Chemical safety of drinking-water: Assessing priorities for risk management

World Health
Organization

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Contents

Part A – Assessing and managing priorities

Part B – Identifying specific chemicals

Part C – Appendices

Tables

Foreword

Contamination of drinking-water is a significant concern for public health throughout the world.

Microbial hazards make the largest contribution to waterborne disease in developed and developing countries. Nevertheless, chemicals in water supplies can cause serious health problems – whether the chemicals are naturally occurring or derive from sources of pollution. At a global scale, fluoride and arsenic are the most significant chemicals, each affecting perhaps millions of people. However, many other chemicals can be important contaminants of drinking-water under specific local conditions.

Often, identification and assessment of risks to health from drinking-water relies excessively on analysis of water samples. The limitations of this approach are well recognized, and contributed to the delay in recognizing arsenic in drinking-water as a significant health concern in Bangladesh and elsewhere. To overcome such limitations, the latest edition of the World Health Organization (WHO) *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) emphasizes effective preventive management through a "framework for drinking-water safety" that incorporates "water safety plans".

Effective preventive management of chemicals in drinking-water requires simple tools for distinguishing the few chemicals of potential local or national concern from the unmanageably long list of chemicals of possible significance. The aim is to identify and prioritize the chemicals of concern, to overcome the limitations of direct analysis of water quality, and ensure that limited resources are allocated towards the monitoring, assessment and control of the chemicals that pose the greatest health risks.

Identifying and prioritizing chemical risks presents a challenge, especially in developing countries, because information on the presence of chemicals in water supplies is often lacking. This document provides guidance to help readers to meet that challenge. It shows how information on aspects such as geology and industrial and agricultural development, which is often readily available, can be used to identify potential chemical contaminants (and potential sources of chemicals), from catchment to consumer, and thus prioritize risks.

As a supporting document to the *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006), this publication is aimed at policy-makers, regulators, managers and public health practitioners at national and local level. It is divided into three parts:

➔ *Part A* provides general guidance on using limited information in prioritizing chemicals in drinking-water for risk management. The need for such guidance is outlined in Chapter 1, which also describes the administrative and policy context. Chapter 2 describes the principles applied in prioritizing chemicals, provides information on some factors that affect chemical concentrations along pathways, and highlights several specific chemicals that are frequently considered priorities because of their widespread occurrence or significant health effects. Chapter 3 discusses the role of drinking-water standards and guidelines, and provides an overview of contemporary water quality management procedures.

➔ *Part B* provides practical guidance on identifying specific chemicals that are likely to be of concern in individual water supply systems. It groups chemical contaminants into five categories on the basis of their potential sources: naturally occurring, from agriculture activities, from human settlements, from industrial activities, and from water treatment and distribution processes themselves.

➔ *Part C* comprises the appendices. It includes guidance on the most likely sources of potential contaminants and on identifying chemicals that could be of concern in particular circumstances. The appendices address potential sources of chemicals considered in the WHO drinking-water guidelines (WHO, 2004; WHO, 2006), chemicals potentially discharged in effluents from industrial sources, and the association of pesticides with crops and crop types. This information is presented in an accessible format that will help users to determine the chemical hazards that can arise in the catchment, in treatment and in distribution, in large, medium and small water supplies.

Many experts worldwide contributed to this work over a period of several years, beginning with the *1st Meeting of Experts on Monitoring Chemicals in Drinking Water*, held in Bangkok, Thailand, in January 2001. This was followed by the *2nd Meeting of Experts on Monitoring Chemicals in Drinking Water*, also held in Bangkok, in December 2001. Both meetings were sponsored by WHO and hosted by the Department of Health, Ministry of Public Health, Thailand. The draft guidance document was subsequently tested in a series of field trials in 2002–2003 in Indonesia, Fiji, Nepal, Mongolia, the Philippines and Thailand. Lessons learnt through the field trials provided feedback that was valuable in revising and finalizing the document.

Readers should note that while this publication has been developed as a supporting document for, and with reference to, the *Guidelines for Drinking-water Quality*, the guidelines themselves are frequently updated and the latest information should always be sought by reference to relevant World Health Organization publications and web site.
(http://www.who.int/water_sanitation_health/dwq/guidelines/en/index.html)

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Abbreviations and acronyms

AMD	acid mine drainage
BGS	British Geological Survey
BTEX	benzene, toluene, ethylbenzene and xylenes
DDT	dichlorodiphenyltrichloroethane
EDTA	ethylenediaminetetraacetic (edetic) acid
FAO	Food and Agriculture Organization of the United Nations
GDWQ	WHO *Guidelines for Drinking-water Quality*
HAA	haloacetic acid
MTBE	methyl tert-butyl ether
NTA	nitrilotriacetic acid
PAH	polycyclic aromatic hydrocarbon
PTWI	provisional tolerable weekly intake
PVC	polyvinyl chloride
TBA	terbuthylazine
TBTO	tributyltin oxide
TDS	total dissolved solids
THM	trihalomethane
UN	United Nations
WHO	World Health Organization
WHOPES	WHO Pesticide Evaluation Scheme

A

Assessing and managing priorities

1

Introduction

1|1

The need for guidance on assessing priorities for risk management

Safe drinking-water is a basic need for human development, health and well-being, and because of this it is an internationally accepted human right (WHO, 2001). This document provides guidance on the chemical safety of drinking-water. Chemical contaminants of drinking-water are often considered a lower priority than microbial contaminants, because adverse health effects from chemical contaminants are generally associated with long-term exposures, whereas the effects from microbial contaminants are usually immediate. Nonetheless, chemicals in water supplies can cause very serious problems.

Nitrate in ground and surface water associated with agricultural activity was one of the earliest chemicals to cause general concern among public health authorities and water suppliers. More recently, the presence in groundwater of naturally occurring chemicals, such as arsenic and fluoride, has caused widespread exposure and unacceptable health effects in many countries. Also, there are examples from around the world of waste discharges from industrial developments and human settlements that have contaminated water supplies. Thus, there is a clear need to take into account chemical contaminants in developing risk management strategies for the safety of drinking-water.

Theoretically, it is possible to assess at a national or local level the health risks from chemicals in drinking-water for every chemical for which a guideline has been set. The World Health Organization (WHO) has published procedures for assessing chemical health risks (WHO, 1994; WHO, 1999). These assessments may be used to manage chemical risks to water safety by the development of control and monitoring programmes, and of national standards for drinking-water quality. However, to make such assessments and develop management strategies for every chemical would be impractical and would require considerable resources, posing problems for many countries. A more effective approach where resources are limited is to identify and focus on those priority chemicals for which significant human exposure is expected to occur, recognizing that priorities may vary from country to country, and within countries.

In many countries, the development of appropriate risk management strategies is hampered by a lack of information on the presence and concentration of chemicals in drinking-water. Water authorities attempting to identify priority chemicals despite having limited information would benefit from guidance on simple and rapid assessment methods. These could be applied at a national or local level to provide a shortlist of priority chemicals, which could then be more rigorously assessed for health risks. The present publication seeks to meet the need for such guidance.

1|2

Objective

The objective of this publication is to help users at national or local level to establish which chemicals in a particular setting should be given priority in developing strategies for risk management and monitoring of chemicals in drinking-water. The document will be useful to public health authorities, those responsible for setting standards and for surveillance of drinking-water quality, and water supply agencies responsible for water quality management.

In particular, this publication will be applicable in settings where information on actual drinking-water quality is limited, which is the case in many developing countries and in rural areas of some developed countries.

Once priority chemicals have been identified, subsequent risk management strategies may include setting standards, monitoring and control.

1|3

Background

The WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) cover both microbial and chemical contaminants of drinking-water and describe in detail the scientific approaches used in deriving guideline values for those contaminants. They thus provide sound guidance for ensuring an appropriate level of safety and acceptability of drinking-water for the development of national standards, while taking into consideration the specific problems and cultural, social, economic and environmental conditions of a particular country.

The criteria for including specific chemicals in the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) are any of the following:

- there is credible evidence of occurrence of the chemical in drinking-water, combined with evidence of actual or potential toxicity
- the chemical is of significant international concern
- the chemical is being considered for inclusion, or is included, in the WHO Pesticide Evaluation Scheme (WHOPES) programme (approval programme for direct application of pesticides to drinking-water for control of insect vectors of disease).

Applying these criteria, the guidelines list nearly 200 chemicals for which guideline values have been set or considered (WHO, 2004; WHO, 2006). This number may change over time.

It is important to note that the lists of chemicals for which WHO guideline values have been set do not imply that all those chemicals will always be present, nor do they imply that specific chemicals for which no guideline values currently exist will not be present in a water supply. However, it is not necessary for national or local authorities to develop risk management strategies for each and every chemical for which guideline values have been set, but rather to identify and select those chemicals that may be of greatest priority for risk management purposes in the particular setting.

1|4

Administrative and policy context

Many countries currently have administrative processes that could form part of a risk management approach for drinking-water quality. Some of the processes commonly carried out are described below.

- *Formation of interagency committee.* National policy and legislation frequently assign clear responsibility to specific agencies for various aspects of drinking-water quality management (e.g. risk assessment, standard setting, surveillance and control). Concerned authorities, such as public health, environmental, water resources, water supply, agricultural, geological, industrial and commercial authorities, often establish an interagency committee as a mechanism for sharing information, building consensus and coordination.
- *Review of national and international standards, guidelines and practices*. National authorities are frequently guided in their decision-making by the norms and guidelines of international and regional bodies, and by the standards and practices of developed countries, neighbouring countries and countries having similar cultural, social, economic and environmental conditions. These norms and guidelines may be useful as a starting-point for establishing a management strategy, particularly in the absence of other information.
- *Known problems are given priority.* Many countries, and many individual water supply organizations, have already identified a number of drinking-water quality issues through years of experience, and have made such issues their highest priority for risk management. This is especially true if the issues have caused obvious health effects or aesthetic problems.
- *Consideration of available resources.* Decisions on implementing risk management strategies for chemicals in drinking-water are frequently constrained in practical terms by the resources available for sampling and testing. Constraints may include human resources, field equipment, and transportation and laboratory resources. Therefore, setting priorities requires objective and pragmatic consideration of the resources available.
- *Consideration of feasibility of control.* National authorities sometimes debate whether resources should be allocated to monitoring chemicals that the country or water supply organization lacks the resources to control. Depending on the potential for adverse health effects, it is often desirable to build up a water-quality database so that an informed analysis can be made of the costs and benefits of controlling such chemicals.

These administrative practices are valid and useful, but may not fully meet the needs of water authorities that need to select a limited number of chemicals as priorities from among the many that could be under consideration. For example:

- the various interests represented in interagency committees frequently bring their own particular priority chemicals into discussions, and these chemicals may not necessarily be of high priority from a health perspective;
- international norms and standards set by other countries may not be representative of the particular environmental, cultural, social or economic conditions of the country in question.

Limiting the number of chemicals to be managed on the basis of available resources for monitoring or control, without consideration of the potential for health effects associated with particular chemicals, could result in unacceptably high levels of hazardous chemicals in drinking-water. A more rational way to set priorities is needed. The present document is intended to meet this need by providing a simple, rapid and rational basis for assigning priority to specific chemicals, which can complement administrative practices at local or national level.

1|5

How to use this publication

Figure 1.1 shows the overall risk management strategy for identifying priority chemicals at local or national level. It is assumed that those using this publication are familiar with the principles for assigning priority to chemicals, as discussed in Chapter 2 of this document, and have a good understanding of the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006).

Except in very simple water supply systems, the application of this guidance normally requires collaboration by a multidisciplinary working group, made up of professionals with at least a university degree or equivalent. The composition of the working group will vary according to the particular sources of chemicals within the study area, but normally it requires some combination of expertise in geology, public health, agriculture, water chemistry and engineering.

Initially, the probability that specific chemicals may be present in a water system can be assessed by applying the techniques described in Part B of this document – *Identifying specific chemicals*. The chapters in Part B, listed in Table 1.1, consider chemicals according to their potential source category.

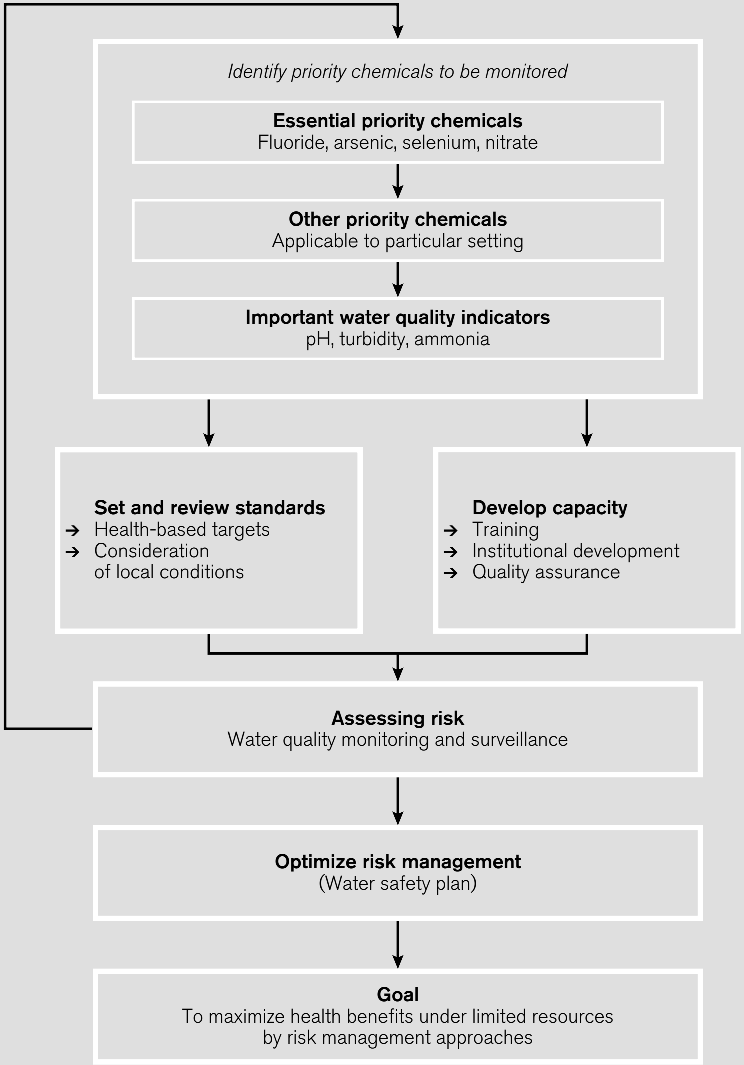
Table 1.1 | Categorization of sources of chemicals in drinking-water

Chapter number	Source	Examples
4	Naturally occurring chemicals (including naturally occurring algal toxins)	Rocks and soils, cyanobacteria in surface water
5	Chemicals from agricultural activities (including pesticides)	Application of manure, fertilizer and pesticides; intensive animal production practices
6	Chemicals from human settlements (including those used for public health purposes; for example, for vector control)	Sewage and waste disposal, urban runoff, fuel leakage
7	Chemicals from industrial activities	Manufacturing, processing and mining
8	Chemicals from water treatment and distribution	Water treatment chemicals; corrosion of, and leaching from, storage tanks and pipes

The great majority of chemicals that may be of concern in drinking-water are associated with these five source categories, but other sources not considered in this publication may occasionally be important. Examples of other sources are military operations and facilities, and accidental or intentional contamination of water supplies. These situations need to be assessed on a case-by-case basis, and may require highly specialized expertise.

The techniques described in Part B generally entail collecting, collating and interpreting data and information on risk factors associated with the occurrence of chemicals in each source category. The data and information sources to be consulted are usually somewhat broader than those traditionally familiar to public health authorities and water supply agencies. They may include geological surveys, agricultural, industrial and commercial authorities, customs agencies and others.

Figure 1.1 | Risk management strategy for the identification of priority chemicals



By applying the techniques described in this publication, users can make informed judgements as to whether or not specific chemicals in each source category are likely to result in significant exposure of consumers. These judgements may be recorded on the worksheet provided in Appendix 1. That appendix lists all of the chemicals for which guideline values have been established in the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) and leaves space for users to add other chemicals that may be of local concern.

1|6

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2

General principles and basis for prioritizing chemicals

2|1

Principles for assigning priorities for risk management

The two main criteria for identifying specific chemicals of concern to public health in any particular setting are:

- high probability of consumer exposure from drinking-water
- significant hazard to health.

Chemicals judged to be more likely to occur and to be highly hazardous to human health should be given greater priority for risk management than those judged less likely to occur in the drinking-water and to have lower health hazards. The period of exposure should also be considered, because health effects caused by chemicals in drinking-water generally result from long-term exposure. Few chemicals in drinking-water have been shown to cause acute health problems in the short term, except through intentional or accidental contamination on a large scale. In such instances, the water frequently (but not always) becomes undrinkable due to unacceptable taste, odour or appearance (WHO, 2004; WHO, 2006).

Risk management strategies for chemicals in drinking-water should also take into account the broader context. For example, if drinking-water is not the main route of exposure for a chemical, then controlling levels in water supply systems may have little impact on public health. Thus, risk management strategies need to consider alternative routes of exposure (e.g. food) that equal or surpass the importance of exposure through drinking-water (WHO, 2004; WHO, 2006). The management strategies should also consider national and local disease surveillance data, and epidemiological studies (provided that these are available and reliable). Unusual prevalence of certain illnesses in the community (e.g. arsenicosis) may justify an investigation of specific chemicals in drinking-water. Often, disease surveillance data or relevant epidemiological studies are not available at community level; therefore, other approaches are needed. Section 2.2 (below) provides guidance on assigning priorities in situations where data are limited.

Where there are adequate data on drinking-water quality, it may be possible to establish priorities for managing risks due to chemicals simply by studying such data. However, in many locations these data too may be lacking, and limited resources may mean that it is impractical to attempt to conduct comprehensive field studies on a broad range of chemicals in drinking-water. In such situations, it is important to focus available resources on investigations of a limited number of chemicals that are likely to occur in drinking-water at concentrations near or exceeding guideline values. Similarly, any initiatives to build national or local capacity for sampling and analysis through equipment procurement or training should be targeted at chemicals that have been identified as priorities through a methodical desktop analysis.

