *E. coli* and may infect related coliform bacteria. The presence of coliphages, therefore, probably indicates the presence of their bacterial hosts, such as *E. coli*. Coliphages are shed in large numbers in the faeces of warm-blooded animals and humans. Their presence in faecal matter means that they can serve as indicators of faecal pollution and may indicate the concurrent presence of pathogenic viruses.

Coliphages are broadly divided into two groups, somatic coliphages and male-specific coliphages. Somatic coliphages infect *E. coli* by adsorbing to viral receptors in the cell wall (somatic receptors). Male-specific coliphages infect *E. coli* by adsorbing to threadlike appendages (*sex fimbriae* or *sex pili*) and are produced only under specific conditions and elevated temperatures, similar to those found in the gastrointestinal tracts of humans and other warm-blooded animals. Hence, multiplication of male-specific coliphages is unlikely to take place in the aquatic environment. This makes them highly specific indicators for faecal pollution by warm-blooded animals, including humans.

Male-specific phages are also very similar in structure, composition and morphology to several important human viruses. However, they are not as readily detectable as somatic coliphages, for which simple, rapid and cost-effective methods are available. Hence most studies, including these guidelines, use somatic phages, even though replication of somatic coliphages in the aquatic environment has been demonstrated.

**Occurrence** Somatic **coliphage** counts in the faeces of man and animals may vary from less than 10 plaque-forming units (pfu)/g to  $10^8$  pfu/g, although in human faeces counts rarely exceed  $10^3$  pfu/g and may often be undetectable. Phages are often found in faeces of patients suffering from systemic diseases. Somatic coliphages counts in sewage range from  $10^3$  pfu/mR -  $10^4$  pfu/mR. In natural waters, coliphages can also be detected in high numbers, primarily due to pollution from sewage. Inactivation of coliphages is affected by similar constituents to those which determine inactivation of bacteria. The most significant factors are temperature, suspended solids, biological activity and sunlight.

**Interactions** Any constituent or parameter that affects the growth rate of coliphage bacterial hosts, for example, *E. coli*, should be considered. See **indicator organisms**.

**Measurement** Coliphage counts (number of pfu) are usually reported per 10 mR. In this guideline counts/100 mR are presented for easier comparison to counts of other indicator organisms, particularly faecal coliforms.

Coliphages are usually detected in water by their ability to form visible plaques in a plaque assay using an *E. coli* host under conditions of 16 hours incubation at 35 EC. However, standard methods of analysis have not been defined. Generally, a particular strain of *E. coli* known as *E. coli* C, in which viral defence mechanisms have been eliminated is used, making it susceptible to a wide range of coliphages. Coliphages occurring at concentrations too low to be detected by direct analysis may be detected by either enrichment or concentration of phages.

**Note:** Guidelines are generally specified for somatic coliphages, which are capable of multiplication in the aquatic environment in the absence of the *E. coli* host strain.

**Data Interpretation** Mean values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. See **indicator organisms**.

**Treatment Options** See **indicator organisms**.

## The Effects of Coliphages

**Norms** The norm used in the guideline for coliphages is human health.

**Effects** Viruses are important causative agents of waterborne diseases and can cause illnesses such as gastroenteritis, hepatitis, poliomyelitis and respiratory illness. Coliphages are used to indicate faecal pollution and may indicate the concurrent presence of pathogenic viruses, particularly the enteric viruses.

The risk of being infected by microbial pathogens correlates positively with the level of contamination of the water and the amount of contaminated water consumed. Viruses have a considerably lower minimum infectious dose than bacteria, namely one to 10 viral particles, as compared to 10 - 1 000 bacteria, respectively. This means that even at low levels of viral pollution a high risk of infection exists.

**Mitigation** A person who has contracted a suspected waterborne disease caused by a virus should receive medical attention.

### Criteria **Effects of Coliphages on Human Health**

Coliphage Range (counts/100 mR)	Effects
<i>Target Water Quality Range</i> <i>0 - 1</i>	<i>Sewage pollution is not indicated. Negligible risk of viral infection is indicated</i>
1 - 10	Slight probability of sewage pollution. A very slight risk of viral infection is indicated for continuous exposure, but negligible risk is expected for short, occasional exposure
10 - 100	Probable sewage pollution. A low risk of viral infection is indicated with continuous exposure; minimal effects expected for occasional exposure
> 100	Significant sewage pollution and increasing risk of viral infection as coliphage levels increase

## Sources of Information

See **indicator organisms**.





# Indicator Organisms

## *Enteric Viruses* Tentative guideline

### Background Information

**Introduction** Viruses are submicroscopic inert particles of protein and nucleic acid which are unable to replicate or adapt to environmental conditions outside a living host. Human enteric viruses require man as their specific host and are associated with the digestive tract. Enteric viruses are viruses which are primarily transmitted by the faecal-oral route, that is, transmission by faecally-contaminated water or food. The enteric virus group includes enteroviruses (that is, polio, coxsackie A and B and echo viruses), enteric adenoviruses, reoviruses, rotaviruses, hepatitis A and E viruses, calciviruses (that is, Norwalk virus) and astroviruses. Possible health effects associated with the presence of such viruses in water includes paralysis, meningitis, hepatitis, respiratory illness and diarrhoea.

Enteric viruses can also be transmitted via the consumption of raw vegetables which have been irrigated with polluted water.

**Occurrence** Enteric viruses are excreted in faecal matter and may occur in water as a result of stormwater discharge, runoff, sewer overflows or sewage discharge. Viruses are excreted by infected individuals in numbers up to  $10^{11}$ /g faeces. Compared with most pathogens, the minimal infectious dose is extremely low. In many cases, a single virus can cause infection. Quantitative data on the occurrence of enteric viruses in the environment are limited due to the complexity of virus recovery and detection methods.

Since viruses cannot multiply outside a living host and are exceptionally resistant to unfavourable conditions, virus levels tend to decrease only gradually after discharge into the aquatic environment and may, therefore, be present for a very long period. Enteric virus levels in source water are influenced by treatment, but are not necessarily reduced consistently since they display relatively high resistance to environmental stress and to treatment.

**Interactions** A number of physical, chemical and biological factors determine the rate of decline in virus levels. The most significant factors are temperature, biological activity and sunlight. Since viruses may be found in association with sediments and particulate matter, the **turbidity** level in water may also be important in determining viral load.

**Measurement** For optimal detection of enteric viruses water samples should be cooled immediately (4 - 10 EC) and analysed as soon as possible, preferably within six hours of collection. The volume of water tested is important because even low numbers of viruses pose a meaningful risk of infection. On the basis of risk assessment studies, testing of 100 R samples has been recommended. Viruses are generally recovered from test samples by adsorption-elution techniques. In conventional testing viruses are detected by propagation in appropriate cell cultures. This detection method is limited to cytopathogenic viruses, that is, viruses which replicate in cell cultures and cause visible damage to the cells. In this guideline the concentration of enteric viruses refers to cytopathogenic enteric viruses and is expressed as the TCID<sub>50</sub> (tissue culture infectious dose required to cause 50 % infection)/10 R. Cytopathogenic enteric viruses are primarily restricted to polio, coxsackie B, echo and reo viruses.

The detection of other enteric viruses requires a different approach. For instance, molecular techniques such as the polymerase chain reaction (PCR) are now being optimised for meaningful testing. Since methods for the detection of non-cytopathogenic viruses are still in the research and development stage, water quality guidelines are worldwide based on cytopathogenic enteric viruses. This implies a need for less expensive, faster and more sensitive techniques for the detection of a wider variety of viruses, including the non-cytopathogenic viruses primarily involved in waterborne diseases.

**Data Interpretation**

The criteria should be interpreted as maximal values that should not be exceeded.

The detection of viruses is relatively expensive and most microbiological laboratories in South Africa do not possess the necessary facilities and expertise for routine virological monitoring. Assessment of virological safety would, therefore, generally have to rely on regular testing for appropriate indicator organisms and sanitary surveys. Virological analysis is recommended only for situations in which there is reason to suspect the presence of viruses, such as outbreaks of enteric viral disease.

**Treatment Options**

In water environments viruses are inactivated by exposure to sunlight, physico-chemical damage (that is, heavy metals and oxidising agents), antagonism by predator organisms and enzymes which degrade proteins and nucleic acids.

Several conventional water purification processes such as sedimentation, absorption, coagulation and flocculation will result in the partial removal of viruses and/or their host organisms in water. These processes, however, do not necessarily inactivate viruses and additional disinfection processes need to be applied. Chlorine or other oxidising agents are commonly used. Disinfection may be effective, but requires careful process control of the disinfectant species, dosage and contact time.

**Effects of Enteric Viruses**

**Norms**

The norm used in the guideline for enteric viruses is human health.

**Effects**

Enteric viruses which may occur in polluted water include adenoviruses, reoviruses, rotaviruses, hepatitis A virus and Norwalk virus. These viruses can cause diseases such as gastroenteritis, pneumonia and viral hepatitis.

The risk of being infected by microbial pathogens correlates with the level of contamination of the water and the amount of contaminated water consumed. As few as one to 10 viruses can initiate an infection. This means that even at low levels of viral pollution a high risk of infection exists.

Viruses are known to have been responsible for at least 12 % of reported waterborne disease outbreaks in the USA in the period 1946 - 1980 and it has been suggested that this may be as much as 64 % of the total.

**Mitigation Criteria**

Persons showing symptoms of a viral infection should seek medical attention.  
**Effects of Enteric Viruses on Human Health**

Enteric Virus Range (TCID <sub>50</sub> /10R)	Effects
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<i>Target Water Quality Range</i> 0	<i>Negligible risk of enteric virus infection expected</i>
1	Slight risk of enteric virus infection for continuous exposure; minimal risk for short or occasional exposures
1 - 10	Medium risk of enteric virus infection for continuous exposure; probable low risk for occasional exposure
> 10	Risk of enteric virus infection is significant and increases as virus levels increase

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# Indicator Organisms

## *Protozoan Parasites*

### Tentative Guideline

## Background Information

**Introduction** *Giardia* and *Cryptosporidium* are protozoan parasites with several lifecycle stages, of which the cysts (*Giardia*) or oocysts (*Cryptosporidium*) are infective to humans. Species which infect humans are *Giardia lamblia* and *Cryptosporidium parvum*. Infection occurs by ingestion of the cysts or oocysts and disease takes the form of gastroenteritis, diarrhoea, vomiting and anorexia. Acute, chronic and asymptomatic manifestations of infection are known.

The infective dose for parasites is extremely low. Theoretically, one cyst or oocyst is sufficient to cause infection and an infective dose of 10 *Giardia* cysts has been demonstrated. *Giardia lamblia* has been identified as one of the most common causes of waterborne disease outbreaks in recent studies.

**Occurrence** *Giardia* cysts and *Cryptosporidium* oocysts have been found in a number of different waters in South Africa. They have been isolated from treated drinking water on several occasions and are commonly found in surface waters. In addition to man, *Giardia* and *Cryptosporidium* are excreted by several mammalian species, hence the possibility of cross-infection from other species also exists. *Giardia* and *Cryptosporidium* are extremely resistant to environmental stress and to treatment and are minimally affected by chlorination. They may also survive for days or months in environmental water and animals may act as reservoirs of infection.

Cysts and oocysts from animals and humans can enter the aquatic environment by various routes, including runoff and effluent discharge. Domestic wastewater and agricultural runoff are considered to be major sources.

**Interactions** The most significant factors which govern the inactivation and removal of parasite cysts and oocysts are temperature, suspended solids, biological activity and sunlight. Temperature and desiccation are thought to be the main factors affecting cyst and oocyst persistence. However, inactivation is very slow and cysts and oocysts may persist for long periods.

**Measurement** Monitoring of protozoan parasites is difficult and to date no standard monitoring practices, concentration procedures or detection methods have been established. Methods for concentrating water samples and recovery of cysts and oocysts vary in procedure and efficacy. The most common method for the identification of *Giardia* and *Cryptosporidium* cysts and oocysts uses fluorescent-conjugated antibody staining. A disadvantage of this detection method is that the difference between viable and non-viable cysts or oocysts cannot be distinguished. For the detection of protozoan parasites, 100 R of sample should be concentrated and cartridge filters are best suited for this purpose.

**Data Interpretation** No quantitative criteria limits have been provided and the recommendations given on this are guidelines based largely on the opinions of South African experts. Not all laboratories can concentrate 100 R of water and the criteria are therefore based on the concentration of cysts/oocysts in 10 R.

Protozoan parasites are generally not included in domestic water quality guidelines. The US Environmental Protection Agency has set criteria for treatment options to be used and specific concentration values for domestic consumption are not given.

**Treatment Options** Sand filtration plays a major role in the removal of protozoan parasite cysts and oocysts from polluted water. Several other conventional water treatment processes, such as sedimentation, adsorption, coagulation and flocculation may remove cysts and oocysts from water, but without inactivation.

## Effects of Protozoan Parasites

**Norms** The norm used in the guideline for protozoan parasites is human health.

**Effects** Cysts (*Giardia*) and oocysts (*Cryptosporidium*) are part of the lifecycle of these protozoan parasites and are infective to humans. Infection occurs by ingestion of the cysts or oocysts and disease takes the form of gastroenteritis, diarrhoea, vomiting and anorexia. Acute, chronic and asymptomatic manifestations of infection are known. The infective dose for parasites is extremely low. Theoretically, one cyst or oocyst is sufficient to cause infection, and an infective dose of 10 *Giardia* cysts has been demonstrated.

Most outbreaks of giardiasis and cryptosporidiosis are associated with untreated water supplies, water that has been disinfected (for example, chlorinated) but has not been passed through slow sand filters, and a breakdown in conventional treatment.

**Mitigation** A person who has contracted a suspected waterborne disease caused by a protozoan parasite should receive medical attention.

**Criteria** **Effects of Protozoan Parasites on Human Health**

Protozoan Parasite Range (cysts or oocysts/10R)	Effects
<i>Target Water Quality Range</i> 0	<i>Negligible risk of protozoan parasite infection is expected</i>
> 1	There may be a risk of protozoan parasite infection for continuous short or occasional exposures

**Note:**

There is at present insufficient data to develop comprehensive water quality criteria for protozoan parasites in water intended for domestic use. The criteria are intended as an indication of safe levels only.

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# Iron

## Background Information

**Introduction** Pure iron is silvery in colour but usually appears as greyish black or brown deposits as a result of oxidation. Iron is found in three oxidation states, namely, 0, II and III of which the III oxidation state is the most common. In water, iron can be present as dissolved ferric iron, Fe(III), as ferrous iron, Fe(II) or as suspended iron hydroxides. Biologically iron is an essential micronutrient required by all living organisms. High concentrations of iron are predominantly an aesthetic concern since ferrous salts are unstable under the pH conditions prevailing in drinking water and precipitate as insoluble ferric hydroxide, which settles out as a rust-coloured silt.

**Occurrence** Iron is the fourth most abundant element and constitutes five percent of the earth's crust. It is found in many minerals, the most common of which is haematite ( $\text{Fe}_2\text{O}_3$ ), widely used as an iron ore for metallurgical purposes. Other important iron minerals are pyrite ( $\text{FeS}_2$ ), siderite ( $\text{FeCO}_3$ ), magnetite ( $\text{Fe}_3\text{O}_4$ ), goethite ( $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ ) and limonite ( $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ), as well as a number of mixed ores, such as chalcopyrite ( $\text{CuFeS}_2$ ) and arsenopyrite ( $\text{FeAsS}$ ). Pyrite is often associated with coal formations and iron may occasionally also be found in the elemental form, either as terrestrial iron or as meteoric iron. The reddish colour of soil is due to iron, the median concentration in soil being 4.0 % (m/m). Typically, the concentration of dissolved iron in:

- ! unpolluted surface water, is in the range of 0.001 - 0.5 mg/R; and
- ! sea water, is approximately 0.002 mg/R.

The speciation of iron is strongly related to the pH and the redox potential of the water. At neutral or alkaline pH, under oxidising conditions, the dissolved iron concentration is usually in the  $\mu\text{g/R}$  range but under reducing conditions, soluble ferrous iron may be formed and substantially higher concentrations in the mg/R range may be encountered. Where marked acidification of the water occurs and the pH is less than 3.5, the dissolved iron concentration can be several hundred mg/R, as may be the case with acid mine drainage.

There is a natural cycling of iron between the dissolved and precipitated phases at the water sediment interface, in which micro-organisms, particularly iron bacteria such as *Gallionella spp.* play a significant role.

**Interactions** The concentration of dissolved iron in water is dependent on the **pH**, redox potential, **turbidity**, **suspended matter**, the concentration of **aluminium** and the occurrence of several heavy metals, notably **manganese**. The natural cycling of iron may also result in the coprecipitation of trace metals such as **arsenic**, **copper**, **cadmium** and **lead**.

**Measurement** The criteria are given in terms of the total iron concentration, expressed in units of mg/R. The reference method for the determination of iron is by atomic absorption spectrometry (AAS), using an air-acetylene flame. Measurement of the total iron concentration requires acidification followed by filtration prior to AAS analysis. Where other methods are used, their characteristics relative to the reference method should be known.

**Data Interpretation** Mean values should be used to compare with the criteria given. Turbidity and pH must also be taken into account in the interpretation of iron concentrations.

## Treatment Options

Iron in water supplies is most conveniently removed by applying conventional water treatment processes of coagulation with lime or alum, followed by settlement and filtration. Iron can also be removed from water using an oxidising process which will convert the iron into an insoluble hydroxide or hydrated oxide, removable by filtration. The following treatment approaches are used:

- ! The water can be **aerated** by devices such as fountains, cascades or mechanical aeration;
- ! The addition of lime to the water will raise the pH and facilitate the oxidation of iron by air in the water, followed by settlement of the iron oxide;
- ! The water can also be **chemically oxidised** by dosing with chlorine, hydrogen peroxide, ozone or other strong oxidants. On an industrial scale chlorine is commonly used as the chemical oxidant. Post-treatment, high levels of residual chlorine should be avoided since this may interfere with the quality of the water.

Removal of iron can be achieved on a household scale by cascading the water through the air and allowing the iron oxide particles to settle. On an industrial scale the process usually needs to be more closely controlled and monitored because the consequences of incomplete treatment may be severe.

For the optimisation of treatment processes it is important to determine both the total and dissolved iron species and their relative concentrations.