Priority should also be assigned to chemicals in drinking-water that may significantly degrade aesthetic quality or cause significant problems for the operations and maintenance of water supply systems. While aesthetic considerations may not have a direct impact on public health, changes in taste, odour or appearance of drinking-water may prompt some consumers to turn to other sources of drinking-water that may be microbiologically unsafe. Similarly, chemicals that cause operational problems, such as corrosion or encrustation of distribution systems, may have an indirect impact on public health by compromising the ability to maintain the water supply.

2|2
Setting priorities with limited information

Identifying chemicals of concern to public health in drinking-water is based on the hazard to health of those chemicals and the probability of exposure. In many parts of developing countries, and in rural areas of some developed countries, water quality data are limited or nonexistent, making it difficult to determine priorities for risk management based on both criteria. In such cases, the priority for risk management must be determined on the probability of exposure alone.

Health-based targets for chemicals (e.g. the guideline values in the WHO *Guidelines for Drinking-water Quality* – WHO, 2004; WHO, 2006) are concentrations that would generally not have a negative health impact if consumed over a lifetime. Therefore, the likelihood of a particular chemical occurring at concentrations that would cause health impacts is the most appropriate indicator that the chemical may be of concern in such situations.

Human exposure to any particular chemical through drinking-water requires a source of that chemical and a pathway from the source of contamination to the consumer. Pathways for transport of chemicals may be through natural features such as aquifers, surface water bodies, soils and rock, or overland flow, or through human-made components of water supply systems.

The concentration of a chemical in water may be reduced before the water reaches consumers – physical, chemical and biological processes may reduce the concentration of particular chemicals between their sources and consumers. For example, human-made interventions, such as drinking-water treatment, are a well-known means of lowering chemical concentrations, and many natural processes will also significantly reduce chemical concentrations in drinking-water (as discussed in Section 2.3, below). Specialized expertise may be needed to rigorously evaluate the effects of such processes in any particular setting, but a general understanding of the processes may enable informed judgements to be made that may be adequate for decision-making purposes. The ability of general and specific water treatment processes to achieve concentrations of chemicals below their respective guideline values is discussed in the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006). Where detailed information about reduction in concentration of a chemical as it travels from water source to consumer is lacking, an initial conservative approach would be to assign priority for management of chemicals in drinking-water solely on the likelihood of the occurrence and estimated concentration of those chemicals in a particular setting.

The presence of a particular chemical in drinking-water does not necessarily result in human exposure to a concentration that may cause concern; for example, the concentration of the chemical may be well below the guideline value. Part B of this publication provides guidance on assessing the likely occurrence of chemicals associated with the main sources of chemicals in drinking-water.

Appendix 1 includes a summary of potential sources of all chemicals for which guideline values have been set or considered.

2|3

Factors affecting chemical concentrations along pathways

As indicated above, chemicals that occur within a catchment may not necessarily be present in drinking-water in significant concentrations, because water treatment and natural processes can reduce the concentrations of particular chemicals between their source and the consumer. The principal natural processes involved are discussed briefly below.

2|3|1 Mixing and dilution

Mixing of source water as it enters a stream, river or lake will lower the concentrations of specific chemicals if the levels of those chemicals are lower in the receiving body of water. (Similarly, dilution by mixing two sources of water in a water supply system can reduce chemical concentrations.) Thus, larger water bodies with high flow rates and good mixing characteristics may be less vulnerable to chemical contamination from discharges or runoff than smaller sources with low volumes and flow rates.

2|3|2 Volatilization

Organic chemicals with a low boiling-point, such as some chlorinated solvents, frequently disperse from surface water by volatilization, particularly if the water is turbulent. Such chemicals are known as volatile organic compounds.

2|3|3 Adsorption

Both inorganic and organic chemicals may be adsorbed to soil, sediment or rock, particularly in the presence of clay, or of soils or sediment rich in organic carbon. Adsorption can occur as water percolates through soil or rock, or as it flows over sediments. However, this process is less significant for inorganic chemicals at low pH. In the case of organic chemicals, those with a high octanol/water partition coefficient (i.e. those that are more fat soluble) are more likely to adsorb to soil, or to sediments and particles in the water column than chemicals with a low coefficient. This effect can be a major factor in reducing the mobility of chemicals in the environment and reducing their concentration in water. Water treatment processes designed to act as barriers to pathogens (e.g. coagulation and filtration) will remove particles and will thus significantly reduce the concentrations of substances that are adsorbed to particles.

2|3|4 Chemical environment

Metals such as iron and copper are generally most soluble in acidic water (i.e. $pH < 7$), and solubility increases as the pH drops. Other metals, such as aluminium and zinc, are more soluble in alkaline water, especially when the pH is above 10. In mildly acidic water (i.e. pH 4.5–6.5), metals such as iron and copper have a low solubility under extreme anaerobic and aerobic conditions. This is due to the formation of sulfide minerals that have a low solubility under highly anaerobic conditions, and the formation of low-solubility hydroxide and oxide minerals under highly aerobic conditions.

2|3|5 Biological degradation

Many microorganisms can break down organic chemicals in the environment. For a lot of chemicals, this is one of the most important mechanisms for reducing environmental concentrations, and it is particularly important in soils and sediments.

2|3|6 Groundwater vulnerability

Groundwater is abstracted from many different types of aquifers, some of which may be highly susceptible to pollution as a consequence of human activity. The vulnerability of groundwater sources is important when assessing the risks to groundwater posed by various activities. Some aquifers are protected by one or more layers of impermeable material, such as clay, that lie above the saturated zone and that will prevent or retard the transport of chemicals from their sources to the saturated zone. Also, aquifers at certain depths may be protected from chemicals (even from some naturally occurring chemicals) that may be present at other depths in the geological profile.

2|4
Frequent priorities for risk management

As discussed above, for risk management purposes, priority should be assigned to specific chemicals on the basis of site-specific assessments. However, it is also important to pay particular attention to chemicals that have been found in many locations worldwide to present serious human health hazards due to exposure through drinking-water. These chemicals are mentioned below and are discussed in greater detail in the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006).

2|4|1 Fluoride, arsenic and selenium

Fluoride, arsenic and (to a lesser extent) selenium are naturally occurring chemicals that have been responsible for severe health effects due to exposure through drinking-water in many countries. Their distribution in groundwater is widespread and their possible presence in surface water should not be ruled out, because groundwater discharge is frequently a major contributor to surface water bodies.

2|4|2 Nitrate

Nitrate may be naturally occurring, although its presence in drinking-water is more often associated with contamination by excessive use of fertilizers (both inorganic and organic), in combination with inappropriate farming practices and/or sewage. This chemical occurs widely throughout the world in both groundwater and surface water, and presents a particular problem in shallow wells. Nitrate is a major problem for bottle-fed infants, in whom the risk of methaemoglobinaemia (“blue-baby syndrome”), increases as the concentration of nitrate rises above 50 mg/L. The risk is increased by the presence of nitrite, which is a much more potent methaemoglobinaemic agent than nitrate, and by the presence of microbial contamination, which can lead to gastric infections in infants.

2|4|3 Iron and manganese

Significant concentrations of iron and manganese occur throughout the world. Although these chemicals are not suspected of causing direct health effects through their presence in drinking-water, they can cause severe discolouration of water, which may lead to consumers turning to other, microbially unsafe sources of drinking-water. Iron and manganese also frequently cause operational problems.

2|4|4 Lead

The presence of lead in drinking-water can cause severe health effects and is primarily a consequence of the use of lead plumbing and lead-containing metal fittings in buildings. Although lead may be present in source waters, this is unusual except in some mining areas. Generally, lead is not a high priority for routine monitoring programmes because of the variability from building to building, but possible risks posed by lead in drinking-water should be assessed in localities where lead has been extensively used in plumbing materials, particularly if the water supplied is corrosive or is likely to dissolve lead. If lead concentrations significantly exceed guideline values, it may be appropriate to apply mitigating measures, such as corrosion control or replacement of pipes and plumbing materials. This is discussed further in Chapter 8.

2|5

References

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3

Developing and implementing risk management strategies

3|1

Identifying priority chemicals in a drinking-water supply

Many different chemicals may occur in drinking-water; however, only a few are important in any given circumstance. Of particular importance are adverse health outcomes relating to chemical constituents of drinking-water arising primarily from prolonged exposure. It is extremely unlikely that all the chemicals included in the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) will be present in a drinking-water supply system. Consequently, it is important that countries identify those chemicals of concern according to local circumstances. Chemical contaminants in drinking-water should be prioritized to ensure that scarce resources are not unnecessarily directed towards management of chemicals that pose no threat to health and do not affect the acceptability of drinking-water.

As it is neither physically nor economically feasible to test for all chemical constituents in drinking-water, monitoring efforts and resources should be carefully planned and directed at significant or key parameters.

The process outlined in this publication provides guidance to assist water supply utilities, in collaboration with public health authorities, to identify those chemicals that are likely to be present in an individual water supply, and may represent a potential public health risk. Identifying such chemicals is achieved by developing an understanding of the characteristics of the drinking-water catchment, including natural influences on groundwater and surface water, the types and size of industrial and agricultural activities, and human settlements within a catchment. Treatment and distribution of drinking-water also influence the final quality of water delivered to the consumer. In addition, chemicals, materials and processes used in the production and distribution of water will influence the chemical quality of drinking-water.

In assessing the chemical quality of a water supply, it is important to include the four priority chemicals (fluoride, arsenic, selenium and nitrate) first, before assessing the water supply system for chemicals of local concern. Extensive international experience has shown that these four chemicals produce adverse health effects as a consequence of exposure through numerous water supplies around the world. Two other commonly occurring constituents, iron and manganese, are of high priority because they can give rise to significant discolouration of drinking-water, making it unacceptable to consumers, who may turn to supplies that are more aesthetically acceptable but may be microbiologically contaminated.

Once priority chemicals within a particular drinking-water system have been identified, a management policy should be established and implemented to provide a framework for the prevention and reduction of these chemicals. Appropriate monitoring programmes should be established to ensure that the chemical quality of drinking-water remains within appropriate national standards.

3|2

Drinking-water standards and guidelines

Every country should have a policy on drinking-water quality. This would normally embody different approaches depending on whether formal responsibility for drinking-water quality is assigned to a defined entity, or whether community management prevails.

Effective national programmes to control drinking-water quality depend ideally on the existence of adequate legislation, standards and codes. The precise nature of the legislation in each country will depend on national, constitutional and other considerations. Generally, the legislation should outline the responsibility and authority of a number of agencies, describe the relationship between them and establish basic policy principles.

The nature and form of drinking-water standards may vary between countries and regions – no single approach is universally applicable. It is essential in the development and implementation of standards to take into account current and planned legislation relating to the water, health and local government sectors and to assess the capacity of potential regulators in the country. Approaches that may have worked in one country or region do not necessarily transfer to other countries. It is essential that each country undertake a review of its needs and capacity for drinking-water standards before embarking on the development of a regulatory framework. This review should include an assessment of existing and future supporting activities.

Standards developed by countries should be applicable to large metropolitan and small community piped systems, and also to non-piped drinking-water systems in small communities and individual dwellings. National and regional standards should be developed from the scientific basis provided by the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006), adapted to take account of local or national environmental, sociocultural (including dietary) and economic conditions. The guidelines provide further information on the development and implementation of national standards.

3|3

Overview of management procedures

The implementation of a successful risk management strategy requires the development of an understanding of those hazards that may impact on the quality of water being provided to a community. A wide range of chemicals in drinking-water could potentially cause adverse human health effects. The detection of these chemicals in both raw water and in water delivered to consumers is often slow, complex and costly, which means that detection is too impractical and expensive to serve as an early warning system. Thus, reliance on water-quality determination alone is insufficient to protect public health. As it is neither physically nor economically feasible to test for all drinking-water quality parameters, monitoring effort and resources should be carefully planned and directed at significant or key characteristics.

A preventive management strategy, operating from the water catchment to the tap, should be implemented to ensure drinking-water quality. The strategy should combine protection of water sources, control of treatment processes and management of the distribution and handling of water.

The management procedures developed by water suppliers can be described as a water safety plan. Such a plan, which is the basis of ensuring water safety, contains three key components:

- A full system assessment to determine whether an existing or planned drinking-water supply is capable of meeting health-based targets.
- Identification of measures that will control identified risks and ensure that those health-based targets are met within the system. For each measure, appropriate monitoring procedures should be defined to ensure that deviations from performance criteria are quickly detected.
- Development of management plans to describe actions to be taken during normal operation or incident conditions and to document the system assessment (including upgrades and improvements), monitoring and communication plans and supporting programmes.

The water safety plan should address all aspects of the water supply and should focus on the control of water production, treatment and delivery of drinking-water, up to the point of consumption. The plan provides the basis for a process control methodology to ensure that concentrations of chemicals are acceptable.

Development of water safety plans is discussed in detail in the *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) and in the WHO *Water Safety Plans* (Davison et al. 2005).

3|3|1 Health-based targets

For individual constituents of drinking-water, health-based targets are established. These targets represent a health risk from long-term exposure, in a situation where fluctuations in concentration are small or occur over long periods. It is important that such targets are defined by the relevant local authority, are realistic under local operating conditions and are set to protect and improve public health.

A health-based target specifies the agreed criteria for the quality of water delivered to the consumer. It is used to evaluate the adequacy of existing installations and to assist in verification (through inspection and analysis).

Table 3.1 presents an overview of the health-based targets. For further information on the development and application of health-based targets, refer to the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006)

Table 3.1 | Health-based targets for application to microbial and chemical constituents of drinking-water

Type of target	Nature of target	Typical application	Assessment
Health outcome *– epidemiology based*	Reduction in disease incidence or prevalence	Microbial or chemical hazards with high measurable disease burden, largely water-associated	Public health surveillance and analytical epidemiology
– risk assessment based	Tolerable level of risk by contaminants in drinking-water, absolute or as a fraction of the total burden by all exposures	Microbial or chemical hazards in situations where disease burden is low and cannot be measured directly	Quantitative risk assessment
Water quality	Guideline value applied to water quality	Chemical constituents with effects on health or acceptability of drinking-water	Periodic measurement of chemical constituents to assess compliance with relevant guideline values (see GDWQ Chapter 8)
	Guideline values applied in testing procedures for materials and chemicals	Chemical additives and by-products	Testing procedures applied to the materials and chemicals to assess their contribution to drinking-water exposure taking account of variations over time (see GDWQ Chapter 8)
Performance	Generic performance target for removal of groups of microorganisms	Microbial contaminants	Compliance assessed through system assessment and operation monitoring (see GDWQ Chapter 4)
	Customized performance targets		Individually reviewed by public health authority; assessment would then proceed as above
	Guideline values applied to water quality	Threshold chemicals with effects on health that vary widely (e.g. nitrate and fluoride)	Compliance assessed through system assessment and operation monitoring (see GDWQ Chapter 4)
Specified technology	National authority specifies processes to adequately address constituents with potential health effects (e.g. generic water safety plans for an unprotected catchment)	Constituents with potential health effect in small municipalities and community supplies	Compliance assessed through system assessment and operation monitoring (see GDWQ Chapter 4)

For individual countries, guideline values are the first step towards establishing specific health-based targets for their particular circumstances, based on local and regional determinants.

3|3|2 System assessment

Drinking-water quality can vary significantly throughout the system, and any assessment of the drinking-water supply should aim to determine whether the final quality of water delivered to the consumer is capable of meeting established health-based targets. The assessment needs to take into consideration the behaviour of individual constituents or groups of constituents that may influence water quality. It also needs an understanding of source quality. These influences require expert input. If the assessment indicates that the system is unlikely to be able to meet the targets, this means that the targets are unrealistic under current operating conditions.

A comprehensive assessment of the water supply is essential in the development of a preventive approach to the management of drinking-water quality. Such an assessment should be undertaken through a desktop study of the water supply, combined with site visits. Although many chemicals can be of health concern, the true nature and severity of their impact often remains uncertain (Howard, 2001). When assessing the chemical constituents of drinking-water, the following factors should be carefully considered before undertaking more extensive, and often expensive, analysis of the water:

- What is the extent of the problem – is there strong evidence that the chemicals are present in water sources or are likely to be present?
- What is the relevant contribution from drinking-water sources compared with other sources (e.g. food)?
- How severe is the potential health concern in the context of other health problems?

Unless there is strong evidence that particular chemicals are currently found or will be found in the near future, at levels that may compromise the health of a significant proportion of the population, the inclusion of those chemicals in drinking-water monitoring programmes is not justified, particularly where resources are limited. It is often more effective to maintain an ongoing programme of pollution control and risk assessment in the catchment.

3|3|3 Operational monitoring

Operational monitoring involves planned observations or measurements to assess whether the critical components of a safe water supply are operating properly. If the components are operating properly collectively, the system should be able to meet water quality targets.

In most cases, operational monitoring is based on simple and rapid observations or tests, such as turbidity or structural integrity, rather than complex chemical analyses. The complex tests are generally applied as part of verification activities rather than routine operational monitoring.

In order to have confidence that the chain of supply is not only operating properly, but to confirm that water quality is being maintained and achieved, verification is required. Verification is the use of methods, procedures or tests, in addition to those used in operational monitoring, to determine whether the water safety plan complies with the stated objectives outlined in the water quality targets, or whether it needs to be modified and revalidated.

3|3|4 Management procedures

Management procedures outline requirements in both normal operational situations and in incident situations where a loss of control of the system occurs. The management procedures should also outline practices and other supportive measures required to ensure optimal operation of the drinking-water system. Targets, assessment and operational monitoring provide information needed for the development of management procedures.

3|3|5 Surveillance

Surveillance of drinking-water quality is the continuous and vigilant public health assessment and overview of the safety and acceptability of drinking-water supplies. It contributes to the protection of public health by promoting improvements of the quality, quantity, access, affordability and continuity of water supplies. The role of the surveillance agency is complementary to the quality control function of the drinking-water supply agency. Surveillance does not remove or replace the responsibility of the water supply agency to ensure that a water supply is of acceptable quality and meets predetermined health-based (and other) performance targets.

Surveillance is based on a systematic programme of surveys and audits, including regular sanitary inspections and field surveys, as well as laboratory testing that provides recommendations for remedial actions.

3|4
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B

Identifying specific chemicals

4

Naturally occurring chemicals

4|1
General

There are a number of sources of naturally occurring chemicals in drinking-water. All natural water contains a range of inorganic and organic chemicals. The inorganic chemicals derive from the rocks and soil through which water percolates or over which it flows, whereas the organic chemicals derive from the breakdown of plant material or from algae and other microorganisms growing in the water or on sediments. Most of the naturally occurring chemicals for which guidelines have been developed or which have been considered for guideline development are inorganic. Many of the health problems caused by chemical constituents in water supplies throughout the world are due to chemicals of natural origin rather than those from human-made pollution.

4|1|1 Approach to dealing with naturally occurring chemicals

The approach to dealing with naturally occurring chemicals will vary according to the nature of the chemical and the source. For inorganic contaminants, which come from rocks and sediments, it is important to screen possible water sources to determine whether the source is suitable for use or whether it will be necessary to treat the water to remove chemical contaminants of concern along with microbial contaminants. Where a number of different sources of drinking-water are available, dilution of a body of water containing high levels of a contaminant with one containing much lower levels may achieve the desired result. However, in circumstances where there are many small local water supplies, often based on hand pumps, dealing with naturally occurring chemicals may present considerable difficulties, especially if alternative supplies are very limited.

Where possible, authorities should consider which areas are likely to be affected by the chemicals of highest concern and determine how concentrations can be minimized (e.g. by determining the best depth to sink tubewells to avoid contamination). In situations where there are significant concentrations of natural contaminants of concern, it may be appropriate to encourage community-based action to minimize concentrations (e.g. through local treatment or sharing water from wells with the lowest concentrations).

4|1|2 Aesthetic effects

Not all natural constituents are of direct concern for health – some may impact on the aesthetic quality of drinking-water by affecting the taste or odour, or by causing discolouration. Chemicals most commonly causing discolouration are iron and manganese, which are considered to be a high priority for consideration because consumers may find water contaminated with these metals unacceptable and may turn to other sources of drinking-water that may be microbially unsafe. High concentrations of sulfate, in association with cations, such as magnesium, may have a laxative effect on people not accustomed to the water. Similarly, chloride in high concentrations can contribute to a salty taste, although neither sulfate nor chloride is harmful in moderate concentrations.

4|1|3 Common health hazards

A number of the most important chemical contaminants (i.e. those that have been shown to cause adverse health effects as a consequence of exposure through drinking-water) fall into the category of naturally occurring chemicals. These are fluoride, arsenic, selenium and, in some circumstances, nitrate. In many parts of the world, the long-term consumption of hazardous, naturally occurring chemicals such as arsenic and fluoride, particularly through drinking groundwater, is a major cause of chronic disease, disablement and premature death.

High concentrations of naturally occurring chemicals generally occur where water has been in contact with rocks or soil for long periods under certain conditions. Such conditions, which generally occur in aquifers where groundwater flow rates are low, are more likely to be found in arid and semiarid regions. To a large extent, health problems caused by naturally occurring chemicals are associated with the use of groundwater as a source of drinking-water in these regions, where there is often no feasible alternative to groundwater. In addition, some springs and (during dry periods) most of the water in rivers may originate from groundwater discharge. Thus, surface water resources for drinking-water supply may also contain high concentrations of naturally occurring chemicals. The high fluoride concentrations found in some parts of India are an example of surface waters being contaminated by a naturally occurring chemical from groundwaters.

It is important that the geological conditions where chemicals are likely to occur at toxic levels are well understood, so that water sources can be located in safe areas, or treated to remove toxic constituents. This is particularly important when sources are being considered for use for drinking-water.

4|2

Environmental factors affecting inorganic constituents in water

Whether or not a naturally occurring chemical constituent in drinking-water is of concern depends on the geology and on the physical and chemical conditions affecting solubility. Climate also has an important role in affecting the way that rocks are broken down and the extent to which minerals are leached into rivers or groundwater.

Table 4.1 (pages 36-37) lists environmental factors affecting the distribution of naturally occurring toxic chemicals in water and soil. It gives the geological environments in which particular chemicals are most likely to be present in water supplies. An example is the presence of hot springs, which are associated with volcanic activity and may contain very high concentrations of natural chemicals of concern. Such springs can drain to waters that are used as drinking-water sources.

4|3

Data sources

Authorities at the national, regional or local level may develop water supply systems. Where the water supply developer has not established a comprehensive profile of chemicals in water sources (which is often the case), it may be appropriate to seek additional information from other sources. In many countries, government geological survey departments and the geology departments of universities have information on naturally occurring chemicals in the soil and on the risk of these chemicals being found in water sources. Mining companies can also be an important source of geological information. The presence of a significant local mining industry should be taken as a sign that extra caution is required with regard to water quality of groundwater and, in some cases, surface water. All relevant sources of data and information should be consulted.

4|4

Indicator parameters and simple tests

Indicator parameters are measurements that give information about the chemical condition of groundwater or a surface water body. These parameters are easily measured in the field and are valuable in guiding further investigations. For example, pH is an important indicator of the ability of water to dissolve minerals from rocks and soil; dissolved oxygen concentration indicates whether the water is aerobic or anaerobic; and redox potential can indicate whether or not the water is reducing in nature. The results of measurements of such parameters can indicate the potential presence of hydrogen sulfide or dissolved iron and manganese. An example of a very simple test would be to shake a water sample in a bottle to aerate it – if the water becomes brown, this would indicate the presence of dissolved iron or manganese in a water that was anaerobic.

4|5

Guidance on identifying relevant chemicals

The facilities and resources available may be sufficient to allow a comprehensive analytical assessment of the inorganic constituents in a source.[1] However, such an assessment is often not possible; in which case, the following sections and Table 4.1 indicate the naturally occurring chemicals that should be considered in setting priorities for chemicals in drinking-water sources.

Fluoride, arsenic, selenium and, in certain circumstances, nitrate should be given high priority. As noted in Chapter 2, the presence of these chemicals in drinking-water has been shown to cause health effects. The natural occurrence of these chemicals is relatively common in water supplies around the world in both developing and developed countries; therefore, they should be assumed to be potentially present, and consideration should be given as to whether they are actually present in concentrations of concern.

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[1] Guidance on analytical methodology to determine the inorganic constituents and their concentrations in drinking-water is outlined in the WHO *Guidelines for Drinking-water Quality* (WHO, 2004).

Table 4.1 | Environmental factors affecting the distribution of naturally occurring toxic chemicals in water and soil

Geological setting[1]	Source of water	Climate	Naturally occurring toxic chemicals that may be found in water	Land uses that may increase concentrations of possible constituents of water	Additional chemicals that may be released from natural sources, due to land uses given in previous column
Granite-like igneous rocks (e.g. granites, pegmatites)	Groundwater from fractured bedrock and from regolith overlying bedrock	Humid, arid	As, Ba, B, F, Rn, U; concentrations of B, F, U likely to be higher in drier areas	Irrigated agriculture, mining	B, Mo, Pb
Alkaline igneous and volcanic rocks	Groundwater from fractured bedrock and from regolith overlying bedrock	Humid, arid	As, Ba, B, F, Rn, U; very high concentrations of F occur in groundwater in these rock types in East Africa	Irrigated agriculture, mining	Mo, Pb
Basalts and magnesium-rich igneous and volcanic rocks (e.g. serpentine, talc-rich rocks)	Groundwater from fractured bedrock and from between lava flows	Humid, arid	SO_4^{2-}	Drainage, mining, groundwater pumping	Co, Cr, Ni
Contact metamorphic rocks	Groundwater from fractured bedrock	Humid, arid	Mo, U, Rn	Drainage, mining, groundwater pumping	Other metals, depending on mineralization
Iron-rich sedimentary rocks (e.g. sandstones, siltstones)	Groundwater from porous rock, fractures	Mainly arid	As, Se, Co	Irrigated agriculture	Ni
Manganese-rich sedimentary rocks	Groundwater from porous rock, fractures	Mainly arid	As, Ba, Mn	Irrigated agriculture	Co, Mn, Ni
Phosphorus-rich sedimentary rocks (limestones, mudstones, siltstones)	Groundwater from porous rock or from karst features (limestone, dolomite and calcrete)	Mainly arid	F, U, Rn	Irrigated agriculture	Mo, Pb
Black shales	Groundwater from fractured bedrock	Humid, arid	As, Mo, Sb	Drainage, mining, groundwater pumping	Ni, Pb

Geological setting[1]	Source of water	Climate	Naturally occurring toxic chemicals that may be found in water	Land uses that may increase concentrations of possible constituents of water	Additional chemicals that may be released from natural sources, due to land uses given in previous column
Sulfide mineralization	Groundwater from fractured bedrock	Humid, arid	Al, As, Co, Cd, Cr, Pb, Mo, Ni, Sb, Se	Drainage, mining, groundwater pumping	
Gold mineralization	Groundwater from fractured bedrock	Humid, arid	As	Drainage, mining, groundwater pumping	Hg
Alluvial plains and deltas, mainly in coastal areas (including buried channels)	Groundwater from extensive alluvial aquifers (the most significant source of water in many areas of the world)	Humid, arid	As, Se, U	Drainage, groundwater pumping	Co, Cd, Cr, Pb, Mo, Ni, Sb, SO_4^{2-}
All	Groundwater from fractured bedrock, alluvial aquifers or calcrete	Arid	NO_3 – high concentrations may occur where there are leguminous plants (e.g. *Acacia* species), and widespread termite activity		
All	Surface water	Humid	Cyanobacterial toxins	Agriculture	
All	Groundwater from organic-rich sediments or stagnant surface water bodies	Humid	NH_3	Intensive animal husbandry, agriculture	
All	Groundwater from fractured bedrock and surface drainage	Humid	I – very low concentrations occur in areas of very high rainfall or very high relief		
All	Surface runoff and groundwater in seasonally submerged soils	Humid	As	Agriculture involving flooding of fields (e.g. rice paddies), aquaculture ponds	

[1] Geological association of inorganic constituents based on data presented by Rose et al. (1979)

4|5|1 Catchment information

If groundwater is being used, it is important to know where wells and tubewells are located, because there may be localized areas where chemicals in the groundwater are of concern. Also, groundwater may be stratified, with water at different depths having different chemical profiles. In such cases, it is important to understand the potential variation in chemicals caused by the stratification.

When there is no geological information for a water supply catchment, or there is no information relating the siting of wells and tubewells and surface sources to the geology of the catchment, chemicals of natural origin (i.e. fluoride, arsenic, selenium, iron and manganese) should be regarded as being present in the water.

Appendix 1 of this document, and the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006), contain additional comments on individual chemicals.
Box 4.1 summarizes the main risk factors associated with the catchment.

Box 4.1 | Risk factors – catchment information

Geological or mineralogical information suggests that potentially hazardous chemicals may be present in elevated concentrations in the rocks, soils or groundwater within the catchment area.

4|5|2 Acidity and potential acidity

A low pH is likely to lead to greater leaching of inorganic constituents from rocks and soil, thereby increasing the probability that naturally occurring inorganic substances will be present at higher concentrations than would otherwise be expected. When groundwater or surface water used for water supply has a pH of less than 4.5 and there are nearby mineral deposits containing metals, it would be appropriate to consider those metals in particular. Low pH is widely encountered in groundwater from the weathered crystalline basement rocks that provide water supplies for villages and small towns in much of sub-Saharan Africa and peninsular India; thus, mobilization of iron and manganese is to be expected, and indeed is frequently observed, in these areas.
Box 4.2 summarizes the main risk factors associated with acidity and potential acidity.

Box 4.2 | Risk factor – acidity

Ground or surface water used for water supplies has or is suspected of having a pH of less than 4.5

4|5|3 Algal toxins

Cyanobacteria (also known as blue-green algae) occur widely in lakes, reservoirs, ponds and slow-flowing rivers. Many species are known to produce toxins, a number of which are of concern for health. Several different cyanotoxins, varying in structure, may be found within cells or released into water. There is wide variation in the toxicity of known cyanotoxins (including among different varieties of a single toxin, such as the microcystins), and it is likely that there are further cyanotoxins yet to be discovered.

Health hazards from algal toxins are primarily associated with overgrowth (bloom) events. Algal blooms may develop rapidly and be of short duration; they are generally seasonal and are frequently associated with the presence of nutrients, particularly phosphate. Levels of nutrients are often increased by human activity (see also Chapters 5, 6 and 7), increasing the likelihood of cyanobacterial blooms.

Analytical standards are frequently not available for algal toxins, and analysis of the toxins is slow and difficult (although rapid methods are becoming available for a few of these toxins, such as the microcystins). Therefore, the preferred approach is to monitor source water for evidence of blooms, or bloom-forming potential, and to increase vigilance where such events occur. Chemical analysis of cyanotoxins is not the preferred focus of routine monitoring, and it is used primarily in response to bloom events.

Various actions can be used to decrease the probability of bloom occurrence, and some effective treatments are available for removal of cyanobacteria or their toxins.
Box 4.3 summarizes the main risk factors associated with algal blooms.

Box 4.3 | Risk factor – occurrence of algal blooms

High concentrations (blooms) of cyanobacteria (blue-green algae), such as *Microcystis* sp. and *Anabaena* sp. occur in slow-moving or still surface waters with a moderate to high concentration of nutrients, particularly phosphorus. Blooms can occur in both deep and shallow waters, but are more usual in relatively still periods with a moderate to high light intensity. It is difficult to predict whether a bloom will produce toxins, but experience in a number of countries has shown that more than 50% of blooms will generally produce toxins at some stage.

4|6
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5

Chemicals from agricultural activities

5|1

Introduction

World population and economic growth are driving an increasing demand for agricultural products. Coupled with the finite extent to which further land can be converted to agricultural use, this increasing demand has intensified the use of available agricultural land – a trend that is expected to continue. Intensification of agricultural production carries several potential risks to water supplies.

While agricultural practices vary enormously throughout the world (due to variations in population density, economics, climate, soil types and methods of cultivation), there are a number of common activities that are significant sources of pollution. The most common chemical contaminants in drinking-water sources arising from agricultural activity are nitrate and pesticides, although organic contamination from slurry may create threats to drinking-water and drinking-water treatment. Human excrement (night soil), animal manures, fertilizers and biosolids (sewage sludge) used for agricultural purposes may be a source of excess nutrients, particularly phosphorus, which can contribute to algal blooms in slow-flowing or still bodies of water (see Chapter 4).

Many agricultural activities are highly seasonal although some, such as intensive animal husbandry, are not. Thus, it may be appropriate to consider seasonal changes in risk.

5|2

Data sources

Information on agricultural practices that may impact on drinking-water may be obtained from direct surveys of catchments and from a variety of other sources, such as farmers' associations, agricultural authorities or university extension services. Information on pesticide use may be available from these sources but, in many countries, registration authorities are the most important source of information. Where pesticides are imported, customs authorities may also be able to provide valuable advice. The department of agriculture or farming organizations may know which pesticides are used in a particular catchment. Information on production of pesticides for local markets may be available from departments of industry, chambers of commerce, industry associations and similar bodies.

Simple field observations may prove useful in situations where official sources of information are deficient. For example, it may be difficult to obtain a full picture of pesticide use from official sources because there may be widespread illegal use of pesticides, or use of unregistered pesticides in some instances; also, official records may be incomplete due to smuggling of pesticides for purposes of evading taxation or other controls. In such situations, judgements need to be made about which pesticides are likely to be applied under observed field conditions.

5|3
Use of human excrement, animal manure, inorganic fertilizer and biosolids

5|3|1 Human excrement and animal manure

Animal manures have a long history of use as a fertilizer and are still widely used. Wastewater from intensive animal production farms and other sources is commonly used for irrigation. Human excrement is also used in some countries for fertilization of agricultural land. Animal manures and human excrement contain nitrogen in a variety of chemical forms (as nitrate, ammonium salts and organic nitrogen compounds). The nitrogen content of manure varies considerably, depending on the species from which it is derived and their feeding methods; generally, the nitrogen content is much higher in manure from poultry than from other livestock. The age of the manure and the conditions under which it has been stored also affect the nitrogen content. Longer storage, and the application of manure to the surface of soils, can result in the loss of up to 20% of the nitrogen content through the evaporation of ammonia. This loss is reduced to about 5% if the manure is ploughed into the soil.

Depending on local chemical conditions in soil, organic nitrogen may be broken down to inorganic nitrogen. Ammonium compounds can be oxidized to nitrite, and eventually nitrate, which may leach into groundwater and surface water should there be insufficient plant growth to take up the available nitrates. In anaerobic waters contaminated with nitrogen, ammonia and nitrite may also be present. Nitrite and nitrate should always be considered together, since they have the same toxicological effect and the same mechanism of action.

Slurries of animal manure may also be disposed of by application to land. Leaching of nitrates will occur where there is insufficient plant growth to take up the nitrogen and there is a net movement of water away from the root zone.

5|3|2 Chemical fertilizers

Chemical fertilizers are used in most parts of the world, although less so in developing countries because of the high cost. The nitrogen content in chemical fertilizers is known, and application rates can be determined accurately. These may vary depending on the cropping system used. Nutrients are more immediately available for plant uptake in chemical fertilizers than in manure; however, they may be more easily leached into groundwater if used in excess. Slow-release fertilizers reduce this loss.

5|3|3 Biosolids

Biosolids are the residue of the chemical, biological and physical treatment of municipal and industrial wastes, and septic tank treatment processes. A proportion of this material is used as a source of nutrients and as a soil amendment in many agricultural areas. Used at appropriate application rates, these sludges are a valuable resource. However, excessive application can lead to a number of problems, including leaching of nitrates into water sources. Depending on the source of the sewage, sludge may also contain a number of metals, but there is very little evidence for these being a significant source of contamination of water sources.