## The Effects of Iron

### Norms

The norms used in the guideline are based on aesthetic and health effects. The major effects of the presence of iron in domestic water are aesthetic, but in some cases distribution systems may also be affected. Health effects may occur at extremely high concentrations.

### Effects

Excessive ingestion of iron may result in haemochromatosis, wherein tissue damage occurs as a consequence of iron accumulation. Haemochromatosis generally results from prolonged consumption of acid foodstuffs cooked in kitchenware made of iron. Poisoning is rare since excessively high concentrations of iron do not occur naturally in water. The extreme unpalatability of such water would probably prevent consumption. Further, iron in the distribution system promotes proliferation of iron-oxidising bacteria which oxidise ferrous iron to ferric iron, and manifest as slimy coatings in plumbing when the iron concentration of the water in the distribution system approaches 0.3 mg/R. Effects are predominantly aesthetic, such as the staining of enamelled surfaces of baths, hand basins and lavatory cisterns/bowls and laundry. Iron causes discolouration of water supplies when present at low concentrations in association with aluminium. Iron that settles out in distribution systems gradually reduces the flow rate of water. The only associated health effects are those that could arise from the presence of microbial deposits on internal surfaces of plumbing.

Iron complexed with humic acid, a natural water constituent in certain regions, causes a brown discolouration of water at high concentrations. This may be aesthetically unacceptable, but has no adverse health implications.

**Mitigation**

Mitigation against aesthetic effects of the presence of iron in domestic water involves regularly cleaning of bathroom and sanitaryware to prevent the buildup of permanent stains. Mitigation of the effects of ingesting excessive concentrations of iron is not normally an issue, since poisoning from water is rare. However, iron poisoning in children from accidental consumption of anaemia-treatment iron supplement tablets, is not that rare. If iron poisoning, acute or chronic, is suspected, medical advice should be sought.

**Criteria****Effects of Iron on Aesthetics, Human Health and Household Distribution Systems**

<b>Iron Range (mg/R)</b>	<b>Effects</b>
<b><i>Water Quality Target Range</i></b> <b><i>0 - 0.1</i></b>	<b><i>No taste, other aesthetic or health effects associated with consumption and use</i></b>
0.1 - 0.3	Very slight effects on taste and marginal other aesthetic effects. Deposits in plumbing with associated problems may begin to occur. No health effects; the water is generally well tolerated.
0.3 - 1.0	Adverse aesthetic effects (taste) gradually increase as do possible problems with plumbing. No health effects.
1 - 10	Pronounced aesthetic effects (taste) along with problems with plumbing. Slight health effects expected in young children, and sensitive individuals.
10 - 30	Severe aesthetic effects (taste) and effects on the plumbing (slimy coatings). Slight iron overload possible in some individuals. Chronic health effects in young children and sensitive individuals in the range 10 - 20 mg/R, and occasional acute effects toward the upper end of this range.
30 - 100	As above Long-term health effects gradually increase.
100 - 300	As above Chronic health effects. Acute toxicity may begin to appear.
300 - 3 000	As above Chronic and acute health effects. Accidental iron poisoning from water is rare.
3 000 - 30 000	As above Lethal toxicity occurs.

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# Lead

## Background Information

**Introduction** Lead is a bluish-white, very soft metal, which is highly malleable and ductile. It is also highly resistant to corrosion.

**Occurrence** The most common mineral ores of lead are galena (lead sulphide), cerussite (lead carbonate) and anglesite (lead sulphate). The occurrence of lead in its elemental state is rare. Lead tends to accumulate in sediments and soils in the environment. Lead which has been absorbed by vertebrate organisms is to a large extent deposited in the bony skeleton.

Typically, the concentration of lead in:

- ! surface water is less than 0.010 mg/R;
- ! sea water is no greater than 0.003 mg/R; and
- ! contaminated water can be several mg/R. Dissolution of lead from lead pipes occurs particularly with soft water, low in calcium carbonate.

Lead has many industrial applications which can give rise to sources of lead contamination in water supplies. Lead is used in batteries, in domestic water distribution pipes, in paints and as an organic lead compound, alkyl lead, in gasoline.

**Interactions** Metabolically, lead interacts with **iron** and interferes with haemoglobin synthesis. Lead uptake is affected by the action of **calcium** and an intake of adequate dietary calcium tends to suppress uptake.

**Measurement** The criteria are given in terms of the total lead concentration, in units of Fg/R. Lead can be measured colorimetrically at low concentration (0 - 30 Fg/R) using the dithizone method to form the cherry red lead dithizonate, which is measured spectrophotometrically. Alternatively, lead may be measured by atomic absorption spectrophotometry. These two types of methods constitute the reference methods for lead. If other methods are used, their characteristics relative to the reference methods should be known.

**Data Interpretation** Mean values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. Chronic lead poisoning, which is far more common than acute poisoning, results from intake over a period of months or years, rather than from episodic exposure. Further, single-sample values can fluctuate widely, especially where lead dissolution from the distribution system takes place.

**Treatment Options** Lead in water supplies is most conveniently removed by applying conventional water treatment processes of coagulation with alum, ferric salts or lime followed by settlement and filtration.

The coagulation/flocculation process requires careful monitoring to ensure that removal is complete. A watery sludge containing lead is generated in the process, and may present disposal difficulties.

## The Effects of Lead

<b>Norms</b>	The norm used in the guideline is human health.
<b>Effects</b>	Exposure to lead, particularly of young children, should be minimised as far as possible. At relatively low concentrations, particularly with continuous exposure, lead can cause neurological impairment in foetuses and young children. This can lead to behavioural changes and impaired performance in intelligence quotient tests. The effects are slight at low or intermittent exposure to lead, but become more pronounced as the exposure to lead increases. In adults the neurological effects are much less pronounced and the effects of exposure to toxic concentrations of lead take the form of anaemia and lead colic, that is, acute episodes of abdominal pain. An adult is approximately one order of magnitude less sensitive to lead toxicity than a growing child.
<b>Mitigation</b>	As lead is often introduced into water by corrosion from plumbing materials in the home, an important aspect of mitigating against the exposure to lead is in the treatment of the water and control of the pH and calcium concentrations, so that dissolution of lead from plumbing is minimised. The toxicity of lead is markedly influenced by the calcium nutritional status of the individual and is reduced where there is adequate calcium intake. This is partly due to decreased absorption of lead, and partly as a result of binding of any absorbed lead in the bones. Mitigation should be directed at reducing exposure. Adults are not seriously affected by transient intakes of lead levels slightly exceeding the TWQR. However, children are highly susceptible to lead intoxication, and should be protected from exposure. For example, replacing lead piping with other materials and reducing exposure to lead-containing materials, such as, old flaking paint, soil and dust.

**Criteria**

**Effects of Lead on Human Health**

<b>Lead Range (Fg/R)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 10</i>	<i>No danger of any adverse effects by exposure from water</i>
<b>It is recommended that the TWQR not be exceeded due to the potentially acute and/or irreversible effects of lead on human health</b>	
10 - 50	No danger of any adverse health effects except for a slight risk of behavioural changes and possibility of neurological impairment, where the exposure to lead from other sources, such as food, is not minimised
50 - 100	Possible neurological damage where the nerve and brain tissues are developing, that is, in foetuses and young children. Young children and pregnant women should avoid exposure
100 - 300	Definite danger of neurological impairment in children Alternative water supply should be used by sensitive groups (children and pregnant women)
> 300	Symptoms of chronic lead poisoning are possible with continuous exposure

**Sources of Information**

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# Magnesium

## Background Information

**Introduction** Magnesium is an alkaline earth metal which reacts with oxygen and water to form magnesium oxide and magnesium hydroxide, respectively. Magnesium is a common constituent of water and occurs as a doubly positively-charged magnesium (II) ion. The solubility of magnesium in water is governed by the carbonate/bicarbonate equilibrium and hence, the pH. Magnesium, together with calcium, is responsible for the hardness of water. Magnesium is also an essential nutritional element, and the normal dietary intake is approximately 250 mg/day. Magnesium in water can make a significant contribution to the total dietary intake.

Magnesium is also a basic, essential element for plants (the central metallic ion in chlorophyll) and most other living organisms, since it is a component of important enzyme co-factors.

**Occurrence** Common minerals of magnesium are magnesium carbonate and various magnesium silicates. The solubility of magnesium in water is governed by the pH. Magnesium hydroxide is relatively soluble at pH 7, but gradually becomes less soluble as the pH increases. Magnesium bicarbonate, chloride, nitrate and sulphate are very soluble in water, whereas magnesium carbonate, silicate and the phosphate are insoluble. Typically, the concentration of magnesium in:

! fresh water is between 4 - 10 mg/R; and

! sea water is approximately 1 300 mg/R.

When water containing high concentrations of magnesium is heated, the magnesium will tend to precipitate out of solution with calcium, especially if the bicarbonate concentration is high, and give rise to scaling problems in hot water systems. See **calcium**.

**Interactions** Magnesium interacts with **calcium** and with various anions and organic acids.

**Measurement** The reference method for the determination of magnesium is atomic absorption spectrometry, using a phosphate interference inhibitor, such as lanthanum, and an ionisation suppressant, such as caesium or potassium. If other methods are used, their characteristics relative to the reference method should be known.

**Data Interpretation** Mean values should be used to compare with the criteria given, and should be interpreted in conjunction with the:

! major associated anion(s), usually bicarbonate, sulphate or chloride; and

! calcium, sodium and potassium concentrations.

**Treatment Options** Lime softening followed by recarbonation is the most commonly used treatment for domestic water supplies containing magnesium. However, magnesium is also removed from water using the following treatment approaches:

! **Precipitation** of magnesium as magnesium hydroxide by the addition of sodium

hydroxide. This process raises the pH of the water substantially and is more suitable as a pretreatment step prior to ion exchange.

- ! **Cation exchange** columns are used to replace the magnesium (and calcium if present) in the water with sodium. The columns are regenerated with a sodium chloride brine. Ion exchange is a simple technique to operate on a household scale, but on an industrial scale the process usually needs to be closely monitored because the consequences of incomplete treatment may be severe.
- ! **Demineralisation** in mixed bed ion exchange columns will remove all magnesium ions together with other ions in solution, where water of a particularly low salinity is required.

The same result may be obtained using a range of desalination techniques such as membrane treatment or distillation. On an industrial scale the processes need skilled operation and control. All of the processes produce a concentrated waste stream that may cause disposal difficulties.

## The Effects of Magnesium

**Norms** The norms used in the guideline for magnesium are based on human health and aesthetic effects.

**Effects** Magnesium has a bitter taste. This property serves as a natural protection against the ingestion of potentially harmful concentrations.

As excess magnesium is readily excreted by the kidney, adverse effects such as the suppression of the central nervous system and heart function are rarely seen. Excess magnesium intake, particularly as the sulphate, results in diarrhoea.

Magnesium, together with calcium, is responsible for scaling problems caused by deposits of carbonates in appliances using heating elements and plumbing which transports hot water, and also for inhibiting the lathering of soap which results in scum formation. See **calcium** and **total hardness**.

**Mitigation** Household appliances require regular descaling. Where practicable, mild acid treatments to remove magnesium carbonate should be used. Scum deposits on enamelled surfaces of baths and hand basins should be removed regularly using proprietary, mildly abrasive alkaline cleaning agents to prevent staining.

## Criteria

## Effects of Magnesium on Aesthetics and Human Health

Magnesium Range (mg/R as Mg)	Effects
<i>Target Water Quality Range</i> 0 - 30	<i>No bitter taste. No scaling problems. No health effects</i>
30 - 50	No bitter taste. Slight scaling problems may occur. No health effects
50 - 70	No bitter taste; No health effects; Scaling problems
70 - 100	Slight bitter taste. Taste threshold for magnesium is • 70 mg/R. Scaling problems. Diarrhoea in sensitive users
100 - 200	Water aesthetically unacceptable because of bitter taste. Increased scaling problems. Diarrhoea in most new users if sulphate present
200 - 400	Severe scaling problems. Diarrhoea in all new users
> 400	Severe scaling problems. Diarrhoea in all new users. Health problems may occur

**Modifications** Magnesium is sometimes represented as  $MgCO_3$ . To convert mg/R of Mg to mg/R of  $MgCO_3$ , multiply by a conversion factor of 3.47.

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# Manganese

## Background Information

**Introduction** Manganese is a grey-white brittle metal and is found in several oxidation states, namely -III, -I, 0, I, II, III, IV, V, VI and VII. It is an essential element for humans and animals, but is neurotoxic in excessive amounts. At concentrations usually encountered in water, manganese has aesthetic, rather than toxic effects.

**Occurrence** Manganese is a relatively abundant element, constituting approximately 0.1 % of the earth's crust. Commonly occurring minerals which contain manganese include pyrolusite ( $\text{MnO}_2$ ), manganite ( $\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$ ), rhodochrosite ( $\text{MnCO}_3$ ) and rhodonite ( $\text{MnSiO}_3$ ). Manganese is found in solution predominantly as the manganous, Mn(II) ion, which may be stabilised by complexation to humic acids. On oxidation to the manganic, ion, Mn(IV), manganese tends to precipitate out of solution to form a black hydrated oxide which is responsible for the staining problems often associated with manganese-bearing waters.

Typically, the median concentration of manganese in:

- ! fresh water is 8  $\mu\text{g}/\text{R}$ , with a range of 0.02 - 130  $\mu\text{g}/\text{R}$ ;
- ! soils is 1 000 mg/kg; and
- ! sea water is approximately 0.2  $\mu\text{g}/\text{R}$ .

Manganese concentrations in the mg/R range can be found in anaerobic, bottom level waters, where manganese has been mobilised from the sediments. Industrial uses of manganese include:

- ! the manufacture of steel and manganese alloys;
- ! the salts of manganese as drying compounds in varnishes and oils;
- ! manganese chloride in dry cell batteries;
- ! manganese carbonate as the pigment "manganese white"; and
- ! manganese dioxide in the making amethyst glass and decorative porcelain.

**Interactions** The aquatic chemistry of manganese is closely associated with that of **iron** chemistry. Both elements tend to behave synergistically in their dissolution from sediments under anaerobic conditions and reprecipitation under aerobic conditions. Manganese, once in solution, is more readily stabilised by complexation than iron is, and is often difficult to remove from solution except at high pH, where it precipitates as the hydroxide. Like iron, manganese can be utilised by metallophilic bacteria.

Other water constituents and properties that govern the action of manganese in water are **pH**, redox potential, **turbidity**, suspended matter and the concentration of **aluminium**.

**Measurement** Manganese is measured as total manganese, in units of mg/R. The reference method for the determination of manganese in water is atomic absorption spectrometry, using an air-acetylene flame. Samples should be acidified prior to analysis to dissolve manganese adsorbed to suspended matter.

Where other methods are used, their characteristics relative to the reference method should be known.

**Data Interpretation** Mean values should be used to compare with the criteria given. The occurrence of elevated manganese concentrations in surface waters is typically cyclic unless directly due to pollution by manganese-bearing effluents. Transient episodes of elevated manganese concentrations in pipelines can result in a long-standing manganese problem through precipitation followed by gradual release. In the investigation of consumer complaints of manganese staining, point of use analyses should be done in conjunction with that of the source water.

**Treatment Options** Manganese is commonly removed from water using an oxidising process which converts the manganese into an insoluble oxide removable by filtration. At pH  $\geq 9$ , manganese is oxidised by the dissolved oxygen in the water. If this is not possible, then a **strong oxidising agent** is used. (The reaction is considerably more difficult to achieve than with iron). Agents commonly used include:

- ! Chlorine
- ! Hydrogen peroxide
- ! Potassium permanganate
- ! Ozone

Where the oxidant used leaves a residual, as is the case with chlorine, the residual should be removed before the water is supplied for use.

Removal of manganese is difficult to achieve on a household scale, but some removal will be obtained by addition of sodium hypochlorite (household bleach) to the water. On an industrial scale the process usually needs to be closely controlled and monitored because the consequences of incomplete treatment may be severe.

## The Effects of Manganese

**Norms** The norms used in the guideline are primarily based on aesthetic effects; human health effects are only relevant at elevated concentrations.

**Effects** Adverse aesthetic effects limit the acceptability of manganese-containing water for domestic use at concentrations exceeding 0.15 mg/R. An unpleasant taste is imparted to beverages, and staining of plumbing fixtures and laundry occurs. Oxidation of manganous Mn(II) compounds in solution results in precipitation of hydrated manganese(IV) oxide/hydroxide causing encrustation in plumbing fixtures.

Uptake of manganese occurs by ingestion from both food and water, but more so from food. Manganese exhibits a low solubility in gastric fluids; only three to four percent of ingested manganese is absorbed from the gastrointestinal tract. Manganese in the body is regulated primarily by excretion through the pancreas, although excretion directly through the gut wall and in the urine also takes place.

It has been suggested that the presence of manganese in drinking water may be inversely related to cardiovascular mortality. Deficiencies result in anaemia, growth impairment and skeletal abnormalities. The absorption of manganese in the digestive tract is closely linked to the absorption of iron. Manganese absorption is also inversely related to the level of calcium in the diet and directly related to the level of potassium.

Neurotoxic effects may occur at high concentrations, but manganese is considered to be one of the least potentially harmful of the elements. Only extreme exposure to manganese, such as may occur from industrial exposure, is likely to lead to manganese poisoning. A causative link between manganese ingestion and Parkinson's Disease has been tentatively suggested but not confirmed.

Manganese supports the growth of certain nuisance organisms in water distribution systems, giving rise to taste, odour and turbidity problems.

**Mitigation**

Mitigation against the aesthetic effects of manganese is difficult since it should preferably be removed by treatment processes. Bathroom and sanitaryware should be cleaned regularly to prevent the buildup of permanent stains. Mitigatory measures to counteract the effects of ingestion are unnecessary except in exceptional circumstances when medical attention should be sought if poisoning is suspected.

**Criteria**

**Effects of Manganese on Aesthetics and Human Health**

<b>Manganese Range (mg/R)</b>	<b>Effects</b>
<i>Target Water Quality Range</i> <b>0 - 0.05</b>	<i>No health or aesthetic effects; marginal aesthetic problems occasionally found in the 0.02-0.05 mg/R range</i>
0.05 - 0.10	Tolerable range, although slight staining may occur. No health effects
0.10 - 0.15	Threshold for significant staining and taste problems. No health effects
0.15 - 1.0	Increasingly severe staining and taste problems. No health effects
1.0 - 2.0	Very severe staining and taste effects. No health effects
2.0 - 5.0	Extreme staining, likely to be aesthetically unacceptable to a large proportion of users. No health effects
5 - 14	Unacceptable levels of aesthetic effects. Health effects rare
14 - 20	Very severe, aesthetically unacceptable staining. Domestic use unlikely due to adverse aesthetic effects. Some chance of manganese toxicity under unusual conditions
> 20	Domestic use unlikely due to extreme aesthetic effects Chronic toxicity; at high concentrations, possible acute effects

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# Mercury

## Background Information

**Introduction** Mercury is a heavy metal of quite rare geological occurrence and concentrations thereof in the environment are normally very low. Mercury occurs in three oxidation states in the natural environment, as the metal, as mercury(I) and as mercury(II). It is also found as organomercurials, the most important of which is methyl mercury. The occurrence of mercury contaminants in water is predominantly site-specific and related to identifiable site-specific discharges. Mercury and organomercurial complexes are severely neurotoxic. Intake may occur via air, food or water. Food, particularly fish and fish products are usually the major source of exposure to mercury.

**Occurrence** The principal source of mercury in the environment is the natural degassing of the earth's crust. Mercury deposits occur in igneous, sedimentary and metamorphic rocks. Mercury is present in the atmosphere as metallic mercury vapours and as volatilised organic mercury compounds. Atmospheric mercury can enter terrestrial and aquatic habitats through particle deposition and precipitation.

Mercury concentrations in surface waters are generally less than 1 Fg/R, except in areas where mineral deposits of mercury occur. Although mercury is unlikely to occur naturally in surface waters at concentrations which are of concern to human health, it may occur at high concentrations in water bodies subject to industrial pollution. Several industrial activities contribute significantly to the presence of mercury in the environment. Major sources are the chloralkali industry and the paint and fungicide industries. Mercury is also used in dentistry, in pulp and paper manufacturing processes, in thermometers, electrical equipment and in some therapeutic medicinal compounds.

Mercury has a strong affinity for -SH and -OH groups and is therefore strongly associated with sediments and suspended solids where bacterial methylation occurs readily under anaerobic conditions. Methyl mercury, being lipid soluble, readily accumulates in food chains and is the main form in which mercury is found in the tissues of fish and mammals.

**Interactions** Alkylated mercury compounds, such as mono- and dimethyl mercury, are of serious concern in the aquatic environment because they are much more toxic to man and animals than the inorganic forms of mercury. As alkylation is bacteriologically and biologically mediated, factors such as **pH**, and the concentrations of **dissolved oxygen and organic carbon** influence both the degree of methylation and type of organomercurials formed.

**Measurement** The criteria apply to total mercury concentrations and the methods used must measure both the dissolved and particulate forms of mercury, particularly if water is consumed without the removal of finer particulates, where most of the mercury tends to be concentrated. The reference method for the determination of mercury is flameless atomic absorption spectrometry (AAS). Acid digestion of the sample is required before analysis by AAS.

**Data Interpretation** Since mercury accumulates in the body, a single, exposure to a high concentration of mercury can have very serious effects. The criteria given should therefore be treated as maximal values, not to be exceeded.

Mercury can occur in different forms in water, for example in the dissolved state, as

suspended particles, and as complexes with other substances. Both the method of analysis selected and the treatment of water samples before analysis will determine how much mercury in each of the above categories is included in the analysis. It is therefore crucial that the analyst state whether the method measures one or more of the mercury forms present, or total mercury.

**Treatment Options**

Current technology capable of removing inorganic mercury within the TWQR includes:

- ! precipitation:
  - coprecipitation with aluminium hydroxide by addition of alum; and
  - coprecipitation with ferric hydroxide by addition of iron salts;
- ! adsorption, using powdered or granular activated carbon; and
- ! ion exchange, using appropriate resins

Mercury residuals within the TWQR will not be consistently achieved without skilled process control of precipitation reactions; or careful monitoring for breakthrough from activated carbon or ion exchange columns. Inorganic mercury can be removed to a significant extent (70 % - 80 %) by coagulation and flocculation with iron salts, followed, if necessary, by powdered activated carbon or granular activated carbon treatment.

Organically-bound mercury is not satisfactorily removed by precipitation but is effectively removed by adsorption to activated carbon.

Disposal of the hazardous mercury-rich precipitates, regeneration solutions or loaded activated carbon require appropriately designed and licensed facilities.

## The Effects of Mercury

**Norms**

Human health is the primary norm used in the guideline for mercury. Aesthetic effects associated with mercury are not significant for domestic water use.

**Effects**

Mercury serves no known beneficial physiological function in humans, and is a chronic neurotoxin. Poisoning takes the form of neurological (organic mercury) and renal (inorganic mercury) disturbances. Both organic and inorganic forms are toxic although organic mercury is about one order of magnitude more toxic because it is able to cross biological membranes more readily. This is attributable to the greater lipid solubility conferred to the mercury by the associated organic groups.

Depending on the dosage, effects associated with the ingestion of mercury are either chronic or acute. There is a risk of chronic toxicity with exposure to concentrations greater than 20 Fg/R, particularly if the mercury is organically complexed. Acute effects with damage to the nervous system may occur with concentrations greater than 6 mg/R, although fatalities are unlikely at concentrations less than 100 mg/R, unless the mercury is in the organically complexed form.

**Mitigation**

Mercury poisoning is very serious, sometimes irreversible, and qualified medical help should be sought immediately.

**Criteria**

**Effects of Mercury on Human Health**

Mercury Range (Fg/R)	Effects
<i>Target Water Quality Range 0 - 1</i>	<i>No health effects expected</i>
<b>It is recommended that the TWQR not be exceeded due to the potentially acute and/or irreversible effects of mercury on human health</b>	
1 - 5	At two Fg/R water provides up to 13 % of the safe daily intake, and at five Fg/R water provides 33 % of the safe daily intake. Risk to the general population is unlikely A very slight risk of neurotoxicity due to organic mercury may exist for sensitive individuals at the upper limit of this range
5 - 20	Brief, episodic exposure unlikely to have adverse effects. Some risk of chronic neurotoxic effects due to organically complexed mercury
20 - 50	Risk of neurotoxicity with consequent serious disabilities with continuous exposure
50 - 1 000	Risk of neurotoxicity with continuous exposure, particularly to organic mercury compounds. Acute effects may occur, particularly with organic mercury compounds
1 000 - 10 000	Chronic effects; acute poisoning with damage to the nervous system and brain may occur with single exposure, and definitely with continuous exposure
> 100 000	Acute poisoning; permanent brain damage and/or death is possible

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# Nitrate

## Background Information

**Introduction** Nitrate is the end product of the oxidation of ammonia or nitrite. Nitrate ( $\text{NO}_3^-$ ) and nitrite ( $\text{NO}_2^-$ ) are the oxyanions of nitrogen in which nitrogen is found in the +V and +III oxidation states, respectively. Nitrates and nitrites occur together in the environment and interconversion readily occurs. Under oxidising conditions nitrite is converted to nitrate, which is the most stable *positive* oxidation state of nitrogen and far more common in the aquatic environment than nitrite.

Nitrate in drinking water is primarily a health concern in that it can be readily converted in the gastrointestinal tract to nitrite as a result of bacterial reduction.

**Occurrence** Mineral deposits of nitrates are rare due to the high water solubility of nitrates, although large deposits of sodium nitrate (saltpetre) occur in the desert regions of Chile. Nitrates are ubiquitous in soils and in the aquatic environment, particularly in association with the breakdown of organic matter and eutrophic conditions.

Concentrations of nitrate in water are typically less than 5 mg/R of nitrate-nitrogen (or, alternatively, 22 mg/R nitrate). A significant source of nitrates in natural water results from the oxidation of vegetable and animal debris and of animal and human excrement. Treated sewage wastes also contain elevated concentrations of nitrate.

Nitrate tends to increase in shallow ground water sources in association with agricultural and urban runoff, especially in densely populated areas. Nitrate together with phosphates stimulate plant growth. In aquatic systems elevated concentrations generally give rise to the accelerated growth of algae and the occurrence of algal blooms. Algal blooms may subsequently cause problems associated with malodours and tastes in water and the possible occurrence of toxicity.

**Interactions** Interactions with nitrate are present with all conditions associated with the presence or breakdown of organic matter. For example, enrichment of waters with **dissolved organic carbon** can increase the rate of denitrification by providing an energy source for the denitrifying bacteria. The processes of nitrification, denitrification and the active uptake of nitrate by algae and higher plants are regulated by temperature and **pH**.

**Measurement** The criteria for nitrate are given in terms of the concentration of nitrate plus nitrite nitrogen in units of mg/R. The reference method for the determination of the sum of the nitrate and nitrite concentration is by cadmium reduction followed by diazotisation. Nitrite alone can be determined by diazotisation without prior reduction of the nitrate. Where other methods are used, their characteristics relative to the reference method should be known.

**Data Interpretation** Single-sample maximal values should be used to compare with the criteria given and should be interpreted as non-exceedance limits for children under two years of age and as mean values for older children and adults.

Transient elevations of nitrate and nitrite concentrations above non-exceedance limits are of less importance than continuous elevated concentrations.

Where water is well-oxygenated, it can be assumed that the nitrate plus nitrite nitrogen concentrations are largely due to the presence of nitrate. Nitrite concentrations only become significant in deoxygenated systems.

### **Treatment Options**

Nitrate is not readily removed from domestic water supplies. Some reduction of nitrate may be achieved using slow sand filtration, but the method is not reliable. Biological reduction of nitrate to nitrogen gas (denitrification) is feasible in the presence of a suitable carbon source, but the increase in carbonaceous matter is not compatible with a high quality water supply. Non-specific methods of removing nitrate include:

- ! Passing the water stream through an **ion exchange** column with a selective affinity for nitrates. The method is expensive because other anions will be removed at the same time, depending on the nature of the resin used. However, it may be attractive on a household scale where only water used for drinking purposes is treated.
- ! **Reverse osmosis**, which will remove nitrate effectively from water, along with high percentages of virtually all other ions and many organic compounds. A low-pressure home unit will conveniently treat small quantities of drinking water satisfactorily. The module is replaced when it begins to block through fouling or scaling.

On a commercial scale the processes described require competent operation, control and maintenance.

## **The Effects of Nitrate and Nitrite**

### **Norms**

The norm used in the guideline for nitrate and nitrite is human health. There are no direct aesthetic impacts.

### **Effects**

Upon absorption, nitrite combines with the oxygen-carrying red blood pigment, haemoglobin, to form methaemoglobin, which is incapable of carrying oxygen. This condition is termed *methaemoglobinaemia*. The reaction of nitrite with haemoglobin can be particularly hazardous in infants under three months of age and is compounded when the intake of Vitamin C is inadequate.

Metabolically, nitrates may react with secondary and tertiary amines and amides, commonly derived from food, to form nitrosamines which are known carcinogens.

### **Mitigation**

A diet, adequate in Vitamin C, partially protects against the adverse effects of nitrate/nitrite. Methaemoglobinaemia in infants can only be mitigated by blood transfusion.

**Criteria****Effects of Nitrate/Nitrite on Human Health**

<b>Nitrate/nitrite Range (as mg/RN)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 6</i>	<i>No adverse health effects</i>
6 - 10	Rare instances of methaemoglobinaemia in infants; no effects in adults. Concentrations in this range generally well tolerated
10 - 20	Methaemoglobinaemia may occur in infants. No effects in adults
> 20	Methaemoglobinaemia occurs in infants. Occurrence of mucous membrane irritation in adults

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# Odour

## Background Information

**Introduction** Odour perception or olfaction is a complex sensation perceived by receptor organs in the nasal cavity. Perceptions and sensations of odour and taste are complementary and it is difficult to distinguish between the two. The sense of smell is generally more sensitive than that of taste, and concentrations of parts per billion or less of substances may be detected, whereas only parts per million or more are detected by taste. In the assessment of drinking water quality, the sense of taste is more useful in detecting inorganic constituents, while the sense of smell detects organic constituents more effectively.

Odour in water is predominantly caused by the presence of organic substances of either biological or industrial origin. Odours of a biological origin in source water may be due to the dumping of raw sewage into water bodies. This enhances biological growth which in turn can produce odorous products. Ground water tends to have fewer odour problems than surface waters. Odour almost always indicates some form of pollution of the source water or malfunction during water purification or distribution.

**Occurrence** The main causes of taste and odour in water are geosmin and 2-methylisoborneol (MIB). These compounds are produced by certain blue-green algae or by fungi, principally the actinomycetes. Growth of organisms producing geosmin or MIB may be enhanced under conditions resulting from the dumping of raw sewage in water bodies. The reaction of chlorine with these products in the purification process generates a typical "hexadust" odour.

Odours in treated water can originate from stagnant water conditions in low-flow sections of distribution systems or in raw and treated water reservoirs. Water treatment can convert weak-smelling substances, such as phenols and amines, to substances with very strong odours, such as chlorophenols and chloramines. The proliferation of iron and sulphur bacteria in distribution systems may be a source of odour after treatment.

Odours originating in distribution systems in South Africa may be caused by the use of phenolic pipe-jointing compounds (banned in some municipal areas) and certain plastics used in the manufacture of anti-splash nozzles and garden hoses, which generate an antiseptic taste and odour as a result of the reaction of residual chlorine in the water with plastics.

While the detection of odours in water should be viewed as a warning sign which indicates a need for expert assistance, it should not be interpreted as a direct indicator of the presence of toxic substances. Examples of odour-causing compounds are geosmin and MIB. Very low concentrations of these substances result in noticeable odours, but there is no toxic effect at these levels.

**Interactions** Odour (and taste) in water may be masked by high concentrations of certain other dissolved constituents, but are exacerbated in soft waters.

**Measurement** The measurement for odour is expressed in terms of the threshold odour number (TON), which is defined as the greatest dilution of a sample with odour-free water that yields a final water with an odour which is just detectable by a panel of judges under carefully controlled test conditions. For example, at a TON of three, the water sample must be diluted with twice its volume of odour-free water to render the odour just detectable. An alternative to

the TON determination for odour intensity is the odour number determination by forced choice between paired samples. Currently, there is a move away from the use of odour measurement by TON or odour number in favour of sensory profile analysis.

Odour levels in source and treated water can be described either in terms of a quantitative measure, such as TON, or qualitatively as the absence of "objectionable" or "offensive" odours.

**Data Interpretation**

Mean values should be used to compare with the criteria given. Ideally, domestic water should have no perceptible odour to any consumer, but since sensitivity is highly variable among individuals, a more realistic approach is to provide water free of any odour which is acceptable to the majority of the population.

**Treatment Options**

The techniques for removal of odours from domestic water supplies depend on the nature and cause of the odour. For this reason the best methods are often identified empirically from a range of techniques. The following approaches are commonly used:

- ! Because odours are generally characteristic of volatile substances, some are effectively removed by aeration of the water, or by blowing air counter-current to the water flow through a stripping tower.
- ! With some waters, odours may be reduced or eliminated by the coagulation, flocculation, settlement and filtration process, but this is commonly a preliminary step to be followed by either or both of the following processes.
- ! Adsorption of odours using either powdered activated carbon dosed into the water upstream of the filter, or by passing the water through a filter charged with granular activated carbon which may need steam stripping or regeneration periodically. Small disposable cartridges of activated carbon are commonly used to remove tastes and odours from drinking water in domestic households. *However, care should be taken with timely replacement of the cartridges, since clogged cartridges promote bacterial and algal growth.*
- ! Oxidation of odours with powerful oxidants such as ozone or hydrogen peroxide are particularly suitable because they leave no residuals after treatment. Chlorine is seldom suitable because of its propensity to combine with many of the odour-causing organic substances to form strongly tasting components.

Depending on the source of the odour it is often necessary to use two or more of the removal techniques in series. The "off-gas" from a stripping process may cause localised air pollution unless passed through a chemical scrubber system or a biological filter.

## The Effects of Odour

**Norms**

The norms used in the guideline for odour are based predominantly on aesthetic effects. Possible health effects associated with odour cannot be accurately described.

**Effects**

The presence of odour in water is irritating and unpleasant and it may impart undesirable odours to food and drink prepared with such water. Where cooking of food is involved, common, water-associated odours such as those of geosmin and methylisoborneol (MIB),

are evaporated off.

In exceptional cases the odour of water may be particularly noticeable and objectionable, such as when bathing and showering in hot water as the odourants evaporate at elevated temperatures.

Odour may be an indicator of potential health effects, if it is associated with the presence of toxic organic substances.

**Mitigation**

It is normally not possible to mitigate against odours in water used for domestic purposes.

**Criteria**

**Effects of Odour on Aesthetics**

<b>Odour Range (TON)</b>	<b>Effects</b>
<i>Target Water Quality Range 1</i>	<i>Water with a TON of one is odourless, hence adverse aesthetic effects are absent</i>
1 - 5	Water has a noticeable odour
5 - 10	Water has a strong odour which is likely to be objectionable to large sectors of the population
> 10	The odour of water becomes stronger and increasingly objectionable

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### Background Information

**Introduction** The pH of a solution is the negative logarithm to the base ten of the hydrogen ion concentration, given by the expression:

$$\text{pH} = -\log_{10}[\text{H}^+]$$

where  $[\text{H}^+]$  is the hydrogen ion concentration.

At pH less than 7 water is acidic, while at pH greater than 7 water is alkaline.

The pH of natural waters is the result of complex acid-base equilibria of various dissolved compounds, mainly the carbon dioxide-bicarbonate-carbonate equilibrium system, which is also affected by temperature. Conditions which favour production of hydrogen ions result in a lowering of pH, referred to as an acidification process. Alternatively, conditions which favour neutralisation of hydrogen ions result in an increase in pH, referred to as an alkalization process. The pH of water does not indicate the ability to neutralise additions of acids or bases without appreciable change. This characteristic, termed buffering capacity, is controlled by the amounts of acidity and alkalinity present.

The pH of a water does not have direct health consequences except at extremes. The adverse effects of pH result from the solubilisation of toxic heavy metals and the protonation or deprotonation of other ions. The pH of most raw water sources lies within the range of 6.5 - 8.5. The main significance of pH in domestic water supplies relates to its effects on water treatment.