5|3|4 Nitrate levels

Factors such as soil type, climate, depth of the water table and the use of irrigation determine the rate and extent of nitrate transport into groundwater and surface water (Sumner & McLaughlin, 1996).

In relation to soil types, sandy soils are particularly vulnerable to nitrate leaching (Pionke, Sharma & Hirschberg, 1990; Weil, Weismiller & Turner, 1990), because the high permeability provides limited opportunity for plant uptake, a situation compounded by the addition of excess manure or fertilizer to obtain reasonable yields in this type of soil. Nitrate is retained more effectively in loamy soils containing large amounts of organic carbon, although leaching can still occur from this type of soil.

Rainfall is one of the most important climate factors affecting nitrate levels. Heavy rain causes an initial peak when infiltrating water flushes nitrate from the soil. In cold climates, nitrate leaching takes place during the spring thaw, and during the cooler months, when nitrogen uptake by plants is slow. Like rainfall, irrigation, particularly excessive irrigation, may increase the risk of nitrate leaching.

If the water table is shallow, there is a greater risk of high concentrations of nitrate occurring after a relatively short time, whereas in areas where the water table is deep it may take many decades before nitrate reaches the groundwater in sufficient quantities to raise the nitrate concentration above the guideline value.

Box 5.1 summarizes the main risk factors associated with manures, fertilizers and biosolids.

Box 5.1 | Risk factors – manures, fertilizers and biosolids

Use of manures, fertilizers and biosolids for agriculture

The catchment area or water source is subjected to agricultural use.

Manures, fertilizers or biosolids are:

- ➔ applied to fields when no crops are present
- ➔ applied without measurement and without regard for crop uptake rates
- ➔ stored directly on soil with potential to leach liquid to ground or surface water
- ➔ stored in the open, close to a well used for water supply
- ➔ used near a sinkhole, abandoned mine shaft, abandoned well or other feature that will allow water direct access to the water table.

Water table

The water table is close to the surface (e.g. at the end of the wet season, it is easily exposed by a hole dug with a shovel).

The aquifer is vulnerable to contamination.

Soil thickness

Manures and fertilizers are applied to fields where there is little soil cover.

Irrigation

Irrigation is practised.

Health surveillance

There are cases of bottle-fed infants in the catchment suffering from “blue baby” syndrome.

5|4
Intensive animal practices

Intensification of agriculture has increased fertilizer use and stock densities, increasing overall nutrient loadings from these diffuse nonpoint sources. At the same time, the growing demand for animal products has led to an increase in facilities for intensive animal production (sometimes known as "feedlots"), which are often point sources of contamination.

Feedlots, typically used for beef, pork and poultry, confine animals in open-air or completely enclosed pens under controlled environments to optimize growth and the quality of meat and other products. They may generate large amounts of wastes that have the potential to cause pollution of water resources if improperly managed. The main sources of pollution from these facilities are the improper disposal of manure, animal carcasses, wastewater, feeding and bedding materials. Wastewater may be generated by the washing down of the facilities and runoff from manure stockpiles, and may be a significant source of pollution from feedlots. As well as nutrients, it may contain salts that have been added to the feed. With a well-managed facility, much of the wastewater is retained and treated; however, poor management practices can allow large amounts of waste to contaminate water resources. In developed countries, these intensive stock-rearing practices have been implicated in water-pollution incidents.

Box 5.2 summarizes the main risk factors associated with feedlots.

Box 5.2 | Risk factors – intensive animal production (feedlots)

Siting

Feedlots are sited close to existing water supply wells and rivers used for water supply (these pose a greater threat than facilities located at a distance from water supplies).

Feedlots are located next to sinkholes, abandoned mine shafts, abandoned wells or other features that allow drainage direct access to the water table.

Water management

Wastewater and water used for washing livestock stalls is allowed to percolate into the ground locally or through soakaways, or to contaminate surface water through runoff.

Wastewater from feedlots is collected for treatment in unlined or poorly managed treatment ponds, which can leach into the ground or overflow.

Wastewater from treatment ponds is applied to fields in excessive amounts, contributing to nitrate leaching.

Additional information

Feedlots are uncontrolled and not regulated by government authorities.

Blooms of algae are frequently observed in nearby ponds and other water bodies used for drinking-water.

5|5

Use of pesticides

Coinciding with the increasing use of fertilizers is a growing use of pesticides, herbicides and other chemicals for the control of insects, weeds and fungal pathogens. A large number of these chemicals, with a wide range of different physical and chemical properties, are currently used in agriculture, where they have helped to increase crop yields. As analytical methods become more sophisticated, agricultural chemicals have been detected in water supplies more frequently. Many of these chemicals are at trace levels, with detection rates being higher in agricultural areas using these chemicals intensively. WHO has recommended guideline values for a number of specific pesticides (WHO *Guidelines for Drinking-water Quality* – WHO, 2004; WHO, 2006).

The degree to which agricultural chemicals can be leached into groundwater through normal agricultural use depends on a number of factors. These include the extent to which the chemicals are adsorbed onto organic matter in soils, the extent to which they are volatilized from the soil, the rate of degradation within the soil, their solubility in water and the amount of percolating water that is available to mobilize them. The degree to which such chemicals can contaminate runoff to surface waters depends mainly on local rainfall and the extent to which the chemicals are adsorbed onto soil.

5|5|1 Pathways of contamination

The highest concentrations of agricultural chemicals in water supplies generally result from the percolation of contaminated runoff into natural and human-made pathways through the soils, although overspraying of water courses and poor disposal practices may also be important. The most common human-made cause of pollution of wells used to supply water relates to smaller facilities and to direct infiltration by contaminated runoff. Groundwater may be contaminated by leaching through highly cracked soils and fissured rocks. Some very soluble and mobile herbicides may leach to groundwater if they are applied at a time when the net movement of water is downwards and there is little transpiration by plants.

Agricultural chemicals are generally applied directly to plants (foliar spraying etc.) or to the soil, and concentrations in surface waters are dependent on factors such as application rates (including overapplication and misapplication), interception loss on plants, soil characteristics and climate (particularly rainfall) and whether or not irrigation is used. Surface water is particularly prone to contamination by poor agricultural practices, such as inappropriate disposal of excess chemicals, water from the washing of application equipment and spills. Other important potential point sources of contamination include chemical storage facilities (particularly those near water sources), mixing sites for chemicals and animal treatment sites (e.g. dips and sprays) where concentrations, and the chance of spills, are likely to be high.

Box 5.3 summarizes the main risk factors associated with the use of pesticides.

Box 5.3 | Risk factors – pesticides

Storage and mixing

Pesticides are stored and mixed with no appropriate precautions to contain spills.

Use

Pesticides are used:

- → that are not approved for use by a national licensing authority
- → at higher than the recommended application rates.

Pesticides are applied:

- → immediately before heavy rainfall.
- → directly to the soil immediately before irrigation, or to crops before spray irrigation.
- → where the soil is thin and bedrock is exposed or on very sandy soil.
- → near open wells, sinkholes or other features that allow direct access to the water table.

Disposal

Unused pesticide or washings from containers are disposed of in surface water, to soak-aways or in other circumstances that will lead to rapid transfer to groundwater.

5|6

Irrigation and drainage

Irrigation and drainage can play a role in the transport of pollutants from their source to the water supply. They can also affect groundwater quality by altering the water and salt balance in the soil, which in turn changes its physical and chemical characteristics, and affects the leaching of chemicals in the soil. Table 4.1 indicates where irrigation and drainage may increase the concentrations of naturally occurring chemicals (see Chapter 4).

Irrigation water may be applied through surface channels, by subsurface trickle or drip systems, or by spray, all of which may cause salts to leach from soils in certain circumstances. Leaching of salts affects the quality of groundwater and surface water, and can have a severe impact in areas where natural water flows are relatively low. Under extreme circumstances, excess irrigation may not only lead to the leaching of salts to groundwater but may also cause a rise in the water table. In turn, this may result in high levels of salts being reintroduced into the soil at a point where they can impact on crops and contaminate surface water.

A number of contaminants may be introduced into the water system by irrigation. The large amount of water used in agriculture makes the risk of leaching nitrates and other chemicals potentially greater in areas that are irrigated. For example, where soils contain significant concentrations of selenium, the infiltration of irrigation water can leach this element and thereby contaminate water locally. The quality of the water used for irrigation is also important. When water with very high mineral content or relatively acid water is used for irrigation, this can impact on both surface and groundwater by leaching minerals from soil and rock.

Drainage from irrigation systems may increase the rate of oxidation of organically bound nitrogen, giving rise to elevated nitrate concentrations.

Box 5.4 summarizes the main risk factors associated with irrigation and drainage.

Box 5.4 | Risk factors – irrigation and drainage

Water application

Untreated or partially treated wastewater is used for irrigation.

A greater amount of water is applied than is required to maintain growth.

Irrigation is practised

- → close to wells used for water supply
- → on sandy or very permeable soils above aquifers used for drinking-water
- → when the water table is close to the surface.

Soil acidity measurements indicate extreme pH levels

The pH of drainage water is:

- → less than 4.5
- → greater than 8.5.

5|7
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6

Chemicals from human settlements

6|1

Introduction

Urbanisation is increasing, particularly in developing countries. The transition of people from rural areas to cities represents a major, and permanent, demographic shift. This movement to cities creates many problems, particularly when housing and infrastructure are unable to keep pace with population growth. However, problems associated with human settlements do not only arise in large cities – even small settlements can carry risks for drinking-water if insufficient care is taken and drinking-water sources are sited close to human habitation. The chemical risks to drinking-water associated with human settlements described in this section are on-site sanitation and sewerage systems, waste disposal, urban runoff, fuel storage, handling and disposal of chlorinated solvents, and pesticide application for public health and vector control.

Risk management strategies for the chemical quality of water used for drinking in urban areas should take into account chemicals that may possibly be derived from human settlements and may affect drinking-water quality. Strategies should also consider potential sources of such chemicals and the assumed mechanisms by which they may contaminate source water. Often, drinking-water will be abstracted from sources within a city, town or village; usually from groundwater. Thus, the activities within that area of human habitation have the potential to pollute the water supply. However, it is also important to consider pollution of surface waters by human habitation upstream from other settlements, which means that the concept of catchment management should be borne in mind when considering this situation.

Sources of potential pollution fall into three broad categories as indicated in Table 6.1. These categories are:

- **point sources**, where there is a defined and usually identifiable source of pollutant or pollutants;
- **nonpoint sources**, which are widely spread and difficult to clearly identify;
- **diffuse point sources**, which consist of many small point sources.

The approach to considering each pollution source is slightly different, although there will, of course, be circumstances where there is overlap between the categories. In general, diffuse sources of pollution are more difficult to control than point sources, particularly where systems such as pit latrines and septic tanks are established.

Spills of many chemicals found in urban areas (including petroleum and fuel oils) are also a source of contamination of both groundwaters and surface waters. The volatile components of petroleum oils may penetrate some types of plastic water pipes if these chemicals contaminate the ground surrounding the pipe. Choice of materials for water distribution should take into account such risks and should consider whether pipes are to be laid through contaminated ground.

Table 6.1 | Chemicals derived from human settlements

Source category	Activity or hydrological event	Source description	Target water body	Chemicals of concern	Remarks
Point source	On-site sanitation and sewerage	Sanitation facilities, including sewage treatment plants	Surface waters and groundwaters	Nitrate, ammonia	Pit latrines of individual houses should also be taken into account as diffuse point sources
	Waste disposal (land reclamation)	Waste disposal sites	Mainly groundwater	Nitrate, ammonia, other chemicals contained in the waste (in case of industrial waste disposal site)	Past waste disposal sites are also important sources of chemicals. Industrial waste is a more important source of chemicals than domestic waste. Controlled waste disposal may also contaminate surface waters and groundwaters.
Diffuse point source	Fuel storage	Fuel stands, small industries, etc.	Mainly groundwater	Petroleum hydrocarbons, benzene, ethylbenzene, toluene and xylene	Attention to both current and historical sites is necessary
	Chlorinated solvent use	Small industries, cleaning shops, etc.	Mainly groundwater	Trichloroethylene, tetrachloroethylene, trichloroethane	Attention to both current and historical sites is necessary
	Pesticide application	Roadside greens, drinking-water storage tanks, etc.	Groundwater and drinking-water	Pesticides	Pesticide application to a drinking-water storage tank leads directly to contamination of drinking-water
	Any other urban activities	Small industries, public facilities and individual houses	Surface waters and groundwaters	Unspecified	This type of chemical contamination is very important where there are no adequate sewerage systems
Nonpoint source	Urban runoff	Roads, roofs, open spaces and other sources relating to the activities as written above	Surface waters and groundwaters	Nitrate, ammonia, heavy metals, pesticides, other organic chemicals	Deposits during a dry-weather period (e.g. atmospheric fallout of suspended particulate matter) will be flushed out, together with rainwater runoff

6|2

Data sources

In addition to the general types of data sources discussed in other chapters, it may be useful to make enquiries with:

- water supply and wastewater agencies;
- local government and municipal authorities;
- environmental agencies.

6|3

Sewage systems and on-site sanitation

In many cities and towns, a reticulated sewage system collects sewage from domestic premises, public buildings and industrial premises. The sewage is carried to a central treatment works, where it undergoes a number of possible treatments that vary in their ability to break down or remove contaminants. The treated effluent is then discharged, often to a river. In most cases, the point of discharge will be below the city or town, but the impact of such effluent on drinking-water abstracted downstream will depend on the efficiency of the treatment and the quality of the effluent. Indirect reuse of wastewater discharged to rivers or lakes, where it may undergo dilution and further natural purification, has been practised widely for many years. A range of contaminants may be present in wastewater, depending on the nature of the raw sewage and the efficiency of treatment, but these are likely to include nutrients such as nitrogen and phosphorus (unless there is specific treatment to remove nutrients). Many cities and towns on the coast discharge effluent to the sea – a process that does not impact on drinking-water. Less frequently, treated effluent may be used for groundwater recharge.

Poorly maintained or damaged sewers that leak may also contaminate water resources. Where sewers run close to drinking-water mains there is a danger that more direct contamination through ingress into the water mains may occur. System failures may also lead to the discharge of untreated sewage into water bodies.

Sewage treatment and many on-site facilities produce biosolids (sewage sludge). These may be used as a soil conditioner in agriculture or for other purposes, such as land reclamation. Biosolids that are not used for these purposes are disposed of in various ways, including by landfill. In some circumstances, the disposal of biosolids may give rise to leaching, particularly of nitrates. Where biosolids are heavily contaminated with industrial waste, such as heavy metals, these contaminants may also need to be considered.

In settlements where there is little or no reticulated sewerage, human excrement is generally disposed of on-site through pit latrines, septic tanks or leach fields. When pit latrines and septic tanks are badly sited, constructed or maintained, they can contaminate local water supplies, particularly with nitrate. Nitrate concentrations in shallow groundwater commonly exceed drinking-water guidelines in areas with on-site sanitation (BGS, 2001). In some urban settings, other chemicals (including petroleum hydrocarbons, household chemicals and even solvents) may be disposed of through latrines, leading to localized water contamination problems from these chemicals.

Box 6.1 summarizes the main risk factors associated with on-site sanitation and sewage systems.

Box 6.1 | Risk factors – on-site sanitation and sewers

Site suitability

On-site sanitation systems are:

- ➔ used in the vicinity of a potable water supply
- ➔ located in the vicinity of a waterway
- ➔ located in an area where there is little soil cover and bedrock is exposed
- ➔ located near open wells, sinkholes or other features that allow direct access to the water table
- ➔ located where the water table is close to the surface (e.g. it can be readily exposed by a hole dug with a shovel at the end of the wet season).

Sewer lines are installed below the water table.

Composition of the waste

The on-site sanitation system receives wastes from an industrial facility.

Discharges to the sewerage system are unlicensed and unregulated.

Operation and maintenance

Treatment plants and pumping stations are operated without emergency storage facilities to cope with system breakdowns.

Treatment plants are operated without ongoing monitoring of the quality of wastewater entering the plant.

Sewer pipelines are operated without an ongoing regime of inspection and testing.

6|4

Waste disposal

Household and general waste in some urban areas may be disposed of through uncontrolled dumping in vacant areas. In low-lying swampy areas, this form of disposal may be seen as a form of land reclamation. If this disposal is on land associated with surface water collection or groundwater recharge, the potential exists for various chemicals present in the waste to contaminate the water resource. The decay of putrescible organic material within the waste generates considerable amounts of leachate, which can easily percolate into groundwater, especially in low-lying areas where the water table is shallow.

In cities where urban waste is deposited in municipal landfills, there may be limited control over the type of waste deposited at a particular site. Where landfill sites are unlined or unconfined, leachate can potentially pollute groundwater and surface water. The leachate may contain a range of chemical contaminants, including high levels of phenols (which can give rise to significant taste and odour problems in drinking-water following chlorination), ammonia, nitrate and heavy metals. Depending on local hydrogeological conditions, a groundwater contamination plume from a waste disposal site may extend a considerable distance in the direction of groundwater flow from the site, and may affect the quality of groundwater over a large area.

Box 6.2 summarizes the main risk factors associated with waste deposition.

Box 6.2 | Risk factors – waste deposition

Site suitability

Waste is deposited:

- near a source of potable water
- near a waterway that links to a source of potable water
- near open wells, sinkholes, or other features that allow leachate direct access to the water table
- in an area where there is little soil cover and/or bedrock is exposed
- where the water table is close to the surface (e.g. it can be readily exposed by a hole dug with a shovel at the end of the wet season).

Composition of the waste

The waste site receives wastes from one or more industrial facilities.

Sewage or the contents of latrines is deposited at the site.

Operation and maintenance

Wastes have been deposited in an unregulated way with no form of containment or lining to the site.

The site receives significant rainfall.

6|5
Urban runoff

6|5|1 General considerations

Urban runoff will contain both chemical and microbial contaminants, the range and concentrations of which can vary considerably over short periods of time. As the area of impermeable surfaces increases, the problem of stormwater collection and disposal becomes more significant. The major sources of contamination of stormwater include substances deposited on impermeable surfaces from:

- motor vehicles (leakage of fuel, lead from exhaust where leaded petrol is still in use, metals from wearing parts and catalytic converters, and rubber and other substances from wear of tyres);
- atmospheric fallout of suspended particulate matter;
- salts used for de-icing;
- accidental and deliberate spills of industrial effluent into stormwater systems.

6|5|2 Pathways of contamination by urban runoff

Groundwater contamination is most likely where stormwater is discharged into soakaways (e.g. pits filled with rubble to speed transfer to groundwater) or infiltration areas, and where the aquifer is vulnerable. However, in many cases, stormwater is collected in the drainage system, which may discharge into sewers. Stormwater or (when sewer capacity is exceeded) a combination of stormwater and diluted raw sewage may be discharged into surface waters.

Box 6.3 summarizes the main risk factors associated with urban runoff.

Box 6.3 | Risk factors – disposal of urban runoff

Site suitability

Stormwater/urban runoff is discharged to ground close to a well used for potable water supply.

Stormwater is discharged:

- ➔ to a surface water close to a potable water supply point
- ➔ into sinkholes or other features typical of limestone that link to groundwater used for drinking-water
- ➔ to a soakwell or infiltration basin where the water table is close to the surface.

pH

The pH of the stormwater is less than 4.5.

6|6

Fuel storage sites

The leakage of fuels from large storage tanks is a significant source of groundwater contamination in some regions, particularly where the storage and handling of fuels is poor. Many oils can pool on the surface of aquifers, causing long-term contamination. The more volatile fuels (e.g. gasoline) contain compounds that will dissolve in water, in particular, the BTEX compounds – benzene, toluene, ethylbenzene and xylenes. Unleaded gasoline may also contain oxygenated compounds that improve combustion. The most common of these is methyl tert-butyl ether (MTBE), which has caused significant contamination of groundwater in some countries, particularly the United States of America (USA), because of its high solubility in water and its slow degradation. MTBE is of concern for drinking-water because it has a very low taste and odour threshold. Other fuels (e.g. diesel) also contain water-soluble components, such as the trimethylbenzenes, which have a very low taste and odour threshold. Drinking-water contaminated with these fuels can be unacceptable to consumers.

Many countries have introduced regulations for the construction of underground and overground fuel storage tanks and pipelines that will significantly reduce the risks associated with fuel. Relatively small leaks of a few litres per day may not be easily noticed but, over an extended period of time, can give rise to significant problems. Such leaks can also saturate soil, creating the potential for long-term contamination of groundwater.

Box 6.4 summarizes the main risk factors associated with fuel leakages.

Box 6.4 | Risk factors – fuel storage

Fuels are stored in tanks, above or below ground, that are not of an appropriate standard to prevent leakage.

Storage tanks are not checked for leaks and are not monitored to detect leaks.

Water supply wells, including tubewells, are located close to fuel storage tanks or a site previously used for bulk fuel storage.

Petrol or diesel-like odours have been reported by water consumers.

6|7
Chlorinated solvents

A number of small chlorinated organic molecules, such as tri and tetrachloroethylene, are used as solvents for metal degreasing and dry cleaning. These chemical compounds are only sparingly soluble in water but are miscible with water. When discharged or spilt onto the ground they rapidly soak through the soil and, where the aquifer is vulnerable to surface contamination, they percolate through the ground to the aquifer. The rate of degradation of these chemicals is extremely slow, and they have caused significant pollution of groundwater used for drinking-water. In the past, waste solvents were disposed of into shallow pits, in the expectation that they would evaporate. Although this practice is no longer common, it has resulted in significant areas of historical pollution of groundwater dating back many decades. In some cases, the subsequent development of the aquifer as a drinking-water source has resulted in these chemicals being drawn to the groundwater abstraction point after an extended period of pumping.

Box 6.5 summarizes the main risk factors associated with chlorinated solvents.

Box 6.5 | Risk factors – chlorinated solvents

Groundwater is used for water supply in an urban area where chlorinated solvents are, or have been, stored, used or disposed of.

6|8
Public health and vector control

Where public health agencies use pesticides for public health and vector control, it is most appropriate to refer to the agency responsible for vector control, to determine which chemicals are used and the management practices employed. Where the chemicals are applied in circumstances that affect drinking-water either directly or indirectly, the likely impact needs to be considered. However, there is a balance to be struck between the potential toxicity of the pesticides and the risks from insectborne diseases.

Herbicides are sometimes also used in urban areas for control of weeds on railway lines and roadside verges, and around areas of hard standing. Some of the herbicides used are sufficiently persistent to be able to be washed into drains or soil, and possibly percolate into groundwater. One of the most common of these herbicides is atrazine, which has been found in the groundwater of many countries. Awareness of the potential for contaminating groundwater and careful selection of herbicides, where they are required, has significantly decreased contamination in many of the areas where it was common.

6|9
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7

Chemicals from industrial activities

7|1

Introduction

In a catchment area, industries, particularly those involved in extraction, manufacturing and processing, may be important in the assessment of chemical risks of drinking-water because they can be the source of significant contamination.

Mineral production is an important component of the economy for many countries, and in some cases it can be the major source of international revenue. However, mining and mineral production operations that are not well managed can contaminate groundwater and surface water, and can adversely affect the health of nearby communities that rely on this source for drinking-water or agriculture.

Extractive industries include mining of mineral deposits (principally metal-bearing ores and coal deposits), oil and natural gas production, and quarrying for building and road-making materials. Poorly operated or abandoned mine sites are often significant sources of water contamination; contaminants of particular health concern from these sources include heavy metals, and mineral-processing chemicals, such as cyanide.

Water pumped from abandoned mine shafts and open-cut pits is often used for water supply. However, these water sources may sometimes be contaminated by mineral processing chemicals, acid mine drainage (AMD) and waste disposal. These risks must be considered and assessed to determine whether such water sources are safe to be used for drinking-water supply.

Manufacturing and processing industries are also a potential source of chemicals in drinking-water. Assessment of the types and amounts of chemicals in the effluent discharged from industrial sources should be used to make judgements on the possible chemicals that could be present in receiving water used as a drinking-water source.

It is sometimes difficult to identify all industrial sources in a catchment area because there may be many small-scale industrial sources. In such a case, it is best to focus initially on the major industrial areas according to effluent quantity and type. The types of manufacturing and processing industries that are important from the aspect of drinking water contamination include chemical, metal, textile dying, tannery, paper and pulp, electroplating and printed circuit board manufacturing. It is therefore desirable that these industrial sources be identified in the target area.

7|2

Data sources

Information about the distribution and nature of extractive industries can often be obtained from government agencies (principally mines departments or geological surveys), geology departments in universities, and specialist research institutes associated with the mining industry.

Information about the location and nature of manufacturing and processing industries can usually be obtained from environmental protection agencies, departments of trade and industry associations (chambers of commerce, etc.). Information may also be available from government departments or agencies that deal with natural resource management or environmental protection issues.

Where contaminated sites exist, information about historical industrial activities can often be obtained from environmental protection agencies. Such disused sites may continue to pollute drinking-water sources for many years or decades after the industry has closed down if residual soil contamination at the site has not been cleaned up.

Appendices 1 and 2 present information on industrial chemicals listed by industry and by chemical, respectively, and are both useful in identifying chemicals likely to be discharged from industrial sources. Appendix 2 should be used as a guide to identifying the interrelation between industrial activities and chemicals potentially discharged through effluents. This appendix uses a classification based on the United Nations Standard Industrial Classification (United Nations Statistics Division – Classifications Registry: Activity Classifications, ISIC Rev. 2). The information given in appendices 1 and 2 is extensive, but is not exhaustive and does not cover every possibility that may be encountered.

7|3
Extractive industries

7|3|1 Extractive industry activities

The activities of extractive industry include a number of phases that can have different impacts on water quality. Those typical of mining and oil/gas production are listed below.

- **Exploration**. Exploration for mineral and petroleum resources involves field surveys, drilling programmes and exploratory excavations. Some water contamination can be produced at this stage from land clearing; for example, if clearing exposes a layer with high content of heavy metals, leading to contamination of stormwater by the heavy metals and by waste disposal from exploration camps. Unfilled exploration boreholes can allow contaminants from the surface to be washed into groundwater without being attenuated in the soil profile.
- **Project development**. The development of a mining site and supporting infrastructure causes extensive land clearance. Also, groundwater and surface water contamination can be caused by spills and leaks from fuel storage tanks, and from waste disposal.
- **Operation and production**. The type of operations can include pumping from boreholes (oil and natural gas, solution mining), heap leaching of rock piles, underground mining, open cuts and surface edging. Oxidation and leaching of minerals from mining spoil and other waste products can contaminate groundwater and surface water.
- **Beneficiation**. Processing of minerals using a variety of mechanical and chemical treatment processes can be the most significant source of water contamination at a mine site. The major sources of contamination from mineral processing are leaks from storage ponds holding processing liquors, and leakage from tailings dams used to separate and recover processing liquids from fine solid wastes.
- **Closure**. Closure and rehabilitation of a mine site to mitigate environmental impacts (e.g. stabilization and revegetation of waste rock and tailings) can contaminate groundwater if not well managed. Sources of contamination include continued seepage from waste rock and tailings if these are not well stabilized; salinization of groundwater by evaporation from abandoned open pits and the excessive use of fertilizers in rehabilitation programmes.

7|3|2 Effects of extractive industry on water quality

The type of water contamination produced by a mining operation depends to a large extent on the nature of the mineralization and on the processing chemicals used to extract or concentrate minerals from the host rock.

The water contaminants of most concern from extractive industries are summarized in the Table 7.1.

Table 7.1 | Chemical contaminants of extractive industry wastewaters

Type of mine	Wastewater generated	Characteristics of wastewater	Chemicals possibly contained
Open-cut and underground mining of base metal sulfide deposits, precious metal deposits or uranium deposits with sulfide minerals, sulfide-rich heavy mineral sands, coal deposits	Acidic mine drainage from waste rock heaps; and residues from ammonium nitrate–fuel oil (ANFO) explosive used for rock blasting	Low pH (< 4.5, possibly as low as 2) of water in springs, seeps, open cuts and streams draining from the mine site. Extensive vegetation death, yellow or white salt crusts on the soil surface, pale blue cloudy appearance of surface water	Arsenic, antimony, barium, cadmium, chromium, cobalt, fluoride, lead, mercury, molybdenum, nickel, nitrate, selenium, sulfate, uranium (radon may be of concern where there are high uranium concentrations)
Base metal and precious metal deposits	Flotation agents used to concentrate minerals from ore; the main sources of contamination are seepage from processing mills and tailings dams		Depends on the type of mineralization – contaminants from flotation agents of health concern include chromium, cresols, cyanide compounds, phenols and xanthates
Gold deposits	Chemicals used to extract gold from ore (cyanide and mercury), particularly from tailings dams	High pH of water (up to pH 10) when cyanide is used	Arsenic, free cyanide, weak acid dissociable cyanide, mercury
Uranium deposits	Acid leaching (especially sulfuric acid) used to extract uranium from ore	Low pH of water, high sulfate concentrations in water	Arsenic, antimony, barium, cadmium, chromium, cobalt, fluoride, lead, mercury, molybdenum, nickel, radon, selenium, sulfate, uranium
Petroleum and natural gas	Disposal of brines associated with petroleum hydrocarbons	High salinity of water, high concentrations of hydrogen sulfide, methane or detectable hydrocarbon odours in water	Boron, fluoride, hydrocarbons, uranium

AMD is probably the most severe environmental problem that occurs on mine sites. It happens where mineral and coal deposits contain sulfide minerals, particularly pyrite (FeS_2). When waste rock containing sulfides is exposed to air, these minerals are oxidized, releasing sulfuric acid. The process is accelerated by bacteria such as *Thiobacillus ferrooxidans* that obtain energy from the oxidation reaction for their growth. The release of acid can cause the pH of surface water and groundwater to become very low (as low as 2). Under these very acidic conditions, metal concentrations in water can become very high due to the dissolution of elements from waste rock. Acidic water at mine sites often kills vegetation, and may cause fish deaths in rivers. Apart from low pH, visual indicators of AMD at mine sites include the following:

- There are large areas where vegetation has died due to acidic runoff and shallow acidic groundwater.
- Abundant yellow or white salt crusts are present on waste rock and at the surface of the soil. The crusts comprise alum-like sulfate minerals containing variable amounts of sodium, potassium, iron and aluminium, such as the mineral jarosite. They are often very soluble in water, releasing acid and precipitating ferric hydroxides.
- Surface water bodies on the mine sites often appear to have a milky or cloudy blue-white appearance due to the presence of flocs of aluminium hydroxide. If the water is extremely acidic (< pH 3), it may appear to be crystal clear due to the precipitation of the flocs.

Of the chemicals used to process ores, cyanide may be the most problematic due to its toxicity and the complexity of its chemical behaviour in groundwater. Cyanide degrades rapidly into nontoxic chemical compounds when exposed to air and sunlight, but in groundwater it may persist for long periods with little or no degradation. Cyanide (usually in the form of potassium or sodium cyanide) is used to extract gold from its ore, but in the subsurface it can react with minerals in soil and rock to form a wide range of metal cyanide complexes, many of which are very toxic.

Abandoned pits and mine shafts are commonly used for water supply after mine closure. Depending on the type of mining activity, water from these sources could pose a risk to human health from high dissolved metal or cyanide concentrations.

7|3|3 Risk factor checklist

Box 7.1 summarizes the main risk factors associated with chemicals derived from extractive industries.

Box 7.1 | Risk factors – extractive industries

Site suitability

Industries are located within close proximity of:

- a potable water source
- a waterway.

Water from abandoned mine shafts and pits is being used as a source of drinking-water.

Effluent discharge

Discharges to receiving water or onto the ground:

- are unlicensed and unregulated
- take place without reference to effluent acceptance criteria.

There are no effluent treatment facilities.

Industrial operation

Chemicals, including floating agents, are used for operation and maintenance.
Acid leaching of ore is carried out.
Solid wastes are disposed of at the site.

Operation and maintenance of an on-site treatment facility

Effluent treatment facilities are operated without emergency storage facilities to cope with system breakdown.

7|4

Manufacturing and processing industries

7|4|1 Initial indicators

Industrial pollution might be suspected if a water source exhibits any of the following physical properties:

- strong chemical odours (often similar to phenolic disinfectant), like petrol, or sharp and acrid (irritate the back of the nose or throat);
- colours unexplained by iron or manganese tests;
- reports of bitter or metallic tastes not explained by iron or manganese tests;
- persistent foaming on the water surface;
- a multicoloured, iridescent sheen on the water surface that does not break up when prodded with a stick;
- any other unusual appearance.

7|4|2 Developing an inventory

A variety of chemicals used or produced in industrial processes may be harmful to human health if released into drinking-water sources. Chemicals likely to be in a particular watershed may be identified by developing inventories of the industrial processes undertaken in the catchment. An inventory for each industrial source should include the following information:

- type of industry;
- year of the start of operation and historical development;
- occupied land area and number of employees;
- amount and nature of raw materials, final products and by-products;
- industrial processes employed;
- amount of water used;
- amount and nature of wastewater generated;
- details of water receiving the effluent;
- amount and nature of solid wastes;
- solid waste disposal.

7|4|3 Assessing the impact

When assessing the impact of industrial discharges on receiving waters, the most critical characteristics are:

- the types of chemicals discharged – this depends on the type of industries and processes used;
- the amount and concentration of chemicals in the effluent – these vary over time depending on the operation mode of both manufacturing and wastewater treatment processes employed (e.g. hourly, daily, weekly, monthly and seasonal variations).

Solid wastes and/or gaseous emissions generated from industrial sources also contribute to the amount and concentration of chemicals in the effluent if they are treated with water or they have any contact with water.

7|4|4 Site inspection

Section 7.2 (above) discusses data sources for information on types of chemicals used and the amount discharged to the environment. Additional information can be obtained through a site inspection, which is a very useful and effective tool for augmenting and strengthening the information gained from compiling a source inventory.

Collecting site information is very important because chemicals could be used and discharged from industrial sources other than those specified in appendices 1 and 2. For example, a battery-manufacturing industry could be the source of metals such as mercury, cadmium, lead, nickel, manganese, iron, copper and lithium. Certain chemicals listed in the appendices are widely used in industries; for example, degreasing agents (organic solvents) such as dichloromethane, 1,1-dichloroethane, 1,2-dichloroethane, 1,1,1-trichloroethane, 1,2-dichloroethene, trichloroethene and tetrachloroethene. Moreover, effluents from recycling industries contain a variety of chemicals depending on the type of raw and final products.

Important issues to be noted in a site inspection in the context of water safety are:

- amount of chemicals used and their fates in industrial processes;
- water use and its quantity;
- sanitary conditions of the facility;
- wastewater treatment processes, and their effectiveness.

Industrial sources may represent a potential risk from chemical spills. On-site wastewater treatment facilities should be checked for:

- capacity;
- treatment processes employed;
- chemicals used;
- amount and nature of sludge generated;
- effluent monitoring practice and results;
- operation records;
- personnel engaged in the operation of the facilities.

If gaseous emissions are treated with water, the disposal of the wastewater generated, together with its quantity and quality, should be considered. Solid wastes or sludge containing chemicals deposited onto land may contaminate groundwater (through seepage) and receiving water (through surface water runoff of rainfall). If solid wastes or sludge are disposed at points remote from the source, their sites should also be assessed. More details on solid wastes are given in Section 6.4.

7|4|5 Risk factor checklist

Box 7.2 summarizes the main chemical risks associated with manufacturing and processing industries.

Box 7.2 | Risk factors – manufacturing and processing industries

Site suitability

Industries are located close to:

- a potable water source
- a waterway.

Effluent discharge

Discharges to receiving water or onto the ground:

- are unlicensed and unregulated
- take place without reference to effluent acceptance criteria.