**Occurrence** The geology and geochemistry of the rocks and soils of a particular catchment area affect the pH and alkalinity of the water. The pH of most raw waters lies in the range of 6.5 - 8.5. Biological and anthropogenic activities such as nutrient cycling and industrial effluent discharge respectively can give rise to pH fluctuations. Notably, acid mine drainage can have a marked effect on the pH. Further, acid-forming substances, such as oxides of sulphur and nitrogen released into the atmosphere may ultimately alter the acid-base equilibria in natural waters and result in a reduced acid-neutralising capacity and hence lowering the pH.

**Interactions** The pH of natural waters is influenced by various factors and processes, including temperature, discharge of effluents, acid mine drainage, acidic precipitation, runoff, microbial activity and decay processes.

**Measurement** Water pH is measured electrometrically using a pH meter. The pH meter should be calibrated against standard buffer solutions of known pH prior to measurement of a sample. Fresh samples should be used to determine pH. The temperature at which measurements are made should always be reported, since pH measurement is influenced by temperature. Errors may be caused by the presence of sodium at pH values greater than 10.

**Data** Use of individual or mean values to compare with the criteria given depends on the

**Interpretation** application. Normally, individual values are used but the pH should always be interpreted in relation to the full analysis of the water sample and its use. For example, if the pH is acidic, the water should be analysed for metal constituents, which may have dissolved from the distribution system.

**Treatment Options** The main significance of pH in domestic water supplies relates to its effects on water treatment processes. The pH of water can be adjusted up or down by the addition of an alkali or an acid.

Commonly used alkaline reagents are sodium carbonate, sodium hydroxide and lime. Acidic reagents commonly used are carbon dioxide (a gas which forms carbonic acid in water), hydrochloric acid or sulphuric acid. The reagent is usually added in dilute form using a dosing pump controlled by a pH monitor.

The adjustment of pH in water will inevitably increase the salinity of the water by adding ions such as sodium, carbonate, hydroxyl, sulphate or chloride. Reagents should be chosen to minimise secondary effects. For certain purposes the pH of the water will need to be stabilised to within a chosen range by the addition of buffering reagents.

The handling of acids and alkalis is often hazardous requiring special precautions in the form of protective clothing and in materials used in the manufacture of the dosing equipment.

## The Effects of pH

**Norms** The norms used in the guideline for pH are based on human health and aesthetic effects.

**Effects** The selection of raw water as a drinking water source is never based solely on pH. Danger to health would result primarily from the presence of metal ions, which are more likely to influence selection than the pH value. A direct relationship between the pH of drinking water and human health effects is difficult, if not impossible to establish since pH is very closely associated with other aspects of water quality.

The taste of water, its corrosivity and the solubility and speciation of metal ions are all influenced by pH. At low pH water may taste sour, while at high pH water tastes bitter or soapy. The potential toxicity of metal ions and chemicals which can be protonated, for example ammonia, is influenced by pH. Changes in pH affect the degree of dissociation of weak acids and bases. This effect is of special importance because the toxicity of many compounds is affected by their degree of dissociation.

Corrosion in the water supply system is a major source of metal contamination in drinking water. Metals that have the potential for causing such contamination are **lead, copper** and **zinc**. Lead is subject to corrosion at a pH higher than 12. Corrosion of cadmium is only significant below pH 6. Other metals which are frequently used in household plumbing and that may be affected by pH are copper and zinc.

**Mitigation** See **Treatment Options**.

## Criteria

### Effects of pH on Aesthetics and Human Health

pH Range (pH units)	Effects
< 4.0	Severe danger of health effects due to dissolved toxic metal ions. Water tastes sour
4.0 - 6.0	Toxic effects associated with dissolved metals, including lead, are likely to occur at a pH of less than 6 Water tastes slightly sour
<i>Target Water Quality Range 6.0 - 9.0</i>	<i>No significant effects on health due to toxicity of dissolved metal ions and protonated species, or on taste are expected. Metal ions (except manganese) are unlikely to dissolve readily unless complexing ions or agents are present. Slight metal solubility may occur at the extremes of this range. Aluminium solubility begins to increase at pH 6, and amphoteric oxides may begin to dissolve at a pH of greater than 8.5. Very slight effects on taste may be noticed on occasion</i>
9.0 - 11.0	Probability of toxic effects associated with deprotonated species (for example, ammonium deprotonating to form ammonia) increases sharply. Water tastes bitter at a pH of greater than 9
> 11.0	Severe danger of health effects due to deprotonated species Water tastes soapy at a pH of greater than 11

#### Note:

The above criteria indicate possible health effects in the general population and the descriptions given for health effects should be considered tentative. The criteria are tentative since pH does not exert direct health effects, but may exert indirect health effects via metal solubility.

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# Phenols

## Tentative Guideline

### Background Information

- Introduction** Phenol is a benzene ring attached to a hydroxyl group. The benzene ring can have atoms other than hydrogen as substituents, for example, chlorine, nitro-groups, or amino-groups. All substituted phenols are collectively referred to as the *phenol group* or *phenols*. The occurrence of phenols in drinking water is of concern, due to unpleasant tastes and odours imparted to the water, especially by chlorinated phenols. Toxicity-based limits are generally higher than the aesthetic limits for most chlorophenols.
- Occurrence** In natural water systems the phenol group is only found in very low concentrations, usually in the Fg/R range or less. Phenols are produced as byproducts in many industrial processes where organic chemicals are used. Phenols are also used in disinfectants, in various pesticides and as starting materials in a wide variety of synthetic organic processes.
- Phenols are generally biodegraded in water by bacteria. The rate of biodegradation differs widely, and is governed by the nature of the group. Phenols absorbed by fish, taint the flesh with phenol-like flavours. When water containing phenol is chlorinated for disinfection purposes, a range of chlorophenols are formed.
- Interactions** Phenols tend to be a reactive group of compounds because the hydroxyl group is highly electrophilic. Apart from reacting with other organic compounds in reactions typical of organic alcohols, they may also form organometallic complexes. The range of possible interactions of the phenols is extensive, due to the specific reactivities of the substituted groups taken into account.
- Measurement** The criteria are based on the total concentration of phenols, and the method chosen should therefore measure the phenols as a group.
- Phenols are usually measured colorimetrically with 4-amino antipyrine. Individual phenols may be measured chromatographically.
- Data Interpretation** Mean values should be used in applying the criteria given. Since the concentration of phenols usually encountered in water cause aesthetic effects, consumer complaints of objectionable odours, particularly of such statements as "the water tastes like a disinfectant" or similar statements, should be taken into account.
- Treatment Options** Phenolic compounds are not effectively removed from water using conventional water treatment techniques. The methods most commonly used include:
- ! **Oxidation:** Phenols can be destroyed by the action of strong oxidising agents such as ozone. Chlorine should not be used since it combines with phenols to form strongly tasting chlorophenols.
  - ! **Adsorption:** Trace concentrations of phenols can be removed by filtering the water through a granular activated carbon column. The activated carbon column can be washed with a sodium hydroxide solution to remove the adsorbed phenols as phenates.

Disposal of this solution may pose difficulties.

## The Effects of Phenols

**Norms** The norms used in the guideline for phenols are principally based on aesthetic effects. The health risks associated with phenol concentrations usually found in drinking water are thought to be minimal; toxicological information on chlorophenols at low concentrations is sparse.

**Effects** Phenol and chlorophenols impart unpleasant tastes and odours to water at concentrations several orders of magnitude lower than the toxic limits. A toxic concentration of 3.0 mg/l is given for phenol by the WHO, 1984. The ingestion of a concentrated solution of phenol will result in severe pain and shock with renal damage, circulatory collapse and death. The fatal dose is of the order of 1500 mg.

**Mitigation** If phenol poisoning is suspected, medical attention should be sought immediately.

### Criteria **Effects of Phenol on Aesthetics and Human Health**

<b>Phenol Range (Fg/l)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 1</i>	<i>No aesthetic or health effects Suitable for continuous long-term intake</i>
1 - 10	Slight aesthetic effects of disinfectant taste and odour from chlorinated phenols
10 - 100	Pronounced aesthetic effects of objectionable tastes and odours
100 - 3 000	Severe aesthetic effects
> 3 000	Water aesthetically unacceptable; danger of toxic effects

**Modifications Table of Odour and Taste Thresholds for Phenols**

Compound	Threshold concentration (Fg/R)	
	Odour	Taste
Phenol	1 000	100
2-Chlorophenol	1	1
4-Chlorophenol	1	1
2,4-Dichlorophenol	1	1
2,6-Dichlorophenol	10	1
2,4,5-Trichlorophenol	100	1
2,4,6-Trichlorophenol	100	1
2,3,4,6-Tetrachlorophenol	1 000	1
Pentachlorophenol	1 000	100

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# Potassium

## Background Information

**Introduction** Potassium is an alkali metal which reacts violently with water to form positively-charged potassium ions. Potassium always occurs in water in association with anions, usually chloride, but can also occur with sulphate, bicarbonate, or nitrate. Potassium is the main intracellular cation in living organisms and is an essential dietary element.

**Occurrence** Potassium is ubiquitous in the environment. Common potassium-containing minerals are the feldspars and micas, and potassium is also found in association with sodium in many minerals. Typically the concentration of potassium in:

- ! fresh water is within the range of 2 - 5 mg/R; and
- ! sea water is approximately 400 mg/R.

Potassium salts are highly soluble in water and precipitation does not occur on evaporation until very high concentrations are reached and potassium therefore has a strong tendency to remain in water. Since sodium salts are generally cheaper than the corresponding potassium salts, industries predominantly use sodium rather than potassium salts. Therefore sodium is usually found at higher concentrations than potassium in wastes and brines.

High concentrations of potassium may occur in runoff from irrigated lands, and from fertilizer production and domestic wastes. Urine has a relatively high concentration of potassium, and the potassium : sodium ratio is sometimes used as an indicator of pollution or in the assessment of reclaimed waste water.

**Interactions** Interactions between **sodium** and potassium are important in evaluating the effects of potassium on living organisms.

**Measurement** The criteria are given in terms of the dissolved potassium concentration, in units of mg/R. The reference method for the determination of dissolved potassium is by flame photometry, using lithium as an internal standard. If other methods are used to measure potassium, their characteristics relative to the reference method should be known.

**Data Interpretation** Single-sample values should be used to compare with the criteria given. The potassium concentration should also be interpreted in conjunction with:

- ! the sodium to potassium concentration ratio; and
- ! the major anion(s) in solution, usually chloride, sulphate or bicarbonate.

**Treatment Options** Potassium can be removed from water together with other ions which constitute the TDS by a number of desalination processes. These include:

- ! **Demineralisation** in a mixed-bed ion exchange column, usually where the feed TDS concentration is up to about 2 000 mg/R. Demineralisation by ion exchange can be used to produce low-potassium potable water on a household scale using disposable ion exchange cartridges or, on a commercial or industrial scale using banks of large ion exchange filter beds which are capable of being regenerated.

! Treatment by **membrane processes** such as reverse osmosis or electro dialysis, where the TDS concentration is in the range of 2 000 - 3 500 mg/R. Small volumes of low-potassium potable water can be reliably produced on a household scale using small low-pressure reverse osmosis modules fed from a domestic water supply line. These are easily replaced after one to three years if the membrane becomes fouled through scaling. Large-scale water treatment is achieved using banks of reverse osmosis modules in parallel.

! **Distillation**, in cases where the TDS concentration is 10 000 mg/R or more.

All of the processes are easily fouled by suspended matter and are prone to severe scaling with hard waters. On a large scale, all of the processes require high levels of design, operator and maintenance skills. All of the processes produce a concentrated waste stream of the salts removed from the water, and these may cause disposal difficulties.

## The Effects of Potassium

**Norms** The norms used in the guideline for potassium are aesthetic and human health effects.

**Effects** Potassium is an important intracellular cation and the total dietary intake ranges from 1.6 - 4.7 g/day, depending on age. At high concentrations potassium imparts a bitter taste to water, and consumption can induce nausea and vomiting. Consequently, excessive concentrations of potassium salts ingested orally are relatively harmless to healthy adults, since the protective vomiting reflex rids the system of dangerous excesses. Healthy humans are relatively insensitive to any harmful effects caused by potassium, but electrolyte disturbances can occur, particularly in infants or in patients with kidney pathologies on a potassium-restricted diet.

**Mitigation** Mitigatory measures are generally not necessary except in cases where the vomiting reflex has not been activated, and vomiting may have to be induced. Usually the body will restore electrolyte imbalances if fluid intake is adequate.

## Criteria

### Effects of Potassium on Aesthetics and Human Health

Potassium Range (mg/l)	Effects
<i>Target Water Quality Range</i> 0 - 50	<i>No aesthetic (bitter taste) or health effects</i>
50 - 100	No aesthetic effects. No health effects in healthy adults. Undesirable concentration for infants or persons with renal disease
100 - 400	Bitter taste may be noticeable. Electrolyte disturbances may occur in sensitive individuals. Dangerous concentration for infants or persons with renal disease
> 400	Pronounced bitter taste. Occurrence of electrolyte disturbances with nausea, vomiting and irritation of mucous membranes. Dangerous concentration for infants or persons with renal disease

#### Note:

The protection of individuals particularly sensitive to the effects of potassium has been taken into account for the above criteria.

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# Radioactivity

## Tentative Guideline

### Background Information

**Introduction** Radioactivity in water is due to the presence of radioactive nuclides emitting  $\alpha$ - and  $\beta$ -particles or  $\gamma$ -rays. These arise from radioactive nuclides found naturally in the environment. The main contributing nuclides to radioactivity in water are uranium-238, uranium-234, thorium-232, radium-226, radium-228, radon-222, potassium-40 and occasionally lead-210, polonium-210 and thorium-230.

**Occurrence** Of the radioactive nuclides normally found in water, potassium-40 is by far the most common, as potassium-40 is found together with all other potassium deposits, is an essential intracellular mineral and is found in all living organisms and in all water supplies. Potassium-40 is a  $\beta$ -emitter. Measurements of  $\beta$ -activity in water are thus of lesser consequence, unless the potassium-40 activity is first subtracted. In ground water supplies the only other  $\beta$ -emitters which are usually important are radium-228, from the thorium-232 decay series and possibly lead-210, from the uranium-238 decay series.

The  $\gamma$ -activity is not normally considered of health significance in water, since  $\gamma$ -rays pass through the body with very little absorption.

From a health perspective, the risk of radioactivity in water is mainly centred around  $\alpha$ -emitting nuclides. These are uranium-238, uranium-234, thorium-232, radium-226 radon-222 and possibly polonium-210. Internationally, the radioactive elements that are normally monitored in water are mainly uranium, thorium, radium and radon. The occurrence of uranium, thorium, radium and radon is as follows:

Traces of uranium are found in all soils, typically in the concentration range of 0.7 - 9 mg/kg (world mean value), although relatively higher concentrations may be found in South African soils. Of the naturally-occurring uranium, 99.27 % consists of the  $U^{238}$  nuclide, the remainder being  $U^{235}$  and a trace of  $U^{234}$ . From a water quality viewpoint the uranium nuclides  $U^{238}$  and  $U^{234}$  are of practical importance. Uranium-238 decays by  $\alpha$ -emission with a half-life of  $4.468 \times 10^9$  years and further decay yields various daughter products, such as uranium-234, thorium-230, radium-226, radon-222, lead-210 and polonium-210. Examples of uraniferous minerals are uraninite and carnotite. The world mean concentration of uranium in fresh surface water is 0.4  $\mu\text{g}/\text{R}$  and in sea water 3.2  $\mu\text{g}/\text{R}$ . Substantially higher concentrations of uranium are found in association with mineral deposits of uraniferous minerals and uranium concentrations of up to several hundred  $\mu\text{g}/\text{R}$ , may be found in ground waters in such areas.

The inert gas radon-222 has a half-life of 3.83 days and occurs as an emanation from rocks and soil containing uranium minerals. Radon is quite soluble in water and thus ground waters very often contain substantial concentrations of radon-222, particularly in association with uranium-bearing mineral deposits.

Thorium-232 has a half life of  $1.41 \times 10^{10}$  years and decays by  $\alpha$ -emission. The world median concentration of thorium in soils is 9 mg/kg. Thorium is found in the minerals monazite, thorianite and thorite. The world mean concentration of thorium in water is 0.03  $\mu\text{g}/\text{R}$ .

Examples of commercial uses of naturally radioactive elements include:

- ! the nuclear industry in the case of U<sup>235</sup>;
- ! the glass industry (natural uranium) for the manufacture of yellow glasses and glazes;
- ! thorium, in the manufacture of incandescent mantles for portable gas lamps and in special optical lenses;
- ! radium-226 in medicine for the treatment of cancer. (Radium was formerly used in luminescent paints on watch dials.)

**Interactions** The radioactive elements found in water differ considerably in their chemical interactions. Uranium is quite reactive and can form a number of water-soluble species and complexes and therefore tends to be quite mobile in the aquatic environment. Thorium on the other hand is generally far less soluble and less mobile. The mobility of radium, lead and polonium are limited by the insolubility of their sulphates. Radon, on the other hand, being chemically inert but quite soluble in water, is very mobile in the aquatic environment.

**Measurement** The measurement of radioactive nuclides is by the detection of emissions from  $\alpha$ - and  $\beta$ -particles or  $\gamma$ -rays. The criteria given for radioactivity are measured on the liquid portion of the sample. To achieve adequate detection limits, concentration procedures are needed in some cases. Measurements may be expressed either as disintegrations per second, that is, Becquerels/l of water, or as the  $\mu$ g/l mass of the emitting nuclide. *In the case of uranium-238, 1 Bq/l of  $\alpha$ -radioactivity is  $\approx$  to 80.9  $\mu$ g/l uranium.*

**Data Interpretation** As  $\alpha$ - or  $\beta$ -activity in water is each caused by a number of different nuclides, measurement of the gross  $\alpha$ - or  $\beta$ -activity will not indicate specific nuclide emissions. Therefore it is necessary to do a full radioanalytical investigation to determine which nuclides are responsible for the radioactivity present.

In the interpretation of radioactivity levels in water, it is necessary to have some information on the ambient levels of radioactivity normally found in a given area or water supply.