There are no effluent treatment facilities.

Industrial operation

Chemicals are used for operation and maintenance.

Water is used for purposes other than indirect cooling.

Solid wastes are disposed of at the site.

Exhausted gas is washed with water before emission.

Operation and maintenance of an on-site treatment facility

Effluent treatment facilities are operated without emergency storage facilities to cope with system breakdown.

7|4|6 Pathway considerations

Section 2.3 (see Chapter 2) sets out the general principles of concentration changes as a chemical travels from source to consumer. It may be useful to refer to Section 2.3 before deciding, on the basis of pathway considerations, which chemicals are likely to reach the consumer.

Depending on their persistence, chemicals discharged through the effluent from industrial sources to a surface water body may reach an intake of a drinking-water supply. The chemicals accumulate in the bottom sediment of a water body, and may be flushed out in the event of high water flow. Industrial effluents that are discharged into the ground can also contaminate a groundwater source used as a drinking-water supply.

The presence of industrial chemicals in a water source does not necessarily indicate that they will be present in treated drinking-water. The extent to which chemicals will be removed before the water reaches the consumer will depend on the nature of the contamination and the type of treatment processes used. However, many industrial chemicals are toxic at relatively low concentrations, and water polluted by industrial activities often contains a number of different toxic chemicals. It is therefore important to identify and assess the risk posed by all the potential chemicals in a polluted water source.

7|5
Reference

United Nations Statistics Division – Classifications Registry: Activity Classifications, ISIC Rev. 2, http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=8&Lg=1

8

Chemicals from water treatment and distribution

8|1
Introduction

Chemicals from water treatment and distribution reach drinking-water by the most direct route. They fall into three broad categories:

- substances resulting from the addition of chemicals used in the treatment process for coagulation and disinfection – these chemicals are intentionally added and can give rise to residues or by-products;
- disinfectants that are deliberately added with the intention of maintaining a residual in distribution, usually to the tap – these chemicals may also give rise to by-products;
- substances that leach from materials used in distribution or plumbing, or that arise from the corrosion of pipes.

The WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) cover a significant number of potential substances from water treatment or distribution (summarized in Table 8.1). It is important that water supply agencies properly manage any chemicals that they use. In many cases, the best method of control is through management practices, such as optimization of the treatment process, and regulation of materials and chemicals that come into contact with drinking-water, rather than through monitoring and chemical analysis.

This chapter gives guidance on the importance of potential chemicals derived from water treatment or distribution, from a management perspective.

8|2
Chemicals used in treatment

8|2|1 Disinfectants and disinfection by-products

The three chemicals most commonly used as primary disinfectants are chlorine, chlorine dioxide and ozone. Monochloramine, usually referred to as chloramine, is used as a residual disinfectant for distribution.

- *Chlorine*

Chlorine is the most widely used primary disinfectant and is also often used to provide residual disinfection in the distribution system. Monitoring the level of chlorine in drinking-water entering a distribution system is normally considered to be a high priority (if it is possible), because the monitoring is used as an indicator that disinfection has taken place. Residual concentrations of chlorine of above about 0.6 mg/L or more may cause problems of acceptability for some consumers on the basis of taste, depending on local circumstances. Monitoring free chlorine at different points in the distribution system is sometimes used to check that there is not an excessive chlorine demand in distribution that may indicate other problems in the system, such as ingress of contamination.

Chlorine is applied in a number of forms from chlorine gas to hypochlorite solution. It is important that the source of chlorine is not contaminated. For example, chlorine gas has been found to be contaminated with carbon tetrachloride, hypochlorite that is stored for a long time gradually breaks down to give chlorate, and hypochlorite generated electrolytically from seawater or brine with a high bromide content can have high concentrations of bromate.

Chlorine reacts with naturally occurring organic matter in raw water to form a range of unwanted by-products. Guideline values have been established for a number of these by-products. The compounds most widely considered as representatives of chlorination by-products for the purposes of setting standards and monitoring are the trihalomethanes (THMs) which include chloroform, bromodichloromethane, chlorodibromomethane and bromoform.

Haloacetic acids (HAAs), monochloroacetate, dichloroacetate and trichloroacetate, can also be formed as the result of reaction of chlorine with organic matter contained in raw water. Some countries monitor HAAs as well as THMs, but HAAs are much more difficult and expensive to analyse than THMs.

THMs and HAAs continue to develop within the distribution system; thus, monitoring can be complex. Optimizing coagulation and filtration is most important in helping to remove the precursors of these by-products and will, in turn, reduce the formation of THMs, HAAs and other unwanted by-products.

In order to ensure the microbial safety of drinking-water, disinfection should never be compromised in trying to meet guidelines for any disinfection by-products.

➔ *Chlorine dioxide*

Chlorine dioxide breaks down to leave the inorganic chemicals chlorite and chlorate. These are best managed by controlling the dose of chlorine dioxide applied to the water. Chlorate can also be found in hypochlorite solution that has been allowed to age. There is no guideline value for chlorate because of limited data on its toxicology, but this chemical has been shown to be less toxic than chlorite and is present at lower concentrations. Controlling chlorite will generally also adequately control chlorate.

➔ *Ozone*

Ozone, used as a primary disinfectant, cannot be monitored in drinking-water, because it leaves no residual. Ozonation in the presence of inorganic bromide, which can occur naturally in raw water, can give rise to low concentrations of bromate. The analysis of bromate is difficult and expensive, because a number of other inorganic substances that interfere with the analysis may be present. It is considered, therefore, that routine bromate monitoring is a low priority, and that management should instead involve controlling the conditions of ozonation.

➔ *Monochloramine*

Monochloramine, used as a residual disinfectant for distribution, is usually formed from the reaction of chlorine with ammonia. Careful control of monochloramine formation in water treatment is important to avoid the formation of di- and trichloramines, because these can cause unacceptable tastes and odours. The formation of nitrite as a consequence of microbial activity in biofilms in the distribution system is a possibility when monochloramine is used as a residual disinfectant, particularly if ammonia levels are not sufficiently controlled.

8|2|2 Coagulants

Coagulation and flocculation are important barriers to microbiological contaminants and are key processes for reducing naturally occurring organic matter and turbidity, which can seriously affect the efficiency of disinfection. Chemicals used as coagulants in drinking-water treatment include aluminium and iron salts, such as aluminium sulfate, polyaluminium chloride or ferric sulfate. No health-based guideline values have been set for aluminium and iron, because neither is considered to be of significance to health when used under normal circumstances in water treatment. However, both substances can give rise to problems of discolouration and deposition of sediment in distribution if present in excessive amounts. The concentrations in drinking-water above which problems are likely to occur are 0.3 mg/L for iron and 0.2 mg/L for aluminium. This concentration of aluminium should be achievable by any water treatment works, but a well-run large treatment works should be able to achieve a routine average residual value of 0.1 mg/L.

The best management strategy for both aluminium and iron when used in treatment is to ensure that coagulation is optimized to prevent excessive amounts remaining in the drinking-water.

Sometimes organic polymers, known as coagulant aids, are used to assist with coagulation. These polymers may contain residual acrylamide or epichlorohydrin monomers. Monitoring for these chemicals in drinking-water is not normally appropriate, because measurement in water is very difficult. Instead, these chemicals are managed by specifying a maximum amount of residual monomer in the polymer and a maximum concentration of polymer that can be added to the treatment process. The WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) give additional guidance on the approval and control of chemicals and materials in contact with drinking-water. They also cover the need to ensure that any chemicals used in water treatment do not contain contaminants that could be of concern for drinking-water quality.

8|3

Other chemicals and materials used in water treatment

A number of other chemicals may be added in treatment. These include substances such as sodium hydroxide for adjusting pH and, in certain circumstances, chemicals for fluoridation of drinking-water. In all cases it is appropriate to specify the quality of the chemicals added so that the final water does not contain unacceptable concentrations of unwanted contaminants. Ensuring that chemicals used are of an appropriate quality is generally best managed by product specification rather than by monitoring drinking-water. The WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) have a section on approval and control of chemicals and materials for use in contact with drinking-water that provides guidance on product specification.

Ion-exchange resins and more advanced treatment processes based on membranes are increasingly used in drinking-water treatment. It is possible that chemicals can leach from the materials used in the manufacture of these systems; therefore, these too should be managed by appropriate product and materials specifications.

8|4

Distribution systems

The most widely used metal for pipes and fittings in distribution systems is iron, which may give rise to corrosion products. These products can cause discolouration at the tap if the distribution system is not managed correctly. Monitoring for corrosion products is not appropriate; instead, it is necessary to manage the problem of corrosion and the accumulation of corrosion products in distribution. In some circumstances, iron hand pumps can give rise to discoloured water if they are corroded by water that is too acidic. In such cases, it may be appropriate to screen the raw water for low pH and, where a low pH is detected, consider using alternative materials for the pumps. The corrosivity of water is a function of many factors, including pH, low alkalinity, chloride and sulfate ions, sediment and microbial activity; this topic is covered in more detail in the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006).

Lead, copper and sometimes zinc may be present in drinking-water, as a consequence of the use of these metals in pipework in public, commercial and domestic buildings. Monitoring is complicated by the fact that both occurrence and concentration will vary from building to building and at different times of the day. Concentrations will usually be greater the longer the water is standing in the pipe, so first-draw water will usually have higher levels than water from a fully flushed system. Copper and zinc are less likely than lead to occur at levels of concern, except in very new buildings or where highly corrosive water is supplied; however, concentrations may be increased in some circumstances when copper piping is used as a means of earthing the electrical system in a building. Lead frequently occurs at concentrations greater than the guideline value in situations where lead pipes and solders are present. Lead is also a component of brass, bronze and gun-metal, which are used in fittings in plumbing systems. In some circumstances, fittings made of these metals can be a significant contributor to the concentrations of lead at the tap.

Monitoring of metals in water arising from plumbing is difficult because of variations in concentration with time and the fact that the levels are frequently property specific. Where lead pipes are present in a large number of buildings, the most important requirements are public health surveillance (to ensure that there is no significant public health problem) and identification of the buildings that have lead piping. Consideration of lead in drinking-water should be part of an overall lead-reduction strategy, because lead exposure from other sources may be more significant. There are a number of possible approaches to reducing lead levels in drinking-water, ranging from targeted replacement of lead pipes to central control of corrosion to reduce the possibility that lead will dissolve in water.

Lead can also be present if lead solder is used in the installation of copper piping. A control measure in this case would normally be to avoid the use of lead solders for applications involving drinking-water.

Polyvinyl chloride (PVC) plastic pipe is also widely used in distribution systems. Lead has been used as a stabilizer in unplasticized PVC pipe, and may give rise to elevated lead levels in drinking-water for a time after a new installation. Such pipe is normally of large diameter; thus, the dilution effect of the water flowing through the pipe will reduce the concentration of lead and may result in lead concentrations below the guideline value. There have been cases where the levels of vinyl chloride monomer remaining in the plastic have been higher than desirable. However, chemical monitoring of drinking-water is not normally considered to be appropriate and the most suitable method of management is by product specification, as indicated above for other materials.

8|5
References

WHO (2004). *Guidelines for Drinking-water Quality*, 3rd ed., Volume 1: Recommendations, World Health Organization, Geneva.

WHO (2006). *Guidelines for Drinking-water Quality*, 1st Addendum to the 3rd ed., Volume 1: Recommendations, World Health Organization, Geneva.

WHO (2006). *Health Aspects of Plumbing*, , World Health Organization, Geneva.

Table 8.1 | Suggested risk management strategies for chemicals from water production and distribution

Chemical	Monitoring approach	Management and control strategies
Coagulants:		
Aluminium	Verification*	Above 0.2 mg/L can cause problems of dirty water. Controlled by treatment optimization
Iron	Verification*	Above 0.3 mg/l can cause problems of dirty water, Controlled by treatment optimization
Coagulant aids:		
Acrylamide	None	Addressed by product specification
Epichlorohydrin	None	Addressed by product specification
Treatment chemicals *Disinfectants:*		
Ozone	None	Levels controlled through dose optimization
Chlorine	Indicator of operational effectiveness of disinfection	Critical for good disinfection. Post-treatment monitoring required to ensure adequate disinfection.
Chlorine dioxide	Verification*, together with monitoring of chlorite and chlorate	Controlled through dose optimization
Monochloramine	Verification*	Managed by ensuring correct ammonia dose and operating conditions
Chlorination by-products		
Trihalomethanes	Verification*	Managed by ensuring correct ammonia dose and operating conditions
All other chlorination by-products	Possibly verification for haloacetic acids (HAAs) only	Controlled by optimization of coagulation and filtration to remove precursor substances.
Chlorite/chlorate	Verification*	Levels controlled by optimization of chlorine dioxide dose. Managed by correct storage of hypochlorite and minimizing storage time.
Bromate	Verification*	Controlled by optimization of ozonation conditions. Managed by due care in selection of brine for electrolytic generation of hypochlorite.
Nitrite	None	Managed by ensuring correct ammonia dose and operating conditions
Pipe materials		
Iron	None	Managed by corrosion inspection
Lead	Part of broader public health investigation	Important for consideration. Managed by inspection and investigation of pipework in buildings
Copper	Part of broader investigation of water quality in buildings	Pipework in buildings not usually a problem unless very aggressive water. Managed by inspection.
Zinc	Part of broader investigation of water quality in buildings	Galvanized pipes in buildings. Managed by inspection
Vinyl chloride	None	Managed by ensuring correct product specification of polyvinyl chloride (PVC) plastic pipe

* Verification in this context is the use of analysis to verify that the control and management systems are working and does not imply routine monitoring.


C

Appendices

appendix 1

Potential sources and uses of chemicals considered in the WHO *Guidelines for Drinking-water Quality*

This appendix lists the chemicals considered in the third edition of the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) and their primary sources. Table A1.1 covers chemicals considered for a health-based guideline value (in cases where a health-based value was not considered to be appropriate, no value was assigned). Table A1.2 covers chemicals that affect the acceptability of drinking-water. The values given in Tables A1.1 and A1.2 are only guides – local circumstances need to be considered when determining national or local standards, or when assessing priorities for action (including monitoring). The WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) give more detailed information on the individual chemicals, which may be helpful in setting standards or assessing priorities.

Tables A1.1 and A1.2 also list the major uses of each chemical and the specific industries that may discharge the chemical (classified by the United Nations (UN) industry/process code numbers, details of which are given in Appendix 2). The lists are not comprehensive, because there may be considerable variation in the uses of chemicals by individual industries in different countries and regions. However, the information given may be useful to water authorities and related agencies when preparing an inventory of potential chemical contaminants within a catchment. Some of the uses listed may be very minor, but are nevertheless included in the list because it is not clear that they can be ignored when assessing the potential for contamination from industrial sources.

Pesticides, which may also arise from industrial sources when the pesticides are manufactured or formulated, are covered in Appendix 3.

Table A1.1 | Chemicals considered for health-based guideline values*

* In some cases, substances were considered but no guideline value was proposed, because a health-based guideline was not considered appropriate.

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Acrylamide[b]	0.5				X	X	Chemical intermediate; monomer in the production of polyacrylamide; production of flocculants; grouting agents	3511, 3513, 3529, 354, 4
Alachlor	20		X		X		Pre- or early post-emergence herbicides to control annual grasses and broad-leaved weeds	111, 3512
Aldicarb	10		X		X		Insecticides to control nematodes in soil and insects and mites on a wide variety of crops	111, 3512
Aldrin and dieldrin	0.03		X		X		Insecticides for termite control	111, 3512
Antimony	20	X			X	X	Semiconductor alloy; batteries; antifriction compounds; ammunition; cable sheathing; flameproofing compounds; ceramics; glass; pottery; type castings for commercial printing; solder alloys; fireworks; treatment of parasitic diseases; pesticides	23, 3210, 342, 3512, 3522, 361, 362, 372, 38, 932

Chemical	**Guideline value (µg/L unless otherwise specified)**	**Origin**					**Major use(s)**	**Potential source (UN industry/ process code numbers, as shown in Appendix 2)**
		Naturally occurring	**Agricultural activities**	**Human settlements[a]**	**Industries**	**Production and distribution**		
Aromatic hydrocarbons *(see benzene, toluene, xylenes, ethylbenzene, styrene)*								
Arsenic	10[d]	X			X		Alloying agents in the manufacture of transistors, lasers, and semiconductors; processing of glass, pigments, textiles, paper, metal adhesives, wood preservatives and ammunition; hide tanning process; pesticides; feed additives; pharmaceuticals	111, 12, 23, 3121, 32, 341, 3512, 3521, 3522, 362, 372, 38
Atrazine	2		X	X	X		Pre- and post-emergence herbicides for the control of weeds	111, 3512
Barium	700	X			X		Plastics; rubber; electronics; ceramic glazes and enamels; glass-making; brick-making; paper-making; lubricant additive; pharmaceuticals and cosmetics; case-hardening of steel; oil and gas industries as a wetting agent for drilling mud	22, 23, 341, 3513, 3521, 3522, 354, 355, 362, 3691, 372, 38
Bentazone[f]			X		X		Herbicides used in winter and spring cereals	111, 3512
Benzene	10			X	X		For the production of styrene/ethylbenzene, cumene/phenol, and cyclohexane; as a solvent; as an additive in petrol to increase the octane number	3511, 3521, 353, 354,
Benzo[a]pyrene	0.7				X	X	Incomplete combustion of organic material, forest fires and volcanic eruptions; incomplete combustion of fossil fuels, coke oven emissions, aluminium smelters, vehicle exhausts	37, 4101, 7