**Treatment Options** Treatment options need to be tailored to the chemical nature of the major nuclide causing the radioactivity. In the case of radon, which is chemically inert, the radon may be removed by physical processes, such as aeration of the water.

For the chemically-reactive radionuclides of uranium, thorium and radium, removal processes may range from optimisation of conventional flocculation processes through to processes such as concentrated lime treatment and ion-exchange or reverse osmosis where high removal efficiencies are required. The radioactivity concentration in the sludges or waste streams may present disposal problems. Treatment options for lead-210 are the same as for natural lead (see lead), while the treatment options for polonium are similar to those for Group VI elements in the periodic table (see selenium).

## The Effects of Radioactivity

**Norms** The norms used in the guideline for radioactivity in water are based on long-term health effects.

The limits set for radioactivity in water are based on the possible stochastic risk of cancer induction in the long term through exposure to radioactivity. The lifetime fatal cancer risk of exposure to radiation has been estimated as  $5 \times 10^{-2}$  per Sievert. The absorbed tissue dose in Sieverts may be calculated from the tissue dose to radioactivity conversion factors

for each radionuclide, assuming a mean water intake of 2 l/day. Normally a conservative approach is used, which assumes that 100 % of the ingested radionuclide is absorbed. In practice this is usually not the case.

Applicable tissue doses to radioactivity conversion factors for water ingestion are given below:

- !  $7.6 \times 10^{-6}$  mSv/Bq for  $^{238}\text{U}$ .
- !  $8.3 \times 10^{-6}$  mSv/Bq for  $^{235}\text{U}$ .
- !  $8.3 \times 10^{-6}$  mSv/Bq for  $^{234}\text{U}$ .
- !  $1.2 \times 10^{-3}$  mSv/Bq for  $^{232}\text{Th}$ .
- !  $2.2 \times 10^{-4}$  mSv/Bq for  $^{230}\text{Th}$ .
- !  $1.4 \times 10^{-4}$  mSv/Bq for  $^{228}\text{Th}$ .
- !  $3.3 \times 10^{-4}$  mSv/Bq for  $^{226}\text{Ra}$ .
- !  $2.9 \times 10^{-4}$  mSv/Bq for  $^{228}\text{Ra}$ .
- !  $1.2 \times 10^{-3}$  mSv/Bq for  $^{210}\text{Po}$ .
- !  $8.3 \times 10^{-4}$  mSv/Bq for  $^{210}\text{Pb}$ .

## Effects

In general the effects of exposure to elevated levels of radioactivity in water are an increase in the cancer risk. The organ at risk for cancer will depend on the site in the body where the given radionuclide tends to accumulate. This in turn, depends on the chemical nature of the radionuclide. In the case of radon and its short-lived daughter nuclides, the primary target organ is the lungs and the risk is presented via inhalation of air contaminated with radon. This may occur on showering with radon-rich water in a poorly ventilated area. The radon in the air may arise from contaminated building materials from the underlying ground, or be transported via the water supply, particularly if this is ground water in an area rich in uraniferous deposits.

In the case of radium and thorium, the target organ is the bony skeleton, because of the insolubility of the phosphate salts. Uranium on the other hand tends to accumulate in the kidneys and the liver. *In the case of uranium, chemical toxicity is of more concern than the radiological risk of cancer.*

Most of the effects of natural radioactivity described in the literature are for the elements uranium, radium, radon and thorium. There is little known on the specific effects of lead-210 and polonium-210, other than it is presumed that the major effect is as a consequence of exposure to the mother nuclide radon-222.

## Mitigation

The carcinogenic risks presented by radioactivity in water are of a stochastic nature and are not easily mitigated.

## Criteria

### ! $\alpha$ -radioactivity

The  $\alpha$ -emitters usually encountered in water are radon-222, uranium-238, uranium-234, thorium-232 and radium-226. By far the most common which may be present in water are radon-222, uranium-238 and uranium-234; these nuclides usually account for the major portion of the gross  $\alpha$ -activity in water. Occasionally, situations may be found where thorium-232 and radium-226 are major contributors, as the insolubility of the sulphate and phosphate salts of radium and thorium in water normally limits their presence in solution in water. However, occasionally they may be found in the insoluble suspended matter and clay fraction.

The health effects of gross  $\alpha$ -activity are variable, because of the difference in the

effects of the main  $\alpha$ -emitters which may be present in water. Gross  $\alpha$ -activity should be used for screening purposes only. The significance of the screening for gross  $\alpha$ -activity is given in Table 1. The criteria for the specific  $\alpha$ -emitting nuclides are given in Table 2 for uranium-238, in Table 3 for thorium-232, in Table 4 for radium-226 and in Table 5 for radon-222.

**Table 1: Effects of Gross  $\alpha$ -activity on Human Health**

Gross $\alpha$ -activity (Bq/l)	Interpretation
<i>Target Water Quality Range</i> 0 - 0.5	<i>Under the usual situation where uranium or radon are the main <math>\alpha</math>-emitters, then no health effects (annual cancer risk &lt; 1 in 7 million). However, if radium-226 or thorium-232 are present as the major contributor to the gross <math>\alpha</math>-activity, then there may be an increase in the cancer risk to • 1 in 100 000 p/a</i>
0.5 - 11.0	No health effects if radon gas is the main $\alpha$ -emitting species present. Sample should be analysed for specific $\alpha$ -emitters. Moderate annual cancer risk of 1 in 200 000 if uranium-238 is the main $\alpha$ -emitter. High risk if thorium-232 or radium-226 are the main $\alpha$ -emitters
11.0 - 33.0	If radon gas is the major $\alpha$ -emitter present, then no significant risk for drinking water. Sample should be analysed for specific $\alpha$ -emitters. High risk to health if uranium, thorium or radium are present as major components of the $\alpha$ -emission
> 33.0	Increasing likelihood of the presence of uranium, thorium or radium at levels which would damage health. If radon is the main emitter present, however, then the risk is mainly due to inhalation of radon gas with a subsequent increase in lung cancer risk on showering



**Table 2: Effects of Uranium-238 on Human Health**

Uranium <sup>238</sup> U Range		Effects
Bq/l	mg/l	
<i>Target Water Quality Range</i> 0 - 0.89	<i>Target Water Quality Range</i> 0 - 0.070	<i>No significant effects. Annual cancer risk &lt; one in four million</i>
0.89 - 3.6	0.070 - 0.284	Annual cancer risk < one in a million. May potentially be a slight risk of renal toxicity in sensitive individuals where renal function is impaired, but unlikely to have demonstrable renal toxicity in healthy individuals
<b>If the above concentration is exceeded, human health may be at risk due to chemical toxicity</b>		
3.6 - 18	0.284 - 1.42	Annual cancer risk < one in 200 000, but significant risk of chemical toxicity with renal damage
> 18	> 1.42	Increasing cancer risk in long term. Increasing risk of renal damage in short term

**Table 3: Effects of Thorium-232 on Human Health**

Thorium -232: Range (Bq/l)	Effects
<i>Target Water Quality Range</i> 0 - 0.228	<i>No significant effects. Annual cancer risk &lt; one in 100 000</i>
<b>Human health may be at risk if the above concentration is exceeded</b>	
0.228 - 2.28	Annual cancer risk < one in 10 000
> 2.28	Annual cancer risk > one in 10 000

**Table 4: Effects of Radium-226 on Human Health**

<b>Radium-226 (Bq/R)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 0.42</i>	<i>No significant effects. Annual cancer risk &lt; one in 200 000. The typical background radium concentration in water of 0.015 Bq/R has an associated cancer risk of one in five million/year</i>
<b>Human health may be at risk if the above concentration range is exceeded</b>	
> 0.42	Increasing risk of bone cancer in the long term

**Table 5: Effects of Radon-222 on Human Health**

<b>Radon-222 Range (Bq/R)</b>	<b>Effects</b>
<i>Target Water Quality Range 0 - 11</i>	<i>No significant effects either with drinking water or on showering</i>
11 - 33	No risk on drinking water, slight risk in showering in a non-ventilated area
33 - 100	No risk on drinking water. Moderate risk in showering in a non-ventilated area
> 100	Increasing risk on showering of inhalation of radon gas, leading to an increased risk of lung cancer

**!  $\alpha$ -radioactivity:**

The most common  $\alpha$ -emitter present in all water samples is potassium-40. This is associated with all living organisms. One gram of potassium contains an amount of potassium-40 with a  $\alpha$ -activity of 27.6 Bq. For example, a water sample with 50 mg/R potassium will have a  $\alpha$ -activity of 1.38 Bq/R. There is consequently little sense in setting a criterion for gross  $\alpha$ -activity. One  $\alpha$ -emitter of potential concern that may be present is radium-228, for which the same criterion as for the  $\alpha$ -emitter radium-226 may be set, because of the similarity of their tissue absorbed dose to Becquerel conversion factors.

The criterion for the  $\alpha$ -emitter, radium-228 is given in Table 7. Note that the gross  $\alpha$ -activity (Table 6), is usually largely due to potassium-40 and must be subtracted from any measured gross  $\alpha$ -activity prior to the interpretation thereof.

**Table 6: Effects of Gross  $\alpha$ -activity on Human Health**

Gross $\hat{\alpha}$ -activity (Bq/l)	Interpretation
<i>Target Water Quality Range</i> 0 - 1,38	Under the usual situation where potassium-40 is the main beta emitter present there is no significant health risk. A potassium concentration of 50 mg/l will account for a $\hat{\alpha}$ -activity of 1,38 Bq/l
1,38 - 2,76	There is a strong possibility of other beta emitters, such as radium 228 being present, except where the potassium concentration in the water is or exceeds 100 mg/l, in which case there is no significant health risk
> 2,76	Increased risk from the presence of non-potassium beta emitters, except in the presence of excessive concentrations of potassium, exceeding 100 mg/l

**Table 7: Effects of Radium-228 on Human Health**

Radium-228 Range (Bq/l)	Effects
<i>Target Water Quality Range</i> 0 - 0.42	<i>No significant effects. Annual cancer risk &lt; one in 200 000</i>
<b>Human health may be at risk if the above concentration range is exceeded</b>	
> 0.42	Increasing risk of bone cancer in the long term

**!  $\hat{\alpha}$ -radioactivity:**

$\hat{\alpha}$  radioactivity in water is not normally of health concern and no criterion is specified for this type of radioactivity.

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# Selenium

## Tentative Guideline

### Background Information

<b>Introduction</b>	Selenium is a semi-metallic element with pronounced photoconductivity. At low concentrations it is an essential nutritional micro-element in humans and animals, and is an integral part of the enzyme glutathione peroxidase. The recommended total dietary intake for adults is 1 µg/kg, that is, 70 µg/day for a 70 kg adult. In excess, selenium is toxic and clinical symptoms can be observed at intakes of 700 µg/day and greater.
<b>Occurrence</b>	<p>Selenium occurs in association with sulphide ores of heavy metals such as copper, iron and zinc. Selenium forms insoluble metal selenides, which tend to be incorporated into sediments, particularly under anaerobic conditions. Selenium is also bioaccumulated by certain plants which are used as indicators in the biomeasurement of selenium. Typically, the concentration of selenium in surface water is less than 10 Fg/R. Elevated concentrations can occur in ground waters in seleniferous areas.</p> <p>Selenium is used in a variety of industrial processes. It is used in the manufacture of glass and ceramics, ink and paint pigments, plastics, rubber, photoelectric cells and various alloys.</p>
<b>Interactions</b>	The chemistry of selenium is similar to that of <b>sulphur</b> . Metabolically, selenium interacts with <b>sulphur, iron</b> and <b>arsenic</b> , and with metals such as <b>copper, cadmium</b> and <b>mercury</b> .
<b>Measurement</b>	The criteria are given in terms of total selenium concentration in units of Fg/R. The reference-method for the determination of selenium is atomic absorption spectrometry. Prior to analysis, digestion of the sample followed by reduction of Se(VI) to Se(IV) with hydrochloric acid and the formation of selenium hydride using a borohydride reagent, is required. If other methods of measuring selenium are used, their characteristics relative to the reference-method should be known.
<b>Data Interpretation</b>	Single-sample values should be used to compare with the criteria given, and should be interpreted as maximal values, not to be exceeded. The total dietary intake of selenium should also be taken into account in the interpretation of possible health effects.
<b>Treatment Options</b>	<p>Selenium in water supplies is most effectively removed by one of two processes:</p> <ul style="list-style-type: none"><li>! Coagulation and precipitation by treatment with lime or ferric chloride at pH values greater than 8.5. Careful monitoring is needed to ensure effective removal.</li><li>! Adsorption onto activated alumina at low pH levels.</li></ul> <p>The processes involved require skilled operation and process control. Both processes produce a waste stream that may be rich in selenium, presenting disposal difficulties.</p>

### The Effects of Selenium

**Norms** The norm used in the guidelines for selenium is human health.

**Effects** The norm is based on the allocation of 20 % of the "no-observed-adverse-effect" level in water. There is more data on the toxicity of selenium to animals than to humans. The criteria for humans has therefore been set at precautionary levels. Animals usually get selenium poisoning from their feed intake rather than from water, for example, ingestion of selenium accumulator plants.

Toxic effects of selenium become apparent at intakes 10 times or more of the recommended nutritional requirement. Effects include liver damage and impairment of growth of nails and hair.

**Mitigation** Selenium levels below 0.05 mg/R do not normally require mitigatory measures.

**Criteria** **Effects of Selenium on Human Health**

<b>Selenium Range (Fg/R)</b>	<b>Effects</b>
<i>Target Water Quality Range</i> <i>0 - 20</i>	<i>No adverse health effects</i>
20 - 50	No adverse health effects with short to medium-term use. With lifelong use potential danger of selenium accumulation in individuals with a selenium-rich diet, for example a diet very rich in sea foods
50 - 100	No danger with short-term use, but a danger of liver toxicity with long-term use, particularly in children
> 100	Danger of selenium toxicity, with liver damage

**Note:** It is recommended that the concentration of selenium in potable water never exceed 50 Fg/R, due to the risk of liver damage, particularly in children.

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# Settleable Matter

## Background Information

**Introduction** Settleable solids constitute that portion of the suspended solids which will sediment out of suspension in a specified time period. Some methods used for determining the settleable solids fraction do not include floating material, whereas some do. Settleable material may result from the incomplete removal of suspended solids during water treatment processes, or form in distribution systems as a result of inadequate treatment practices. This may include biological regrowth due to inadequate disinfection and/or dissolved organic carbon removal or the formation of corrosion products and/or ingress of solids from open reservoirs.

**Occurrence** Settleable material occurs wherever water movement or turbulence has resuspended sediments or solid materials into the water. Settleable solids will settle out of the water column where the water is left to stand; floating material will remain near or at the surface of the water.

**Interactions** The settleable solids fraction in water is to a large extent determined by the suspended solids fraction. To a large extent, factors that influence water clarity and **turbidity**, also influence settleable matter measurements.

**Measurement** The settleable solids concentration is determined either by the volumetric method and/or the gravimetric method. The volumetric method is preferentially used and excludes floating matter, whereas the gravimetric method includes it.

A well-mixed water sample is placed in a cone and allowed to settle for 60 minutes. The settleable matter is reported in units of mL/R. With the gravimetric method the settleable solids are determined by the difference between the total suspended solids, measured gravimetrically, and the suspended solids determined after the well mixed water sample has stood for 60 minutes. In this case, settleable matter including floating matter is reported in units of mg/R.

**Data Interpretation** Since the criteria given are qualitative, good judgement and discretion should be used in the interpretation thereof.

**Treatment Options** Sediments in water are removed by sufficiently reducing the water flow to allow for settlement of the material to the bottom of a tank or clarifier.

In cases where the specific gravity of the particles is significantly higher than that of water, effective removal is achieved merely by gravity settlement. In other cases, where many of the particles have a specific gravity only slightly higher than that of water, sedimentation needs to be assisted by coagulation and/or flocculation prior to settlement. Filtration may be required as a further step to remove slowly settling particles. In such cases, coagulants like aluminium sulphate or ferric chloride, are used with or without polyelectrolytes, or polyelectrolytes may be used alone. This is usually followed by filtration of the water using rapid gravity sand filters or pressure sand filters.

Where sediment loads are low, sediment removal may be achieved by passing the water through disposable on-line cartridge filters. This approach may be applicable to small-scale industrial use or for clarifying household domestic water.

Where polyelectrolytes are used, the most effective formulation should be selected on the basis of jar tests.

## The Effects of Settleable Material

<b>Norms</b>	The norms used in the guideline for settleable material are principally based on the economic implications for household distribution systems and water heating appliances.
<b>Effects</b>	The presence of settleable material in any part of a treated water distribution system or household system may be responsible, at least in part, for erosion, corrosion (both chemical and biological), blocking of sieves and filters, lowering of the capacity and general fouling of domestic holding tanks, cisterns and geysers as well as a less appreciable general aesthetic quality of the water. Of these potential problems, biological corrosion may be the most serious since the sediment beds may provide an anaerobic environment for corrosive micro-organisms such as sulphate-reducing bacteria. Sulphate-reducing bacterial growth can also serve to encourage other bacterial growth, as a result of the formation of mucilaginous slime shields which protect bacteria from the effects of chlorine. See <b>corrosion</b> and <b>turbidity</b> .
<b>Mitigation</b>	By filtering the water, most of the adverse aesthetic effects of settleable matter can be prevented.
<b>Criteria</b>	No quantitative criteria are given for settleable material, but the following general procedures should be adhered to: <ul style="list-style-type: none"><li>! The distribution system should not show any visible sediments upon inspection;</li><li>! The quality of the water reaching the end-user should not be lower than that of the water leaving the treatment plant.</li></ul>

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# Sodium

## Background Information

**Introduction** Sodium is an alkali metal which reacts with water to form highly soluble, positively- charged sodium ions. It is an essential dietary element important for the electrolyte balance and the maintenance of many essential physiological functions. Sodium is present in all food to varying degrees.

**Occurrence** Sodium is ubiquitous in the environment and usually occurs as sodium chloride, but sometimes as sodium sulphate, bicarbonate or even nitrate. Sodium is found as solid sodium chloride (rock salt) in areas where geological deposits occur. The levels of sodium in surface waters are generally low in areas of high rainfall and high in arid areas with low mean annual precipitation. Sodium is highly soluble in water and does not precipitate when water evaporates, unless saturation occurs. Hence, water in arid areas often contains elevated concentrations of sodium. High concentrations also occur in sea water, at approximately 11 g/R.

Industrial wastes, especially processes that give rise to brines, contain elevated concentrations of sodium. Sodium is also present at high concentrations in domestic waste water; this is in part due to the addition of table salt (sodium chloride) to foods. Furthermore, with re-use or recycling of water, the sodium concentration will tend to increase with each cycle or addition of sodium to the water. For this reason, sodium concentrations are elevated in runoffs or leachates from irrigated soils.

**Interactions** Metabolically, sodium interacts with **potassium**. Sodium and potassium are the most important extracellular and intracellular cations respectively, and vital to all living organisms.

**Measurement** The criteria are given in terms of the dissolved sodium concentration, in units of mg/R. For all practical purposes this is identical to the total sodium concentration, as sodium is always in the dissolved form, except in supersaturated brines.

The reference method for the determination of sodium is flame photometry, with lithium as the internal standard. If other methods for measuring sodium are used, their characteristics relative to the reference method should be known.

**Data Interpretation** Mean values should be used to compare with the criteria given. The sodium concentration should also be interpreted in conjunction with the major associated cations, usually chloride, sulphate, or bicarbonate. However, the concentrations of other cations such as potassium, calcium and magnesium should also be taken into account, if present.

**Treatment Options** Sodium can be removed from water together with other ions which constitute the total dissolved solids (TDS) by the following desalination processes :

! **Demineralisation** in a mixed-bed ion exchange column, usually where the feed TDS is up to about 2 000 mg/R.

! Treatment by **membrane processes** such as reverse osmosis or electrodialysis, where the TDS concentration is in the range of 2 000 - 35 000 mg/R.

**! Distillation**, in cases where the TDS is 10 000 mg/R and more.

Demineralisation by ion exchange can be used to produce low-sodium, potable water on a household scale using disposable ion exchange cartridges, or on a commercial or industrial scale using banks of large, ion exchange filter beds which are capable of being regenerated.

Small volumes of low-sodium potable water can be reliably produced on a household scale using small low-pressure reverse osmosis modules fed from the domestic water supply line. These are easily replaced after one to three years if the membrane becomes fouled through scaling. Large-scale water treatment is achieved using banks of reverse osmosis modules in parallel.

All of the processes are easily fouled by suspended matter and are prone to scaling with hard waters. All of the processes produce a concentrated waste stream of the salts that may cause disposal difficulties. If used on a large scale, all of the processes require high levels of design, operator and maintenance skills.

## The Effects of Sodium

<b>Norms</b>	The norms used in the guideline for sodium are based on human health and aesthetic effects.
<b>Effects</b>	<p>The taste threshold for sodium in water varies from 135 - 200 mg/R, depending on the associated anion. The common ones include chloride, sulphate, nitrate, bicarbonate and carbonate.</p> <p>Sodium intake can exacerbate certain disease conditions. Persons suffering from hypertension, cardiovascular or renal diseases, should restrict their sodium intake. In the case of bottle-fed infants, sodium intake should also be restricted.</p>
<b>Mitigation</b>	Mitigatory measures other than the ingestion of adequate water after excessive sodium intake are usually unnecessary.

Criteria

Effects of Sodium on Aesthetics and Human Health

Sodium Range (mg/l)	Effects
<i>Target Water Quality Range</i> 0 - 100	<i>No aesthetic or health effects</i>
100 - 200	Faintly salty taste. <i>Threshold for taste</i> No health effects
200 - 400	Slightly salty taste. Undesirable for persons on a sodium-restricted diet
400 - 600	Distinctly salty taste. No health effects in healthy adults with short-term use. Undesirable for infants or persons on a sodium-restricted diet
600 - 1 000	Very salty taste. Health effects may be expected. Very undesirable for infants or persons on a sodium-restricted diet
1 000 - 5 000	Highly salty taste. Likelihood of nausea and vomiting. Highly undesirable for infants or persons on a sodium-restricted diet
> 5 000	Extremely salty taste becoming bitter. Severe health effects with disturbance of electrolyte balance. Extremely undesirable for infants or persons on a sodium-restricted diet

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# Sulphate

## Background Information

**Introduction** Sulphate is the oxy-anion of sulphur in the +VI oxidation state and forms salts with various cations such as potassium, sodium, calcium, magnesium, barium, lead and ammonium. Potassium, sodium, magnesium and ammonium sulphates are highly soluble, whereas calcium sulphate is partially soluble and barium and lead sulphates are insoluble.

Consumption of excessive amounts of sulphate in drinking water typically results in diarrhoea. Sulphate imparts a bitter or salty taste to water, and is associated with varying degrees of unpalatability.

**Occurrence** Sulphate is a common constituent of water and arises from the dissolution of mineral sulphates in soil and rock, particularly calcium sulphate (gypsum) and other partially soluble sulphate minerals. Since most sulphates are soluble in water, and calcium sulphate relatively soluble, sulphates when added to water tend to accumulate to progressively increasing concentrations. Typically, the concentration of sulphate in:

- ! surface water is 5 mg/R, although concentrations of several 100 mg/R may occur where dissolution of sulphate minerals or discharge of sulphate rich effluents from acid mine drainage takes place; and
- ! sea water is just over 900 mg/R.

Sulphates are discharged from acid mine wastes and many other industrial processes such as tanneries, textile mills and processes using sulphuric acid or sulphates. Sulphates can be removed or added to water by ion exchange processes, and microbiological reduction or oxidation can interconvert sulphur and sulphate. The microbiological processes tend to be slow and require anaerobic conditions usually only found in sediments and soils. Atmospheric sulphur dioxide, discharged on combustion of fossil fuels, can give rise to sulphuric acid in rainwater (acid-rain) and as such, this results in the return of sulphate to surface waters in the environment.

**Interactions** The tendency of sulphate to induce diarrhoea depends to some extent on the associated cation. **Magnesium** will induce diarrhoea, whereas sodium will not.

**Measurement** The criteria are given in terms of the dissolved sulphate concentration in, units of mg/R. Dissolved sulphate is normally measured turbidimetrically on precipitation as insoluble barium sulphate. This is the reference method. For rain water, or water with low sulphate concentrations, ion-chromatography is preferentially used. If other methods are used to measure sulphate, their characteristics relative to the reference methods given should be known.

**Data Interpretation** Single-sample values should be used to compare with the criteria given. Sulphate concentrations should also be interpreted in conjunction with the major associated cations, as well as the pH.

**Treatment Options** Sulphate can be removed from water by one of the following processes :

- ! **Ion exchange** in an anion exchange column, which will remove all anions.
- ! Any **desalination** technique in which scaling due to insoluble sulphate can be avoided or tolerated. These include:
  - **demineralisation** in mixed bed ion exchange columns;
  - **membrane treatment** by reverse osmosis or electrodialysis;
  - a range of **distillation** processes.
- ! **Precipitation** with calcium or barium salts followed by settlement and filtration to remove the insoluble calcium or barium sulphate. Barium is strongly toxic and should not be used for the removal of sulphate from water which will be used for domestic purposes, or which may come into contact with foodstuffs. Calcium salts will not reduce sulphate concentrations of 2 000 mg/R or less. Precipitation is only suitable for industrial application, although more commonly the method of choice is ion exchange or membrane treatment.

On a household scale, small volumes of water for potable use can be produced by using disposable ion exchange cartridges, or low pressure reverse osmosis modules which are replaceable when the membrane becomes fouled through scaling.

All of the processes produce a concentrated waste stream or slurry which may cause disposal difficulties. The industrial scale processes require high levels of design, operator and maintenance skills.

## The Effects of Sulphate

<b>Norms</b>	The norms used in the guideline for sulphate are based on human health and aesthetic effects.
<b>Effects</b>	<p>High concentrations of sulphate exert predominantly acute health effects (diarrhoea). These are temporary and reversible since sulphate is rapidly excreted in the urine. Individuals exposed to elevated sulphate concentrations in their drinking water for long periods, usually become adapted and cease to experience these effects. Sulphate concentrations of 600 mg/R and more cause diarrhoea in most individuals and adaptation may not occur.</p> <p>Sulphate imparts a salty or bitter taste to water. The taste threshold for sulphate falls in the range of 200 - 400 mg/R and depends on whether the sulphate is predominantly associated with either sodium, potassium, calcium or magnesium, or mixtures thereof. Elevated sulphate concentrations also increase the erosion rate of metal fittings in distribution systems.</p>
<b>Mitigation</b>	Measures to mitigate against effects of having ingested water containing high concentrations of sulphate are unnecessary. Adverse effects disappear rapidly when use is discontinued.



## Criteria

### Effects of Sulphate on Aesthetics and Human Health

Sulphate Range (mg/l as SO <sub>4</sub> <sup>-</sup> )	Effects
<i>Target Water Quality Range 0 - 200</i>	<i>No health or aesthetic effects are experienced</i>
200 - 400	Tendency to develop diarrhoea in sensitive and some non-adapted individuals. Slight taste noticeable
400 - 600	Diarrhoea in most non-adapted individuals. Definite salty or bitter taste
600 - 1 000	Diarrhoea in most individuals. User-adaptation does not occur. Pronounced salty or bitter taste
> 1 000	Diarrhoea in all individuals. User-adaptation does not occur. Very strong salty and bitter taste

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# Trihalomethanes

## Tentative Guideline

### Background Information

- Introduction** The trihalomethanes (THMs) are single carbon compounds with the general formula of  $\text{CHX}_3$  where X is usually chlorine or bromine, but may also be iodine or fluorine. Trihalomethanes are formed in significant concentrations, if water containing organic material, is chlorinated. The organic compounds in water that may give rise to the formation of trihalomethanes on chlorination are termed trihalomethane precursors. Of the trihalomethane group, chloroform ( $\text{CHCl}_3$ ), bromodichloromethane ( $\text{CHCl}_2\text{Br}$ ), dibromochloromethane ( $\text{CHClBr}_2$ ) and bromoform ( $\text{CHBr}_3$ ) are thought to pose the greatest health risk. THMs have significant vapour pressures at ambient temperature and are released into the atmosphere when water is either aerated or boiled. THMs may be individually specified, but since they usually occur together, total trihalomethanes are measured.
- Occurrence** THMs occur naturally at low concentrations in water, and significant concentrations only occur when water containing THM precursors is chlorinated. The most common THM, chloroform, is found in:
- ! foods at a concentration range of 1 - 30  $\mu\text{g}/\text{kg}$ ; and
  - ! raw water at a concentration below 1  $\mu\text{g}/\text{R}$ , unless the raw water contains chlorinated effluents.
- The total THM concentration in chlorinated drinking water supplies is typically between 30 - 50  $\mu\text{g}/\text{R}$ , but may be several hundred  $\mu\text{g}/\text{R}$  where high concentrations of precursor organics are found. Chlorinated sewage effluents contain elevated concentrations of THMs.
- THMs are lipid soluble and therefore relatively easily absorbed by living organisms. They generally have a short residence time in the organism, and they are lost to the environment through excretion or respiration. In open water bodies, trihalomethanes are slowly lost to the atmosphere.
- Interactions** Organic precursors must be present in the water at the time of chlorination for the formation of THMs to take place. However, definitive correlations between the total organic load and the final concentration of THMs formed, cannot be made, since different organic compounds tend to differ in their potential to form THMs.
- Measurement** The criteria are given in terms of total THM concentration, in units of  $\text{Fg}/\text{R}$  and not in terms of the individual THMs. The reference method for the determination of THMs is purge and trap capillary column gas chromatography. If other methods of measurement are used, their characteristics relative to the above reference method should be known.
- Data Interpretation** Long-term exposure to high concentrations of THMs is of a greater health significance than is brief or episodic exposure. Mean values should be used to compare with the criteria given. The criteria for total THMs is tentative due to uncertainties involved in the extrapolation of animal data to humans.

## **Treatment Options**

Most forms of THMs are volatile. Treatment methods make use of this and subject the water to air stripping in a vertical tower using a countercurrent stream of air blown up through the tower to strip the volatile substances into the atmosphere.

However, some THMs are not easily volatilised and treatment of the raw water to remove the THM precursors (such as humic substances), may be required. Methods for removal include:

- ! Slow sand filtration to remove trace organics from the water.
- ! Coagulation, flocculation, clarification and filtration to remove particulate matter including organic colloids.
- ! Adsorption of the organics onto activated carbon.
- ! Oxidation of the organics using a powerful oxidising agent such as hydrogen, peroxide, ozone or peroxone. Chlorine is not a suitable oxidant as it will form THMs.

A number of these methods may need to be applied in succession to achieve the required water quality. High levels of treatment skills are needed to achieve satisfactory results, together with sophisticated analytical facilities.

## **The Effects of Trihalomethanes**

### **Norms**

The norms used in the guidelines for THMs are based on human health and aesthetic effects.

### **Effects**

The similarity in effects and risks of the four main THM compounds allow them to be evaluated as a group and in practice only the total THM value is of significance and not the individual THM concentrations. The criteria indicate an average risk of contracting cancer of one in  $10^5$ , over and above the background risk at a total THM concentration of  $100 \mu\text{g}/\text{R}$ . This is greater than the "application safety factor" used in estimating human risk, which is in the order of  $10^3$ . Further, the apparently greater risk with bromodichloromethane than with chloroform is vastly overshadowed by the uncertainty of animal to human extrapolations used in these calculations. Sufficient animal experiments as well as confirmative epidemiological studies have shown that there is a very small but significant risk of increased cancer incidence of the bowel and bladder from drinking chlorinated water as opposed to unchlorinated ground water. The risk levels are, however, at the borderline of detection and some well-designed studies do not show a difference in risk.

The most commonly occurring THM is chloroform. In pure form this has strong anaesthetic properties and was one of the first substances used as an anaesthetic. Long-term exposure to dose levels of chloroform in excess of  $15 \text{ mg}/\text{kg}$  can induce pathological changes in the liver, kidney and thyroid gland. When fed to experimental animals in high dosages over a long period, tumour induction has been observed. Epidemiological studies on human populations have been equivocal at exposure levels normally encountered. Extrapolation from animal studies suggests that the risk level for man at a lifetime exposure to  $200 \mu\text{g}/\text{R}$  in drinking water is a cancer risk of one in  $10^5$ , over and above the background cancer risk.

For bromoform, there is evidence of toxicity at high levels of exposure and equivocal evidence of tumour induction, as in the case of chloroform, with a risk level of one in  $10^5$  to a concentration of  $100 \mu\text{g}/\text{R}$  for lifetime exposure.

In the case of bromodichloromethane, toxicity with liver and kidney damage is observed in experimental animals at high levels with long-term exposure. The cancer risk level for a one in  $10^5$  incidence over a lifetime, is extrapolated from animal experiments to give a concentration of 60 µg/l in drinking water.

Dibromochloromethane has similar toxic and carcinogenic risks to bromoform with a risk level of one in  $10^5$  for a lifetime risk of cancer, at a concentration of 100 µg/l in drinking water.

**Mitigation** The concentration of THMs can be reduced by boiling the water. This mitigates against aesthetic impacts, as well as against adverse health effects.

**Criteria** **Effects of THMs on Aesthetics and Human Health**

Total THM Range ( Fg/l )	Effects
<i>Target Water Quality Range 0 - 100</i>	<i>Health effects attributable to THMs insignificant. Lifetime cancer risk &lt; one in <math>10^5</math></i>
100 - 200	A marginal risk of a cancer incidence around one to two in $10^5$ for lifetime, continuous exposure. Slight taste and odour effects noticeable
200 - 400	Slight risk of cancer for continuous lifetime exposure in the order of two to four in $10^5$ . Noticeable taste and odour effects

**Note:**

The risk levels used are based on the linearised multistage model risk data for the individual trihalomethanes, as reported by the WHO, 1993.

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# Total Dissolved Solids

## Background Information

**Introduction** The total dissolved solids (TDS) is a measure of the amount of various inorganic salts dissolved in water. The TDS concentration is directly proportional to the electrical conductivity (EC) of water. Since EC is much easier to measure than TDS, it is routinely used as an estimate of the TDS concentration.

Electrical conductivity (EC) is a measure of the ability of water to conduct an electrical current. This ability is a result of the presence of ions in water such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium, all of which carry an electrical charge. Most organic compounds dissolved in water do not dissociate into ions, consequently they do not affect the EC.

**Occurrence** Virtually all natural waters contain varying concentrations of TDS as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material and the TDS of natural waters is therefore often dependent on the characteristics of the geological formations the water was, or is, in contact with.

Typically, the concentration of the TDS in

- ! rainwater is low, generally less than 1 mg TDS/R;
- ! water in contact with granite, siliceous sand and well-leached soils is generally low, less than 30 mg TDS/R;
- ! water in contact with precambrian shield areas is generally below 65 mg TDS/R; and
- ! water in contact with palaeozoic and mesozoic sedimentary rock formations is generally in the range of 195 - 1 100 mg TDS/R.

TDS are likely to accumulate in water moving downstream because salts are continuously being added through natural and manmade processes while very little of it is removed by precipitation or natural processes. Domestic and industrial effluent discharges and surface runoff from urban, industrial and cultivated areas are examples of the types of return flows that may contribute to increased TDS concentrations .

High TDS concentrations in surface water are also caused by evaporation in water bodies which are isolated from natural drainage systems. The saline pans in the central parts of South Africa are such water bodies.

**Interactions** The properties of the TDS are governed by the characteristics of the constituent inorganic salts dissolved in the water. As such, TDS is also closely related to other water quality constituents such as the **total hardness** and the **corrosion** and scaling potential of water.

**Measurement** The criteria are given in terms of TDS concentration in mg/R, as well as the equivalent EC, expressed in milli-Siemens per metre (mS/m), measured at, or corrected to a temperature of 25 EC.

The TDS concentration can be measured as

- ! an estimate of the EC value (see below);
- ! the dry weight of the salts after evaporation of a known volume of filtered water;

! the sum of the concentrations of the constituent cations and anions.

For most natural waters electrical conductivity is related to the dissolved salt concentration by a conversion factor ranging from 5.5 - 7.5. The average conversion factor for most waters is 6.5. The conversion equation is as follows:

$$EC(\text{mS/m at } 25^\circ\text{C}) \times 6.5 = \text{TDS}(\text{mg/R})$$

The exact value of the conversion factor depends on the ionic composition of the water, especially the pH and bicarbonate concentration. Should very accurate measures of TDS be required, the conversion factor should be determined for specific sites and runoff events.