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Beryllium[f]		X			X		Specialized metal working and alloys such as munitions	
Boron[e]	500	X		X	X		High-temperature abrasives; special-purpose alloys; steel-making; catalysts in the manufacture of magnesium alloy products; metal refining; control of heavy metal discharges in wastewater; jet and rocket fuels; glass manufacture; wood and leather preservation; flame retardants; cosmetic products; neutron absorbers; mild antiseptics or bacteriostats in eyewashes; mouthwashes; burn dressings; nappy rash powders; cleaning compounds; agricultural fertilizers; algicides; herbicides; insecticides	111, 12, 23, 323, 3512, 3522, 3529, 362, 37, 932
Bromate[e]	10				X	X	(Disinfection by-product); permanent wave neutralizing solutions; flour maturing agent; dough conditioning agent; fish paste; beer and cheese	3112, 3114, 3116, 3133, 3529, 92
Bromodichloromethane	60				X	X	(Disinfection by-product); laboratory reagents; chemical intermediates for the synthesis of organic compounds; fluids for mineral ore separation; solvent for fats, waxes and resins; flame retardants	23, 3511, 3529, 354
Bromoform	100				X	X	(Disinfection by-product); laboratory reagents; chemical intermediates for the synthesis of organic compounds; fluids for mineral ore separation; solvent for fats, waxes and resins; flame retardants; sedative and cough suppressant	23, 3511, 3529, 354, 932

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Cadmium	3	X			X		Anticorrosive; electroplated steel; pigments in plastics; electric batteries; electronic components; nuclear reactors	23, 3522, 372, 38
Carbofuran	7		X		X		Systemic acaricides; insecticides; nematicides	111, 3512
Carbon tetrachloride	4			X	X		Production of chlorofluorocarbon refrigerants and foam-blowing agents; solvents; manufacture of paints and plastics; metal cleaning solvent; fumigants	111, 351, 3521, 354, 38
Chloral hydrate[f]					X	X	(Disinfection by-product); sedative and hypnotic in human and veterinary medicine	3522, 3529, 354, 932
Chlorate	700[d]				X	X	(Disinfection by-product); preparation of chlorine dioxide; manufacture of dyes, matches and explosives; tanning and finishing leather; herbicides and defoliants	111, 3529
Chlordane	0.2		X		X		Versatile, broad-spectrum contact insecticides for non-agricultural purposes	3512, 354
Chlorinated acetate *(see monochloroacetate, dichloroacetate, trichloroacetate, chloral hydrate)*								
Chlorinated alkanes *(see carbon tetrachloride, dichloromethane, 1,2-dichloroethane, 1,1,1-trichloroethane)*								
Chlorinated benzenes *(see monochlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, trichlorobenzene)*[f]								
Chlorinated ethenes *(see vinyl chloride, 1,1-dichloroethene, 1,2-dichloroethene, trichloroethene, tetrachloroethene)*								

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Chlorine[c]	5 mg/L				X	X	Disinfectants and bleach for domestic and industrial purposes; disinfection of drinking-water and swimming pools; control of bacteria and odours in the food industry	31, 3511, 3529, 4, 94
Chlorite	700[d]				X	X	(Disinfection by-product); on-site production of chlorine dioxide; bleaching agent in the production of paper, textiles, and straw products; manufacture of waxes, shellacs and varnishes	3529
Chloroform	300				X	X	(Disinfection by-product); production of chlorodifluoromethane (refrigerant); extraction solvent for resins, gums and other products; fumigants; anaesthetic	111, 3511, 3512, 3529, 354, 932
Chlorophenols *(see 2-chlorophenol, 2,4-dichlorophenol, 2,4,6-trichlorophenol)*								
Chlorotoluron	30		X		X		Pre- and post-emergence herbicides	111, 3512
Chlorpyrifos	30		X		X		Acaricides; insecticides; nematicides	111, 3512
Chromium	50[d]	X			X		The leather tanning industry; manufacture of catalysts; pigments and paints; fungicides; the ceramics and glass industries; photography; chrome alloy; chromium metal production; chrome plating; corrosion control	111, 23, 3231, 3512, 3521, 3522, 361, 362, 372, 38, 94

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Copper	2 mg/L			X	X	X	Water pipes; roof coverings; household goods; chemical equipment; the arts; alloys; pest control; inorganic dyes; feed additives; photography; seed disinfectants; fungicides; algicides; electroforming	111, 23, 3512, 3522, 3529, 372, 4, 94
Cyanazine	0.6		X		X		Herbicides	111, 3512
Cyanide	70	X			X		Electroplating	371, 38, 41
Cyanogen chloride (as CN)	70				X	X	(Disinfection by-product); tear gas; fumigant gases; reagent in the synthesis of other compounds	111, 3512, 354
2,4-D	30		X		X		Systemic chlorophenoxy herbicides	111, 3512
2,4-DB	90		X		X		Post-emergence herbicides to control broad-leaved annual and perennial weeds in variety of agricultural crops	111, 3512
DDT and metabolites	1		X		X		Nonsystemic contact insecticide with a broad spectrum of activity	111, 3512
Dibromoacetonitrile	70					X	(Disinfection by-product)	
Dibromochloromethane	100				X	X	(Disinfection by-product); laboratory reagents; chemical intermediates for the synthesis of organic compounds; fluids for mineral ore separation; solvent for fats, waxes and resins; flame retardants	23, 3511, 3529, 354

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
1,2-Dibromo-3-chloropropane	1		X		X		Nematicidal fumigants	111, 3512
1,2-Dibromoethane	0.4[d]				X		Insecticide	111, 3512
Dichloroacetate[e]	50[d]				X	X	(Disinfection by-product); chemical intermediate of synthesis of organic materials; pharmaceuticals and medicines; topical astringent; fungicides	111, 3511, 3512, 3522, 3529, 354
Dichloroacetonitrile	20[d]				X	X	(Disinfection by-product)	
1,2-Dichlorobenzene[c]	1 mg/L				X		Odour-masking agents; dyestuffs; pesticides	111, 3512
1,4-Dichlorobenzene[c]	300				X		Odour-masking agents; dyestuffs; pesticides	111, 3512
1,2-Dichloroethane	30				X		Production of vinyl chloride; solvent; lead scavenger in lead petrol	3511, 3521, 354,
1,1-Dichloroethene[f]					X		Monomer in the production of polyvinylidene chloride co-polymers; intermediate in the synthesis of other organic chemicals	3511, 354
1,2-Dichloroethene	50				X		Intermediate in the synthesis of chlorinated solvents and compounds; extraction solvent for organic materials	3511, 354
Dichloromethane	20			X	X		Organic solvent; paints; insecticides; degreasing and cleaning fluids	111, 3512, 3521, 354, 38

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	**Agricultural activities**	**Human settlements**[a]	**Industries**	**Production and distribution**		
1,2-Dichloropropane (1,2-DCP)	40[d]		X		X		Chemical intermediate; lead scavenger for antiknock fluids; dry-cleaning solvent; soil fumigants; scouring compound; spotting agent; metal-degreasing agent	111, 3511, 3512, 3529, 354, 952
1,3-Dichloropropene	20		X		X		Soil fumigants	111, 3512
Dichlorprop	100		X		X		Post-emergence herbicides to control broad-leaved annual and perennial weeds in variety of agricultural crops	111, 3512
Di(2-ethylhexyl)adipate[f]					X		Plasticizer for synthetic resins such as PVC; lubricant for hydraulic fluid	3513, 3529, 354, 38
Di(2-ethylhexyl)phthalate	8			X	X		Plasticizer in many flexible PVC production and PVC co-polymer resins; dielectric fluids for small (low-voltage) electrical capacitors	3513, 3529, 354, 38
Dimethoate	6		X		X		Acaricides; insecticides; nematicides	111, 3512
Diquat[f]			X		X		Herbicides	111, 3512
Edetic acid (EDTA)	600			X	X		Treatment of lead poisoning in humans and domestic animals; laundry detergents; cosmetics; photochemicals; pharmaceuticals; galvanizing; water softening; electroplating; polymerization; textile treatments; paper production	3210, 341, 3513, 3529, 354, 38, 95
Endosulfan[f]			X		X		Acaricides; insecticides	111, 3512

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Endrin	0.6		X		X		Avicides; insecticides	111, 3512
Epichlorohydrin[b]	0.4[d]		X		X	X	Manufacture of glycerol and unmodified epoxy resins; manufacture of elastomers, water-treatment resins, surfactants, ion exchange resins, plasticizers, dyestuffs, pharmaceutical products, oil emulsifiers, lubricants, and adhesives	3511, 3513, 3529, 354, 38, 4
Ethylbenzene[c]	300			X	X		In xylene mixtures (15–20%); paint industry; insecticide sprays; petrol blends; production in the styrene and acetophenone, solvent; constituent of asphalt and naphtha	3511, 3512, 3521, 354, 38
Fenitrothion[f]			X		X		Insecticides	111, 3512
Fenoprop	9		X		X		Post-emergence herbicides to control broad-leaved annual and perennial weeds in variety of agricultural crops	111, 3512
Fluoranthene[f]					X		Incomplete combustion of organic material, forest fires and volcanic eruptions; incomplete combustion of fossil fuels, coke oven emissions, aluminium smelters, vehicles	37, 4101, 7
Fluoride	1.5 mg/L	X			X		Aluminium production; flux in the steel and glass fibre industries; production of phosphate fertilizers, bricks, tiles, and ceramics; water fluoridation schemes	351, 361, 362, 3691, 37, 4
Formaldehyde[f]					X	X	(Disinfection by-product); production of urea-formaldehyde, phenolic, melamine, pentaerythritol and polyacetal resins; industrial synthesis of a number of organic compounds; cosmetics; fungicides; textiles; embalming fluids	3210, 322, 351, 3529, 354
Glyphosate and aminomethylphosphonic acid (AMPA)[f]			X		X		Herbicides	111, 3512

Chemical	Guideline value (μg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Heptachlor and heptachlorepoxide[f]			X		X		Soil and seed treatment to control ants, cutworm and other insects; to control household insects and pests of human and domestic animals	111, 3512, 354
Hexachlorobenzene[f]			X		X		Fungicides; chemical processes by-product; impurity in some pesticides	111, 3512, 354
Hexachlorobutadiene	0.6				X	X	Solvent in chlorine gas production; intermediate in the manufacture of rubber compounds; lubricant; gyroscopic fluid; pesticides; fumigants in vineyards	111, 3511, 3512, 3529, 354, 355, 38
Isoproturon	9		X		X		Herbicides	111, 3512
Lead	10	X			X	X	Lead acid batteries; solder; alloys; cable sheathing; pigment; rust inhibitors; ammunition; glazes; plastic stabilizers; antiknock compounds in petrol; plumbing fittings; solder; lead pipes	23, 3513, 3529, 353, 361, 372, 38
Lindane	2		X		X		Insecticides; seed treatment; therapeutic pesticides in humans and animals	111, 3512, 932
Malathion[f]			X		X		Acaricides; insecticides	111, 3512
Manganese[c]	400	X			X		Iron, steel, and other alloys; batteries; glass; fireworks; oxidant for cleaning, bleaching and disinfection purposes	23, 3529, 362, 37, 38

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
MCPA	2		X		X		Herbicides	111, 3512
Mecoprop	10		X		X		Herbicides; plant growth regulators	111, 3512
Mercury (inorg)	6				X		Cathode in the electrolytic production of chlorine and caustic soda; lamps; arc rectifiers; mercury cells; switches; thermometers; barometers; laboratory apparatus; dental amalgams; raw material for various mercury compounds; fungicides; antiseptics; preservatives; pharmaceuticals; electrodes; reagents	111, 23, 3511, 3512, 3522, 362, 372, 38, 932
Methoxychlor	20		X		X		Insecticides	111, 3512
Metolachlor	10		X		X		Herbicides	111, 3512
Microcystin-LR	1	X					Toxin from blue-green algae (cyanobacteria).	
Molinate	6		X		X		To control germinating and grassy weeds	111, 3512
Molybdenum	70	X	X		X		Special steel; electrical contacts; spark plugs; X-ray tubes; filaments; screens; grids for radio valves; production of tungsten, glass-to-metal seals, nonferrous alloys and pigments; lubricant additive; direct treatment of seeds; formulation of fertilizer to prevent molybdenum deficiency	23, 354, 362, 37, 38

Chemical	**Guideline value (µg/L unless otherwise specified)**	**Origin**					**Major use(s)**	**Potential source (UN industry/ process code numbers, as shown in Appendix 2)**
		Naturally occurring	**Agricultural activities**	**Human settlements**[a]	**Industries**	**Production and distribution**		
Monochloramine[c]	3 mg/L				X	X	(Disinfection by-product); intermediates in the manufacture of hydrazine; disinfectants for drinking-water	3529
Monochloroacetate	20				X	X	(Disinfection by-product); intermediate or reagent in the synthesis of a variety of chemicals; pre-emergence herbicides	111, 3511, 3512, 3529, 354
Monochlorobenzene[f]					X		Solvent in pesticide formulation; degreasing agent; intermediate in the synthesis of other halogenated organic compounds	111, 3511, 3512, 354, 38
Nickel	70	X		X	X	X	Alloys, including stainless steel, batteries, chemicals, catalysts and the electrolytic coating of items such as chromium-plated taps and fittings used for tap water	23, 3529, 37, 38
Nitrate (as NO_3^-)	50 mg/L (short-term exposure)		X	X	X		Inorganic fertilizers; oxidizing agent; production of explosives; glass making	111, 29, 3511, 3512, 3529, 362
Nitrilotriacetic acid (NTA)	200			X	X		Builder in laundry detergents; treatment of boiler water to prevent the accumulation of mineral scale; photography; textile manufacture; paper and cellulose production; metal plating and cleaning operations; therapeutic chelating agent for the treatment of manganese poisoning and iron overloading	3210, 341, 3529, 354, 38, 932, 94, 95

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Nitrite (as NO_2^-)	3 mg/L (short-term exposure)		X	X		X	Food preservation, especially in cured meats	111, 3111, 3529
	0.2 mg/L[d] (long-term exposure)							
Pendimethalin	20		X		X		Herbicides	111, 3512
Pentachlorophenol	9[d]		X		X		Fungicides; herbicides; insecticides; molluscicides; plant growth regulators	111, 3512
Permethrin[f]			X		X		Contact insecticides	111, 3512
Pyriproxyfen	300		X		X		Insecticides	111, 3512
Selenium	10	X			X		Photocopy machine photoreceptor; colouring agent for heat-absorbing glass; decolouring agent for lead glass; electronic devices; television cameras, photoelectric cells; magnetic core for calculators; solar cells; catalytic agents, copper and copper alloy colouring, insecticides and fungicides, rubber, mineral and vegetable oils	23, 372
Simazine	2		X		X		Pre-emergence herbicides	111, 3512
Styrene[c]	20			X	X		Production for plastics and resins	3513, 354

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
2,4,5-T	9		X		X		Plant growth regulators; herbicides	111, 3512
Terbuthylazine (TBA)	7		X		X		Herbicides	111, 3512
Tetrachloroethene	40			X	X		Solvent in the dry-cleaning industry; degreasing solvent in metal industries; a heat-transfer medium; manufacture of fluorohydrocarbons	3511, 354, 38, 952
Toluene[c]	700			X	X		Solvent for paint, coatings, gums, oils and resins; raw material in the production of benzene, phenol, and other organic solvents; blending of petrol	3511, 3513, 3521, 353, 354, 38
Trichloroacetaldehyde *(see chloral hydrate)*								
Trichloroacetate	200				X	X	(Disinfection by-product); intermediate in the synthesis of organic chemicals; laboratory reagent; herbicides; soil sterilizer; antiseptic	111, 3511, 3512, 3529, 354
Trichloroacetonitrile			X			X	(Disinfection by-product); insecticides	111, 3512
Trichlorobenzenes[f] (tot)					X		Intermediate in chemical synthesis; coolant; lubricant; heat-transfer medium; polyester dyeing; termite-control preparations; insecticides	111, 3210, 3211, 3511, 3512, 354, 38

Chemical	Guideline value (µg/L unless otherwise specified)	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
		Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
1,1,1-Trichloroethane[f]					X		Cleaning solvent for electrical equipment, motors, electronic instruments and upholstery; solvent for adhesives, coatings and textile dyes; coolant and lubricant in metal cutting oils; component of inks and drain cleaners	3529, 354, 38
Trichloroethene	20[d]			X	X		Dry cleaning; degreasing of fabricated metal parts; solvent for fats, waxes, resins, oils, rubber, paints and varnishes; inhalation analgesic and anaesthetic	3513, 3521, 354, 38, 932, 952
2,4,6-Trichlorophenol[c]	200				X	X	(Disinfection by-product); production of 2,3,4,6-tetrachlorophenol and pentachlorophenol; germicides; glue and wood preservative; antimildew agent	111, 12, 3511, 3512, 3529, 354
Trifluralin	20		X		X		Pre-emergence herbicides	111, 3512
Trihalomethanes *(see bromoform, dibromochloromethane, bromodichloromethane, chloroform)*								
Uranium[e]	15[d]	X			X		Fuel in nuclear power stations	23, 372, 4101
Vinyl chloride	0.3				X	X	Production of polyvinyl chloride (PVC); co-monomer with ethenyl ethanoate or 1,1-dichloroethene; raw material in the manufacture of 1,1,1-trichloroethane and monochloraldehyde	3511, 3513, 354
Xylenes[c]	500			X	X		Manufacture of insecticides and pharmaceuticals; component of detergents; solvent for paints, inks and adhesives; blending petrol; manufacture of various chemicals	111, 3511, 3512, 352, 353, 354, 38

a Waste disposal and use of sewage sludges (classified in this publication as originating from human settlements) may result in the presence of chemicals from human settlements additional to those shown in this table.
b Managed through product specification.
c May cause problems with acceptability at concentrations below health-based guideline value.
d Provisional guideline value – refer to the WHO *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006) for complete explanation of provisional guidelines
e In some circumstances, treatment may be difficult at concentrations above the guideline value.
f Health-based guideline value not proposed because not of health concern at levels found in drinking-water.
X Potential source of chemical in drinking water. To be taken into consideration as part of the assessment of priority chemicals.