**Data Interpretation**

The TDS concentrations in water prevailing for long periods of time rather than a few extreme events, is important. Therefore annual, seasonal mean or mean values for TDS concentrations should be used to compare with the criteria for TDS.

**Treatment Options**

Although some salts, such as those of calcium, magnesium and certain heavy metals can be removed by chemical precipitation, most of the inorganic salts dissolved in water can only be removed by distillation or by highly sophisticated physical-chemical separation technologies. All these technologies are characterised by their high cost and/or their high energy requirements.

The technologies available for reducing the concentration of TDS in water are:

! **Demineralisation** in a mixed-bed ion exchange column, usually where the feed TDS concentration is approximately 2 000 mg/R. Disposable ion exchange canisters can be used to produce potable water for domestic consumption whereas large banks of ion exchange filter beds, which are capable of being regenerated, are used on an industrial scale. Ion exchange processes are also used for the production of ultrapure water.

! Treatment by membrane processes such as **reverse osmosis** or **electrodialysis** where the TDS concentration is in the range of 2 000 - 3 500 mg/R. Small low-pressure reverse osmosis modules fed from a domestic supply line reliably produce potable water for household consumption and are easily replaced after one to three years if the membrane becomes fouled through scaling. Large-scale treatment is achieved with banks of reverse osmosis modules in parallel.

! **Distillation**, in cases where the TDS concentration is approximately 10 000 mg/R.

All the process alternatives are usually fouled by suspended matter and may also be impeded by severe scaling from hard waters. All large-scale processes require high levels of design, operator and maintenance skills. Furthermore, all processes produce a concentrated waste stream of the salts removed from the water and may cause disposal difficulties.

## The Effects of Total Dissolved Solids

**Norms**

The norms used in the guideline for TDS are aesthetic and human health effects and economic impacts.

**Effects**

Low concentrations of particularly calcium and magnesium salts have nutritional value, although water with an extremely low TDS concentration may be objectionable because of



its flat, insipid taste. Health effects related to TDS are minimal at concentrations below 2 000 - 3 000 mg/R TDS. In contrast, high concentrations of salts impart an unpleasant taste to water and may also adversely affect the kidneys.

Some of the physiological effects which may be directly related to high concentrations of dissolved salts include:

- ! laxative effects, mainly from sodium sulphate and magnesium sulphate, see **sulphate**;
- ! adverse effects of sodium on certain cardiac patients and hypertension sufferers;
- ! effects of sodium on women with toxemia associated with pregnancy; and
- ! some effects on kidney function.

Bathing and washing in water with excessively high concentrations of TDS may give rise to excessive skin dryness and hence discomfort. Soap may lather poorly or with difficulty, see **calcium** and **magnesium**.

Chemical corrosion may occur when the alkalinity, i.e. the concentrations of carbonate, bicarbonate and hydroxide are low, the TDS concentration is high, particularly the concentrations of chloride and sulphate, and the pH is low. Scaling may also occur, see **corrosion, calcium, magnesium** and **total hardness**. Excessively high concentrations of TDS may adversely affect plumbing and appliances and hence the maintenance and replacement requirements.

### **Mitigation**

Measures to mitigate the effects of having consumed water containing a high TDS concentration are unnecessary since salts are rapidly eliminated in the urine once consumption of such water has been discontinued. Any electrolyte imbalances that may result can be restored by consuming water with more acceptable levels of dissolved salts.

Water with high concentrations of TDS may be diluted with other sources, e.g. rain water.

**Criteria**

**Effects of TDS and EC on Human Health, Aesthetics, Household Distribution Systems and Water Heating Appliances**

TDS Range (mg/R)	EC Range (mS/m)	Aesthetic/Economic Effects	Health Effects
<p><i>Target Water Quality Range</i></p> <p>0 - 450</p>	0 - 70	<p>The taste threshold for dissolved salts in water is in the region of 45 mS/m (300 mg/R TDS), hence a slight salty taste may be detected above this concentration. The threshold varies according to the salt composition</p> <p>Water with extremely low TDS concentrations may be objectionable because of its flat, insipid taste</p> <p>No effects on plumbing or appliances</p>	<p>No health effects associated with the electrical conductivity of water are expected &lt; 45 mS/m (300 mg/R TDS)</p> <p><i>The upper limit of this range takes into account the higher water consumption which may be expected in hot climates</i></p>
450 - 1 000	70 - 150	Water has a noticeable salty taste, but is well tolerated. No effects on plumbing or appliances	No health effects are likely
1 000 - 2 000	150 - 300	<p>Water has a marked, salty taste and would probably not be used on aesthetic grounds if alternative supplies are available</p> <p>Some effects on plumbing and appliances, such as increased corrosion or scaling, may be expected</p>	Consumption of water does not appear to produce adverse health effects in the short term
2 000 - 3 000	300 - 450	Water tastes extremely salty Corrosion and/or scaling of pipes and appliances will increase	Short-term consumption may be tolerated, but with probable disturbance of the body's salt balance
> 3 000	> 450	Water tastes extremely salty and bitter. Effects such as corrosion and/or scaling increase	Short-term consumption leads to disturbance of the body's salt balance. At high concentrations, noticeable short-term health effects can be expected

**Modifications**

EC is usually measured at 20 EC for domestic water use, but in view of the climate of South Africa, EC values should be measured at 25 EC. Since measurement of EC is quick and simple, it is suggested that the standard measurement of EC with the application of a conversion factor to a TDS measurement be adopted.

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# Total Hardness

## Background Information

**Introduction** Water hardness was originally described as the soap-destroying power of water, caused by the presence of calcium and magnesium salts and measured by titration against a standard soap solution. The current definition of total hardness is the sum of the calcium and magnesium concentrations, expressed as mg/R of calcium carbonate. Other metals such as strontium, iron, aluminium, zinc and manganese may occasionally contribute to the hardness of water, but the calcium and magnesium hardness usually predominates. *Temporary hardness* is due to the presence of bicarbonates of calcium and magnesium and can be removed by boiling, whereas *permanent hardness* is attributed to other salts such as sulphate and chloride salts, which cannot be removed by boiling.

Excessive hardness of water can give rise to scaling in plumbing and household heating appliances and hence has adverse economic implications. It also poses a nuisance in personal hygiene. Excessive softness may lead to aggressive and corrosive water qualities which are of concern where copper plumbing installations are used.

**Occurrence** The natural hardness of water is influenced by the geology of the catchment and the presence of soluble calcium and magnesium minerals. Total hardness of water varies and ranges from 0 - 1 000 mg CaCO<sub>3</sub>/R. The hardness in surface waters rarely exceeds 100 mg CaCO<sub>3</sub>/R.

Water hardness depends on whether it is caused by bicarbonate salts or non-bicarbonate salts, such as chloride, sulphate and nitrate. Bicarbonate salts of calcium and magnesium precipitate on heating and cause scaling in hot water systems and appliances, whereas the non-bicarbonate salts do not precipitate on heating.

**Interactions** Hardness is a complex property of water and is governed by the concentrations of **calcium**, **magnesium** and other polyvalent cations.

**Measurement** Total hardness is expressed as mg CaCO<sub>3</sub>/R. Total hardness is calculated from the calcium and magnesium concentrations as follows:

$$\text{! Total hardness (mg CaCO}_3\text{/R)} = 2.497 \times [\text{mg Ca/R}] + 4.118 \times [\text{mg Mg/R}]$$

Hardness of water is classified as follows by Kunin :

Hardness Range (mg CaCO <sub>3</sub> /R)	Description of Hardness
0 - 50	Soft
50 - 100	Moderately soft
100 - 150	Slightly hard
150 - 200	Moderately hard
200 - 300	Hard
> 300	Very hard

<b>Data Interpretation</b>	Mean values should be used to compare with the criteria given.
<b>Treatment Options</b>	<p>Water is commonly softened by the addition of lime followed by recarbonation or by using an ion exchange technique, sometimes preceded by a precipitation step if hardness in the feed water is particularly high. The following processes are employed in the treatment of water hardness:</p> <ul style="list-style-type: none"> <li>! <b>Base exchange softening</b> is used to replace the calcium and magnesium in the water with non-hardness forming sodium in ion exchange columns regenerated with a sodium chloride brine. This is a simple technique and can be operated successfully on a household scale. On an industrial scale, the process usually needs to be closely monitored because the consequences of incomplete softening may be severe.</li> <li>! <b>Demineralisation</b> in mixed bed ion exchange columns may be used to remove all hardness-forming ions together with other ions in solution, where a particularly low salinity water is required.</li> </ul> <p>The same results can be obtained using a range of desalination techniques such as membrane treatment or distillation. However, problems of scaling may occur due to the hardness-forming salts and impair proper functioning of the equipment.</p> <p>All of the processes produce a concentrated waste stream that may cause disposal difficulties. On an industrial scale, the processes need skilled operation and control.</p>

## The Effects of Total Hardness

<b>Norms</b>	The norms used in the guideline for total hardness are based primarily on adverse economic implications of excessive softness and hardness and aesthetic effects.
<b>Effects</b>	<p>Excessive hardness in water used for domestic purposes causes two main problems:</p> <ul style="list-style-type: none"> <li>! It forms scale on heat exchange surfaces such as cooking utensils, hot water pipes, kettles and geysers.</li> <li>! It results in an increase in soap required to produce a lather when bathing and in household cleaning. This may lead to scum formation through the formation of insoluble salts of long-chain fatty acids, the chief component of soaps. These scums are unaesthetic, leading in the long term to the marking of enamel surfaces of baths and handbasins. See <b>calcium</b> and <b>magnesium</b>.</li> </ul> <p>Lathering capabilities of modern detergents, on the other hand, are only slightly affected by water hardness.</p> <p>Excessively soft water can result in poor buffering, the corrosion of copper plumbing and the consequent release of copper into the water. See <b>copper</b>.</p>
<b>Mitigation</b>	Mitigation against excessive hardness in water usually consists of descaling by whatever method is practicable.

**Criteria** Total hardness should be limited to between 50 - 100 mg/R as CaCO<sub>3</sub>, where possible. It should however be noted that many USA cities allow for a final water total hardness value of up to 150 mg CaCO<sub>3</sub>/R in order to limit sludge production and chemical costs of treatment.

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# Turbidity

## Background Information

**Introduction** Turbidity is a measure of the light-scattering ability of water and is indicative of the concentration of suspended matter in water. The turbidity of water is also related to clarity, a measure of the transparency of water and **settleable material**, which refers to suspended matter which settles after a defined time period as opposed to that which remains in suspension.

Micro-organisms are often associated with turbidity, hence low turbidity minimises the potential for transmission of infectious diseases. The probability of the presence of carcinogenic asbestos fibres is also reduced under conditions of low turbidity. Turbidity also affects the aesthetic quality of water.

**Occurrence** Turbidity in water is caused by the presence of suspended matter which usually consists of a mixture of inorganic matter, such as clay and soil particles, and organic matter. The latter can be both living matter such as micro-organisms and non-living matter such as dead algal cells. The turbidity of raw water can range from less than one nephelometric turbidity unit (NTU) in very clear water, to over 1 000 NTU in turbid, muddy water.

Soil particles constitute the major part of the suspended matter contributing to the turbidity in most natural waters. Discharge of sewage and other wastes can contribute significantly to turbidity.

**Interactions** Turbidity is strongly associated with apparent water **colour**. The relationship between turbidity, taste and **odour** of raw and treated water has long been recognised. However, all these constituents may also be present in the absence of excessive turbidity.

**Measurement** The criteria refer to turbidity measured in nephelometric turbidity units (NTU). A nephelometric turbidimeter is used for the measurement of turbidity. Turbidity should be determined on the day of sample collection. If necessary, samples may be stored in the dark for 24 hours, after which irreversible changes in turbidity occur. Samples must be shaken vigorously before examination.

**Data Interpretation** Single-sample values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. Turbidity should also be interpreted in conjunction with the **suspended solids** concentration and content.

**Treatment Options** The settleable fraction of the suspended matter in water will tend to gradually settle to the bottom where the water is not disturbed. However, the smaller particles and colloidal fraction do not settle out and are kept in suspension by Brownian motion, as well as by mutual repulsion of the like-electrical charges which are often present on the surfaces of the suspended matter. When a flocculant is added to a water, the electrical charges are neutralised and the particles cohere and settle out.

Removal of turbidity from domestic or industrial water normally requires an effective coagulation and flocculation process following settlement or deep-bed or multimedia filtration, if the particles involved are colloidal in nature.

Coagulants like aluminium sulphate or ferric chloride are conventionally used, with small doses of polyelectrolytes added to assist in flocculation. With many waters, small doses of polyelectrolytes alone may be sufficient to promote flocculation of the particles for removal by settlement and filtration.

Silica sand filters are most commonly used in large-scale treatment plants. Multimedia filters of anthracite and garnet are also used, even though there is a growing tendency to use membrane processes such as microfiltration or ultrafiltration in more critical applications. Filter backwash water may cause disposal difficulties. The processes require careful design and skilled monitoring and control. They are generally not suited to application on a household scale.

As the turbidity of water increases, the amount of chlorine required for disinfection of the water increases. Low turbidity therefore minimises the required chlorine dose and reduces the formation of chloro-organics that often give rise to taste and odour problems and trihalomethanes. Due to the many advantages associated with water of low turbidity and the relative ease of monitoring, it is often used as an indicator of potential water quality problems during treatment.

## The Effects of Turbidity

**Norms** The norms used in the guideline are based on human health and aesthetic effects.

**Effects** The consumption of turbid water *per se* does not have any direct health effects, but associated effects due to microbial contamination or the ingestion of substances bound to particulate matter, do. Turbidity can have a significant effect on the microbiological quality of water. Microbial growth in water is most extensive on the surface of particulates and inside loose, naturally-occurring flocs. River silt also readily adsorbs viruses and bacteria. During treatment, micro-organisms become entrapped in the floc formed during coagulation and breakthrough of the floc may represent significant microbial contamination. Consumption of highly turbid, chlorinated water may therefore pose a health risk. Particulate matter can also protect bacteria and viruses against disinfection. The adsorptive properties of some suspended particles can lead to the entrapment of undesirable inorganic and organic compounds in water, including metal-humate complexes and herbicides (e.g. 2,4-D, Paraquat, Diquat). This may interfere with the detection of such compounds, and could be an indirect health risk.

Turbidity may also be associated with the presence of inorganic ions such as manganese(II). For example, when water containing manganese(II) ions is treated with chlorine and left to stand, slow reaction kinetics indicate that colloidal manganese(IV) oxide is formed, leading eventually to the formation of a fine precipitate.

**Mitigation** Any adverse effects thought to be due to microbial contamination or adsorbed substances should be referred to a medical practitioner.

Aesthetic effects (appearance, taste, odour) of turbidity can be mitigated or removed by filtration using household water filters if relatively small amounts of water are involved such as for food preparation and drinking.

**Criteria**

**Effects of Turbidity on Aesthetics and Human Health**

<p><b>Turbidity Range (NTU)</b></p>	<p><b>Effects</b></p>
<p><i>Target Water Quality Range</i> <b>0 - 1</b></p>	<p><i>No turbidity visible No adverse aesthetic effects regarding appearance, taste or odour and no significant risks of associated transmission of infectious micro-organisms. No adverse health effects due to suspended matter expected</i></p>
<p><b>1 - 5</b></p>	<p>No turbidity visible A slight chance of adverse aesthetic effects and infectious disease transmission exists</p>
<p><b>5 - 10</b></p>	<p>Turbidity is visible and may be objectionable to users at levels above 5 NTU. Some chance of transmission of disease by micro-organisms associated with particulate matter, particularly for agents with a low infective dose such as viruses and protozoan parasites</p>
<p><b>&gt; 10</b></p>	<p>Severe aesthetic effects (appearance, taste and odour). Water carries an associated risk of disease due to infectious disease agents and chemicals adsorbed onto particulate matter. A chance of disease transmission at epidemic level exists at high turbidity</p>

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# Vanadium

## Tentative Guideline

### Background Information

**Introduction** Vanadium is a white, soft, ductile metal, resistant to corrosion. Vanadium occurs in several oxidation states, namely II, III, IV and V. Soluble vanadium salts are readily taken up by living organisms. Vanadium salts and compounds are often highly coloured.

**Occurrence** Minerals containing vanadium are widespread and include vanadium sulphide and the calcium salt of vanadium. Metallic vanadium does not occur in nature. Vanadium(IV) and vanadium(V) salts are generally soluble in water and tend to remain in solution and are not strongly adsorbed onto soil particles. Compounds of vanadium such as trifluoride, trioxide and trisulphide are insoluble in water and are associated with sediments.

Typically, the concentration of vanadium in

- ! fresh water is less than 1 Fg/R; and
- ! sea water is approximately 3 Fg/R.

Vanadium compounds have various industrial applications and are used as catalysts in the chemical industry, in certain glassware and ceramic products, in the textile industry and in the manufacture of dyes.

**Interactions** Metabolically, vanadium interacts with **chromium** and **iron**.

**Measurement** The criteria are given in terms of the total vanadium concentration in units of mg/R. The reference method for the determination of vanadium is by atomic absorption spectrometry, using a nitrous oxide-acetylene flame. If other methods are used, their characteristics relative to the reference method should be known.

**Data Interpretation** Single-sample values should be used to compare with the criteria given and should be interpreted as maximal values, not to be exceeded. The concentrations of any associated chromium and/or iron should also be taken into account.

**Treatment Options** Vanadium in water supplies is most conveniently removed by raising the pH and precipitating the insoluble vanadium salts after the addition of lime or iron salts in the pH range of 8.5 - 11.5. Precipitation is followed by settlement and filtration as in conventional water treatment. The precipitation process requires careful monitoring to ensure that removal is complete.

To achieve very low residuals, it may be necessary to pass the stream through an ion exchange column charged with the appropriate resin.

A watery, vanadium-rich sludge or concentrate stream is generated in the processes that may present disposal difficulties.

## The Effects of Vanadium

**Norms** The norms used in the guidelines are human health effects.

**Effects** Total dietary intake of vanadium is of relevance in assessing the effects of vanadium rather than the contribution of vanadium in water *per se*. Information on the toxic threshold of vanadium in humans is rather sparse and animal studies suggest that there is a strong interaction between dietary composition and susceptibility to symptoms of vanadium poisoning.

Vanadium affects the metabolism of the amino acid cystine, resulting in a reduction of the concentration of coenzyme A. Symptoms of vanadium toxicity include conjunctivitis, rhinitis, a sore throat and a persistent cough. Exposure to high concentrations of vanadium can cause severe chronic bronchitis.

**Criteria** **Effects of Vanadium on Human Health**

Vanadium Range (mg/l)	Effects
<i>Target Water Quality Range 0 - 0.1</i>	<i>No health effects. Suitable for continuous, long-term intake</i>
<b>As a precautionary measure it is recommended that the TWQR not be exceeded due to the potentially acute and/or irreversible effects of vanadium on human health</b>	
0.1 - 1.0	Suitable for short-term intake, but symptoms of vanadium toxicity such as growth suppression and respiratory symptoms may occur with long-term intake in sensitive individuals
> 1.0	Not suitable for drinking water use Symptoms of vanadium toxicity may appear

**Note:**

The criteria are based on the allocation of 20 % of the probable total dietary intake of vanadium being attributable to water intake.

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# Zinc

## Background Information

<b>Introduction</b>	<p>Zinc is a metallic element. The stable oxidation states of zinc are the metal (0) and the +II oxidation state, which is the form found in nature. The carbonate, hydroxide and oxide forms of zinc are relatively resistant to corrosion and therefore zinc has many applications. The presence of zinc in domestic water arises mainly from the leaching of galvanised plumbing and fittings. Zinc is an essential nutritional trace element for plants and animals. Humans have a high tolerance level to elevated zinc concentrations, while fish are highly susceptible to poisoning.</p>
<b>Occurrence</b>	<p>The most common mineral form of zinc is the sulphide (sphalerite). Zinc is also found as a carbonate, oxide or silicate and may occur in association with many other metal ores such as copper and arsenic. The chloride, sulphate and nitrate salts of zinc are highly soluble in water, but at neutral and alkaline pH they hydrolyse to form relatively insoluble hydroxides which tend to be associated with sediments. On acidification of the water, the insoluble hydroxides are released back into solution. If the water is acidic, zinc leaching caused by dissolution of the protective zinc hydroxide layer of galvanised piping can give rise to relatively high concentrations of zinc in solution.</p> <p>The concentration of zinc in water is usually low, typically about 0.015 mg/R. Elevated zinc concentrations at neutral and alkaline pH arise where zinc occurs largely as a colloidal suspension of zinc hydroxide which imparts a milky white appearance to the water. In sea water the zinc concentration is also very low, typically about 0.005 mg/R.</p> <p>Zinc and zinc salts are used in many industrial processes. Zinc itself is extensively used in galvanising processes and in alloys. Zinc salts are used in paint pigments, in cosmetics and in the manufacture of pharmaceuticals, dyes and insecticides.</p>
<b>Interactions</b>	<p>Zinc strongly interacts with <b>cadmium</b>, to which it is chemically very similar. Zinc is an essential nutritional micro-element of relatively low toxicity, whereas cadmium, which is not essential, is highly toxic to all higher organisms. Metabolically, zinc interacts with <b>copper</b>. As is the case with all metals, the <b>pH</b> of the water determines the concentration of soluble zinc.</p>
<b>Measurement</b>	<p>The criteria are given in terms of the total zinc concentration in units of mg/R. Total zinc is measured after acidification of the sample by atomic absorption spectrometry, which is the reference method. If other methods are used, their characteristics relative to the reference method should be known.</p>
<b>Data Interpretation</b>	<p>Mean values should be used to compare with the criteria given. Zinc concentrations should also be interpreted in relation to the <b>pH</b> and the concentration of <b>suspended solids</b> and related metals, such as <b>cadmium</b> and <b>copper</b>.</p>
<b>Treatment Options</b>	<p>Zinc in water supplies is most conveniently removed by raising the pH and precipitating the insoluble zinc hydroxide with lime treatment in the pH range of 9.5 - 10.0. Precipitation is followed by settlement and filtration as in conventional water treatment.</p>

The precipitation process requires careful monitoring to ensure complete removal. A watery, zinc-rich sludge is generated in the process; this may present disposal difficulties.

## The Effects of Zinc

**Norms** The norms used in the guideline for zinc are primarily based on aesthetic effects.

**Effects** At concentrations sufficient to cause gastrointestinal disturbances, zinc imparts a bitter astringent taste, and an opalescent or milky appearance to water. It does not pose a hazard since the vomiting reflex is activated to rid the body of high levels.

**Mitigation** In view of the above, mitigatory measures are not necessary.

**Criteria** **Effects of Zinc on Aesthetics and Human Health**

Zinc Range (mg/l)	Effects
<i>Target Water Quality Range</i> 0 - 3	<i>No aesthetic or human health effects</i>
3 - 5	Slight opalescence or bitter taste. No health effects
5 - 10	Clearly discernable bitter taste and opalescence. No health effects
10 - 50	Bitter taste; strong opalescence. Some instances of chronic toxicity expected
50 - 700	Bitter taste; milky appearance. Acute toxicity with gastrointestinal irritation, nausea and vomiting
> 700	Bitter taste; milky appearance. Severe, acute toxicity with electrolyte disturbances and possible renal damage

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# **Chapter 6**

## **Glossaries**

# Glossary of terminology

<i>aerobic:</i>	organisms requiring molecular oxygen for respiration <i>or</i> conditions where oxygen is available
<i>aetiological:</i>	causative, as in causing disease
<i>adsorption/elution:</i>	the attachment of molecules or ions to, and their removal from, a substrate by manipulation of electrical charge or pH
<i>amphoteric:</i>	the capability of a substance to react as an acid or a base, hence of dissolving under basic or acidic conditions
<i>anaemia:</i>	an abnormal decrease in red blood cells (i.e. in their production, circulation and degeneration but not in homeostasis); the symptoms include, among others, listlessness, decreased physical capabilities, pale mucous membranes and increased pulse rate
<i>anaerobic:</i>	conditions lacking oxygen <i>or</i> organisms not requiring oxygen for respiration
<i>anions:</i>	negatively-charged ions
<i>anionic:</i>	characteristic behaviour or property of an ion that has a negative charge. Anions move to the anode in electrolysis
<i>ascariasis:</i>	a disease caused by helminthic parasites of the genus <i>Ascaris</i> , in man <i>A. lumbricoides</i>
<i>benthic:</i>	inhabiting the bottom of a water body
<i>biochemical oxygen demand (BOD):</i>	the amount of dissolved oxygen required to meet the metabolic needs of aerobic organisms in water rich in organic matter
<i>buffering capacity:</i>	a measure of the relative sensitivity of a solution to pH changes on addition of acids or bases
<i>calculus (calculi):</i>	the precipitation of various salts, usually inorganic, in the urine; this occurs mostly in males and includes symptoms such as uraemic poisoning; a ruptured bladder may occur
<i>carcinogenic:</i>	capable of causing, promoting or giving rise to the development of cancer
<i>cationic:</i>	the characteristic behaviour or property of an ion with a positive charge. Cations move to the cathode in electrolysis
<i>cations:</i>	positively-charged ions
<i>chemical oxygen demand (COD):</i>	the amount of oxygen required to oxidise all the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant
<i>chlorophyll (a, b):</i>	the green pigment in plants and algae which is a fundamental part of the process of photosynthesis which captures sunlight energy and converts into chemical

energy in the form of carbohydrates. Chlorophyll *a* and *b* are two forms of chlorophyll required in the biochemical reactions of photosynthesis. Chlorophyll is used as a measure of the amount of algae in water

<i>clarity:</i>	the depth to which light can penetrate in a water body and is measured by the depth to which a Secchi disk (a 20 cm-diameter disk printed with black and white quadrants) is visible
<i>coagulation:</i>	the separation or precipitation of particles in a dispersed state from a suspension resulting from their growth. This may result from the addition of an electrolyte (coagulant), prolonged heating or from a condensation reaction between a solvent and solute
<i>curds:</i>	solid particles formed when hardness interferes with soaps used in various washing operations in the textile industry
<i>cyanosis:</i>	the discolouration of the skin due to the presence of oxygen-deficient blood
<i>cytopathogenic or cytopathic:</i>	damage caused to cells
<i>dissolution:</i>	the process of dissolving
<i>electrodialysis:</i>	a process of selective diffusion through a membrane conducted with the aid of an electromotive force applied to electrodes on both sides of the membrane
<i>electron acceptor:</i>	is an atom or part of a molecule that receives electrons from other substances in a chemical reaction binding the substances together with a covalent bond
<i>epidemiology:</i>	the science or study of diseases in the community
<i>eutrophic:</i>	water, particularly in lakes and dams, which is high in nutrients and hence has excessive plant and algal growth
<i>flocculation:</i>	the addition of chemical reagents (flocculants) to bring small particles together in flocs through the process of <i>coagulation</i> , aggregation or biochemical reaction of fine suspended particles
<i>giardiasis:</i>	a disease caused by protozoan parasites of the genus <i>Giardia</i> , in man <i>G. lamblia</i>
<i>haematology:</i>	a study of the physiology of blood
<i>haemochromatosis:</i>	a metabolic disorder, especially in males, involving the accumulation of large amounts of iron in body tissues. This is accompanied by cirrhosis of the liver and progressive involvement of the pancreas and other organs
<i>haemoglobin:</i>	the protein occurring in the red blood cells of vertebrates and responsible for the transport of oxygen and carbon dioxide in the bloodstream
<i>haematocrit:</i>	the ratio of red blood cells to plasma
<i>haemorrhagic inflammation:</i>	inflammation due to the escape of blood from a ruptured blood vessel

<i>hard water:</i>	water that contains high concentrations of calcium, magnesium and to a lesser extent other alkaline earth metal ions, in solution. Under highly alkaline conditions, the calcium and magnesium of hard waters may precipitate out as scale or as some other insoluble salt of these two metal ions
<i>hardness:</i>	defined as the sum of the calcium and magnesium concentrations, both expressed as calcium carbonate, in milligrams per litre
<i>histopathology:</i>	the study of the structure of abnormal tissue. Examination of tissues after death may serve to identify the cause of death and possibly the causative agent
<i>hyperplasia:</i>	excessive development due to an increase in the number of cells
<i>hypertrophy:</i>	excessive development due to an increase in the size of cells
<i>hypoxia:</i>	lack of sufficient oxygen
<i>indole-positive:</i>	producing a positive reaction in a biochemical test for the production of indole
<i>ion exchange:</i>	the interchange of ions of like charge, usually on a solid medium and is used in water treatment, such as water softening
<i>leuco compounds:</i>	compounds of dyes in which the dye is in a reduced form. The original dye may be regenerated by oxidation processes
<i>macrophyte:</i>	any macroscopic form of aquatic vegetation: encompasses certain species of algae, mosses and ferns as well as aquatic vascular plants
<i>mesotrophic:</i>	a term applied to freshwater bodies that contain moderate quantities of plant nutrients and are therefore moderately productive
<i>methaemoglobin:</i>	haemoglobin with the haem iron in the ferric state and unable to bind oxygen. Produced by the action of an oxidising agent, e.g. nitrate
<i>methaemoglobinaemia:</i>	a condition, usually in infants, in which nitrite in the blood combines with the red blood pigment, haemoglobin, to form methaemoglobin. Unlike haemoglobin, methaemoglobin is incapable of carrying oxygen
<i>microbes:</i>	microscopic organisms such as bacteria or viruses
<i>mucilaginous:</i>	the tacky or slimy property of extracellular substances secreted by certain groups of bacteria, such as the slime-producing bacteria
<i>mutagenic:</i>	the capability of inducing mutations, e.g. chemicals, radiation
<i>mycobacteria:</i>	a family of parasitic, rod-shaped bacteria which often show irregular forms. Some species cause disease in man
<i>necrosis:</i>	the death of cells or tissues
<i>necropsy:</i>	the process of establishing the cause of death of cells or tissue
<i>organoleptic:</i>	characteristics of water that affect the sense organs, e.g. taste and odour



<i>osmoregulation:</i>	the regulation of the osmotic pressure of body fluids by controlling the amount of water and/or salts in the body
<i>osmosis:</i>	the diffusion of a solvent, usually water, through a semi-permeable membrane, into a more concentrated solution
<i>ozonation:</i>	disinfection using ozone
<i>palatability:</i>	acceptable, satisfactory taste
<i>pathogenic:</i>	causing disease
<i>permeability:</i>	the condition of allowing the passing of fluid molecules through a particular medium, such as soil, and others
<i>photosynthesis:</i>	the trapping of solar energy and its conversion to chemical energy by plants and algae, which use the energy in manufacturing food molecules from carbon dioxide and water
<i>physico-chemical:</i>	the physical (e.g. temperature, electrical conductivity) and chemical (e.g. concentrations of nitrate, mercury) characteristics of water
<i>point of use:</i>	the point in an industrial operation where the water is actually used in a process
<i>polyvalent metallic ions:</i>	ions of metals having more than one oxidation state, e.g. Cr(III) and Cr(VI)
<i>process water:</i>	water that may be used in a number of processes in the manufacture of a product, but is not part of the product
<i>raw water:</i>	source water in its untreated state
<i>redox potential:</i>	an expression of the oxidising or reducing power of a solution relative to a reference potential. This potential is dependent on the nature of the substances dissolved in the water, as well as on the proportion of their oxidised and reduced components
<i>reducing conditions:</i>	conditions prevailing within an aquatic environment in which the redox potential is such that substances become reduced
<i>reverse osmosis:</i>	a technique in the desalination of water in which pressure is applied to the surface of the saline solution, forcing pure water to pass through a semi-permeable membrane which prevents the passage of other ions
<i>scaling:</i>	the formation of a dense coating of predominantly inorganic material formed from the precipitation of water soluble constituents. The most common substances forming scale are carbonates and sulphates of calcium and magnesium hydroxide
<i>site-specific:</i>	conditions that are unique or specific to a certain site or locality
<i>sub-lethal:</i>	the concentration or dose of a toxic substance below the threshold which causes death
<i>supersaturation:</i>	refers to a solution containing more solute than equilibrium conditions will allow;

	unstable to the addition of solute crystals
<i>teratogenic:</i>	an agent or factor causing deformed embryos or offspring
<i>threshold concentration:</i>	the highest concentration of a water quality variable that can be tolerated before damage is done to the product or operation of a process and the machinery required for the process
<i>threshold odour number (TON):</i>	defined as the greatest dilution of a sample with odour-free water that yields a final odour which is just detectable by a panel of judges under carefully controlled conditions
<i>toxaemia:</i>	blood-poisoning or a disease of pregnancy with increased blood-pressure
<i>treatment breakthrough:</i>	the occurrence of contaminants in final water after treatment as a result of failure of a component of the treatment process. This is usually an isolated event with a clearly definable cause and effect, for example appearance of bacteria in treated water as a result of failure of chlorination
<i>trihalomethanes:</i>	organic molecules containing a single carbon atom on which hydrogen atoms have been replaced by halogens, generally either chlorine or bromine. Frequently formed during disinfection by chlorination or bromination
<i>valency:</i>	the number of electrons required to be gained or lost by an atom to reach a state where the outermost electron shell is full
<i>vascular plants:</i>	plants with woody conducting vessels (i.e. most terrestrial plants)
<i>zeolites:</i>	minerals consisting mainly of hydrous silicates of calcium, sodium and aluminium, which are able to act as cation exchangers and are utilised in the treatment of water to fulfil this function



## Glossary of abbreviations / acronyms

<b>ADI</b>	acceptable daily intake. Refers to a concentration of a chemical or substance which can be tolerated as a daily dose over a long exposure period, usually a lifetime. This is usually applied to toxic chemicals which do not have carcinogenic effects
<b>APHA</b>	American Public Health Association
<b>ASCE</b>	American Society of Civil Engineers
<b>AWWA</b>	American Water Works Association
<b>BOD</b>	biological oxygen demand
<b>COD</b>	chemical oxygen demand
<b>CSIR</b>	Council for Scientific and Industrial Research
<b>DOC</b>	dissolved organic carbon
<b>EC</b>	electrical conductivity
<b>EC</b>	European Community - in this document, the European Community (EC) is referred to as such when discussing it as an economic/political entity. Now changed to European Union (EU)
<b>ED</b>	electrodialysis
<b>EEC</b>	European Economic Community
<b>EDTA</b>	ethylenediamine tetra-acetic acid
<b>GAC</b>	granular activated carbon
<b>HCIO</b>	hypochlorous acid
<b>HPLC</b>	high performance liquid chromatography
<b>IAWPRC</b>	International Association for Water Pollution Research and Control
<b>MIB</b>	2-methyl isoborneol
<b>NAS/NAE</b>	National Academy of Sciences/National Academy of Engineering (USA)
<b>NOAEL</b>	no observed adverse effect level. Refers to that test concentration of a toxicant in a toxicological experiment at which no adverse effect on the test organism is observed or measured.
<b>NTU</b>	nephelometric turbidity units
<b>PAC</b>	powdered activated carbon

<b>PFU</b>	plaque-forming units
<b>PVA</b>	polyvinyl alcohols
<b>SD</b>	Secchi disk depth in metres
<b>TCID<sub>50</sub></b>	dose of virus required to cause 50 % infection in tissue culture
<b>TDS</b>	total dissolved solids
<b>THMs</b>	trihalomethanes
<b>TOC</b>	total organic carbon
<b>TON</b>	threshold odour number
<b>TSC</b>	tryptose-sulphate-cycloserine
<b>TWQR</b>	Target Water Quality Range
<b>US EPA</b>	United States Environmental Protection Agency
<b>WHO</b>	World Health Organization

## Glossary of units of measure

<b>Bq/R</b>	Becquerel per litre
<b>µg/R</b>	micrograms per litre
<b>meq/R</b>	milli-equivalents per litre
<b>mg/R</b>	milligrams per litre
<b>mM/R</b>	millimoles per litre
<b>ng/R</b>	nanograms per litre
<b>nm</b>	nanometre
<b>NTU</b>	nephelometric turbidity units
<b>TCID<sub>50</sub></b>	dose of virus required to cause 50 % infection in tissue culture
<b>EC</b>	degrees centigrade