Table A1.2 | Chemicals that may give rise to consumer complaints

Chemical	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
	Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Aluminium			X	X	X	Antacids; antiperspirants; food additives; vaccine adjuvants; flocculants	23, 311/2, 3522, 372, 38,4
Ammonia	X	X		X	X	Fertilizer and animal feed production; manufacture of fibre, plastics, explosives, paper and rubber; coolant; metal processing; starting production for many nitrogen-containing compounds; cleaning agents; food additive; diuretic	311/2, 3210, 341, 351, 3523, 3529, 355, 38
Chloride	X		X	X		Production of industrial chemicals such as caustic soda, chlorine, sodium chlorite and sodium hypochlorite; snow and ice control; production of fertilizers	3121, 3511, 3512
Chlorine				X	X	See Table A1.1	See Table A1.1
2-Chlorophenol				X	X	See Table A1.1	See Table A1.1
Copper	X			X	X	See Table A1.1	See Table A1.1
1,2-Dichlorobenzene				X		See Table A1.1	See Table A1.1
1,4-Dichlorobenzene				X		See Table A1.1	See Table A1.1
2,4-Dichlorophenol				X	X	See Table A1.1	See Table A1.1
Ethylbenzene			X	X		See Table A1.1	See Table A1.1

Chemical	**Origin**					**Major use(s)**	**Potential source (UN industry/ process code numbers, as shown in Appendix 2)**
	Naturally occurring	**Agricultural activities**	**Human settlements**[a]	**Industries**	**Production and distribution**		
Hydrogen sulfide	X			X		Conversion into sulfur; sulfuric acid manufacture; dye manufacture; tanning; production of wood-pulp; chemical processing; manufacture of cosmetics	3231, 341, 3511, 3529,354
Iron	X			X	X	Drinking-water pipes; pigments in paints and plastics; food colours; treatment of iron deficiency in humans; coagulants	23, 3513, 3522, 3529, 371, 38,4, 932
Manganese	X			X		See Table A1.1	See Table A1.1
Monochloramine				X	X	See Table A1.1	See Table A1.1
Monochlorobenzene				X		See Table A1.1	See Table A1.1
Sodium	X			X		Manufacture of tetraethyl lead and sodium hydride; titanium production; catalyst for synthetic rubber; laboratory reagent; coolant in nuclear reactors; electric power cables; non-glare lighting for roads; solar-powered electric generators; water treatment	3511, 3529, 355, 362, 372, 38, 4
Styrene			X	X		See Table A1.1	See Table A1.1
Sulfate	X			X		Fertilizers; chemicals; dyes; glass; paper; soaps; textiles; fungicides; insecticides; astringents; emetic; mining, wood-pulp, metal and plating industries; sewage treatment; leather processing; sedimentation agent; control of algae	111, 2, 3231, 341, 3511, 3512, 3523, 3529, 362, 37, 38, 4
Synthetic detergents			X	X		Cleaning and washing	(all industries)

Chemical	Origin					Major use(s)	Potential source (UN industry/ process code numbers, as shown in Appendix 2)
	Naturally occurring	Agricultural activities	Human settlements[a]	Industries	Production and distribution		
Toluene			X	X		See Table A1.1	See Table A1.1
Trichlorobenzenes (tot)				X		See Table A1.1	See Table A1.1
2,4,6-Trichlorophenol				X	X	See Table A1.1	See Table A1.1
Xylene			X	X		See Table A1.1	See Table A1.1
Zinc	X			X	X	Corrosion-resistant alloys; brass; galvanizing steel; iron products; rubber; treatment of zinc deficiency in humans; pesticides	111, 23, 3512, 3522, 355, 372, 38, 932

a Waste disposal and use of sewage sludges (classified in this publication as originating from human settlements) may result in the presence of chemicals from human settlements additional to those shown in this table.

X Potential source of chemical in drinking water. To be taken into consideration as part of the assessment of priority chemicals.

References

WHO (2004). *Guidelines for Drinking-water Quality*, 3rd ed., Volume 1: Recommendations, World Health Organization, Geneva.

WHO (2006). *Guidelines for Drinking-water Quality*, 1st Addendum to the 3rd ed., Volume 1: Recommendations, World Health Organization, Geneva.

appendix 2

Chemicals potentially discharged through effluents from industrial sources

The following listings are not intended to be comprehensive, because there may be considerable variation in the uses of chemicals by individual industries in different countries and regions. The listings have been developed to help water authorities and other agencies related to drinking-water quality monitoring and control to undertake an inventory of potential chemical contaminants within a catchment. Some of the uses listed may be very minor, but it is not clear that they can be ignored when assessing the potential for contamination from industrial sources. Where no potential chemical discharges have been included for an activity, this does not necessarily mean that there are no discharges – an assessment of the management programme may be required, based on local knowledge.

Table A2.1 | Chemicals potentially discharged through effluents from industrial sources

Source activity	Chemicals potentially discharged through effluent
0 Activities not adequately defined	
Consumer solvent use, surface coating	
1 Agriculture, hunting, forestry and fishing	
11 *Agriculture and hunting*	
111 Agriculture and livestock production	Alachlor, aldicarb, aldrin and dieldrin, arsenic, atrazine, bentazone, boron, carbofuran, carbon tetrachloride, chlorate, chloroform, chlorotoluron, chlorpyrifos, chromium, copper, cyanazine, cyanogen chloride, 2,4-D, 2,4-DB, DDT and metabolites, 1,2-dibromo-3-chloropropane, 1,2-dibromoethane, dichloroacetate, 1,2-dichlorobenzene, 1,4-dichlorobenzene, dichloromethane, 1,2-dichloropropane (1,2-DCP), 1,3-dichloropropene, dichlorprop, dimethoate, diquat, endosulfan, endrin, epichlorohydrin, fenitrothion, fenoprop, glyphosate and AMPA, heptachlor and heptachlorepoxide, hexachlorobenzene, hexachlorobutadiene, isoproturon, lindane, malathion, MCPA, mecoprop, mercury, methoxychlor, metolachlor, molinate, monochloroacetate, monochlorobenzene, nitrate, nitrite, pendimethalin, pentachlorophenol, permethrin, pyriproxyfen, simazine, 2,4,5-T, terbuthylazine (TBA), trichloroacetate, trichloroacetonitrile, trichlorobenzenes, 2,4,6-trichlorophenol, trifluralin, xylenes
12 *Forestry and logging*	
121 Forestry	Arsenic, boron, 2,4,6-trichlorophenol
2 Mining and quarrying	
21 *Coal mining*	Sulfate
22 *Crude petroleum and natural gas production*	Barium
23 *Metal ore mining*	Aluminium, antimony, arsenic, barium, beryllium, boron, bromodichloromethane, bromoform, cadmium, chromium, copper, dibromochloromethane, iron, lead, manganese, mercury, molybdenum, nickel, selenium, uranium, zinc
29 *Other mining*	Nitrate
3 Manufacturing	
31 *Manufacture of food, beverages and tobacco*	Chlorine
311/2 Food manufacturing	Aluminium, ammonia
3111 Slaughtering, preparing and preserving meat	Nitrite
3112 Manufacture of dairy products	Bromate
3113 Canning and preserving fruits and vegetables	
3114 Canning and preserving and processing of fish	Bromate
3115 Manufacture of vegetable and animal oils and fats	
3116 Grain mill products	Bromate
3117 Bakery products	
3118 Sugar factories and refineries	
3121 Food products not elsewhere classified	Arsenic, chloride
3122 Alfalfa dehydrating	

Source activity	**Chemicals potentially discharged through effluent**
313 Beverage Industries	
3131 Distilling, rectifying and blending spirits	
3132 Wine industries	
3133 Malt liquors and malt	Bromate
3134 Soft drinks	
32 *Textile, wearing apparel and leather*	Arsenic
321 Manufacture of textiles	
3210 Manufacture of textiles	Ammonia, antimony, trichlorobenzenes, EDTA, formaldehyde, nitrilotriacetic acid
322 Manufacture of wearing apparel, except footwear	Formaldehyde
3211 Spinning, weaving and finishing textiles	Trichlorobenzenes
3214 Carpet and rug manufacture	
323 Manufacture of leather and products of leather	Boron
3231 Tanneries and leather finishing	Chromium, hydrogen sulfide, sulfate
34 *Paper and paper products, printing and publishing*	
341 Manufacture of paper and paper products	
342 Printing, publishing and allied industries	Antimony
35 *Manufacture of chemicals, and chemical, petroleum, coal rubber and plastic products*	
351 Manufacture of industrial chemicals	Ammonia, carbon tetrachloride, fluoride, formaldehyde,
3511 Basic industrial chemicals, except fertilizers	Acrylamide, benzene, bromodichloromethane, bromoform, chloride, chlorine, chloroform, dibromochloromethane, dichloroacetate, 1,2-dichloroethane, 1,1–dichloroethene, 1,2–dichloroethene, 1,2-dichloropropane, epichlorohydrin, ethylbenzene, hexachlorobutadiene, hydrogen sulfide, mercury, monochloroacetate, monochlorobenzene, nitrate, sodium, sulfate, tetrachloroethene, toluene, trichloroacetate, trichlorobenzenes, 2,4,6-trichlorophenol, vinyl chloride, xylenes
3512 Manufacture of fertilizers and pesticides	Alachlor, aldicarb, aldrin and dieldrin, antimony, arsenic, atrazine, bentazone, boron, carbofuran, chlordane, chloride, chloroform, chlorotoluron, chlorpyrifos, chromium, copper, cyanazine, cyanogen chloride, 2,4-D, 2,4-DB, DDT and metabolites, 1,2-dibromo-3-chloropropane, 1,2-dibromoethane, dichloroacetate, 1,2-dichlorobenzene, 1,4-dichlorobenzene, dichloromethane, 1,2-dichloropropane (1,2-DCP), 1,3-dichloropropene, dichlorprop, dimethoate, diquat, endosulfan, endrin, epichlorohydrin, ethylbenzene, fenitrothion, fenoprop, glyphosate and AMPA, heptachlor and heptachlorepoxide, hexachlorobenzene, hexachlorobutadiene, isoproturon, lindane, malathion, MCPA, mecoprop, mercury, methoxychlor, metolachlor, molinate, monochloroacetate, monochlorobenzene, nitrate, pendimethalin, pentachlorophenol, permethrin, pyriproxyfen, simazine, sulfate, 2,4,5-T, terbuthylazine (TBA), trichloroacetate, trichloroacetronitrile, trichlorobenzenes, 2,4,6-trichlorophenol, trifluralin, xylenes, zinc
3513 Resins, plastics and fibres except glass	Acrylamide, barium, di(2-ethylhexyl)adipate, di(2-ethylhexyl)phthalate, EDTA, epichlorohydrin, iron, lead, styrene, toluene, trichloroethene, vinyl chloride

Source activity	Chemicals potentially discharged through effluent
352 Manufacture of other chemical organic products	Xylenes
3521 Manufacture of paints, varnishes and lacquers	Arsenic, barium, benzene, carbon tetrachloride, chromium, 1,2-dichloroethane, dichloromethane, ethylbenzene, toluene, trichloroethene
3522 Manufacture of drugs and medicines	Aluminium, antimony, arsenic, barium, boron, cadmium, chloral hydrate, chromium, copper, dichloroacetate, iron, mercury, zinc
3523 Manufacture of soap and cleaning preparations	Ammonia, sulfate
3529 Chemical products not elsewhere classified	Acrylamide, ammonia, boron, bromate, bromodichloromethane, bromoform, chloral hydrate, chlorate, chlorine, chlorite, chloroform, copper, dibromochloromethane, dichloroacetate, 1,2-dichloropropane, di(2-ethylhexyl)adipate, di(2-ethylhexyl)phthalate, EDTA, epichlorohydrin, formaldehyde, hexachlorobutadiene, hydrogen sulfide, iron, lead, manganese, monochloramine, monochloroacetate, nickel, nitrate, nitrilotriacetic acid, nitrite, sodium, sulfate, trichloroacetate, 1,1,1-trichloroethane, 2,4,6-trichlorophenol
353 Petroleum refineries	Benzene, lead, toluene, xylenes
354 Manufacture of misc. products of petroleum and coal	Acrylamide, barium, benzene, bromodichloromethane, bromoform, carbon tetrachloride, chloral hydrate, chlordane, chloroform, cyanogen chloride, dibromochloromethane, dichloroacetate, 1,2-dichloroethane, 1,1–dichloroethene, 1,2–dichloroethene, dichloromethane, 1,2-dichloropropane, di(2-ethylhexyl)adipate, di(2-ethylhexyl)phthalate, EDTA, epichlorohydrin, ethylbenzene, formaldehyde, heptachlor and heptachlorepoxide, hexachlorobenzene, hexachlorobutadiene, hydrogen sulfide, molybdenum, monochloroacetate, monochlorobenzene, nitrilotriacetic acid, styrene, tetrachloroethene, toluene, trichloroacetate, trichlorobenzenes, 1,1,1-trichloroethane, trichloroethene, 2,4,6-trichlorophenol, vinyl chloride, xylenes
355 Manufacture of rubber products	Ammonia, barium, hexachlorobutadiene, sodium, zinc
3551 Tyre and tube industries	
36 *Non-metallic mineral products, except products of petroleum and coal*	
361 Manufacture of pottery, china and earthenware	Antimony, chromium, fluoride, lead
362 Manufacture of glass and glass products	Antimony, arsenic, barium, boron, chromium, fluoride, manganese, mercury, molybdenum, nitrate, sodium, sulfate
369 Manufacture of other non-metallic mineral products	
3691 Manufacture of structural clay products	Barium, fluoride
3692 Cement, lime and plaster	
3699 Products not elsewhere classified	
37 *Basic metal industries*	Benzo[a]pyrene, boron, fluoranthene, fluoride, manganese, molybdenum, nickel, sulfate
371 Iron and steel basic industries	Cyanide, iron
372 Non-ferrous metal basic industries	Aluminium, antimony, arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, sodium, uranium, zinc

Source activity	**Chemicals potentially discharged through effluent**
38 *Fabricated metal products, machinery and equipment*	Aluminium, ammonia, antimony, arsenic, barium, beryllium, cadmium, carbon tetrachloride, cyanide, dichloromethane, di(2-ethylhexyl)-adipate, di(2-ethylhexyl)-phthalate, EDTA, epichlorohydrin, ethylbenzene, hexachlorobutadiene, iron, lead, manganese, mercury, molybdenum, monochlorobenzene, nickel, nitrilotriacetic acid, sodium, sulfate, tetrachloroethene, toluene, trichlorobenzenes, 1,1,1-trichloroethane, trichloroethene, xylenes, zinc
381 Fabricated metal products, except machinery	
384 Manufacture of transport equipment	
3841 Ship building and repairing	
4 Electricity, gas and water	Acrylamide, aluminium, chlorine, copper, epichlorohydrin, fluoride, iron, sodium, sulfate
41 *Electricity, gas and steam*	
4101 Electricity light and power	Benzo[a]pyrene, cyanide, fluoranthene, uranium
6 Wholesale and retail trade	
61 *Wholesale trade*	
62 *Retail trade*	
63 *Restaurants and hotels*	
631 Restaurants, cafes, and other eating and drinking	
632 Hotels, rooming houses, camps and other lodging	
7 Transport, storage and communication	Benzo[a]pyrene, fluoranthene
71 *Transport and storage*	
711 Land transport	
712 Water transport	
713 Air transport	
719 Services allied to transport	
7192 Storage and warehousing	
9 Community, social and personal services	
92 *Sanitary and similar services*	Bromate
93 *Social and related community services*	
931 Education services	
932 Medical, dental and other health services	Antimony, boron, bromoform, chloral hydrate, chloroform, iron, lindane, mercury, nitrilotriacetic acid, trichloroethene, zinc
94 *Recreational and cultural services*	Chlorine, chromium, copper, nitrilotriacetic acid
95 *Personal and household services*	EDTA, nitrilotriacetic acid
952 Laundries, laundry services and cleaning	1,2-dichloropropane, tetrachloroethene, trichloroethene

Notes
1. Classification of source activities is based on the *United Nations Statistics Division – Classifications Registry: Activity Classifications, ISIC* Rev. 2 http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=8&Lg=1.
2. Effluents from all industrial sources have the possibility of containing synthetic detergents.

appendix 3

Association of pesticides with crops and crop types

A wide range of pesticides can potentially be found in drinking-water, usually at very low concentrations. Because chemical analysis can be difficult, common practice is to determine what substances are used in the catchment, and thus determine the monitoring and other risk management practices that are needed. However, the nature of pesticide use is such that concentrations in surface water may be very variable and intermittent. Any monitoring will require careful planning if it is to generate useful data. Some pesticides are not very mobile in soil and, if found in water, they may be adsorbed to particulate matter. Many of the pesticides in current use are broken down rapidly in the environment.

In many countries, groundwater in agricultural areas contains very low concentrations of pesticides, which are not of concern to health. Generally, pesticides in groundwater at levels that are of concern to health occur only at sites where open wells allow pesticide-contaminated runoff to be washed directly to the water table, or where large volumes of pesticides have been mixed and spilt on bare soil where the water table is very shallow. The risk of pesticides being present at high concentrations can usually be assessed through a detailed sanitary survey of an area. Chemical analysis for pesticides is generally not necessary; also, it is expensive and beyond the analytical capacity of many countries. Pesticides used in paddy fields can be a particular problem where there is overflow or drainage into water bodies that may be used as drinking-water sources.

Three of the pesticides considered in the World Health Organization's (WHO) *Guidelines for Drinking-water Quality* (WHO, 2004b; WHO, 2006) – chlorpyrifos, dichlorodiphenyltrichloroethane (DDT) and its metabolites, and pyriproxyfen – are used as larvicides to control the aquatic larval stages of insects of public health significance. In considering such chemicals, a suitable balance needs to be struck between the protection of drinking-water quality and the control of insects of public health significance. However, it is important that every effort should be made to keep the concentration of any larvicide as low as is reasonably possible.

This appendix lists various crops, together with the insecticides and herbicides that may be associated with their production. It thus provides a starting point for determining the pesticides of interest in a particular catchment. Such a listing cannot be definitive; for example, sometimes a pesticide may be used that is not specifically recommended for control in a particular crop. This situation can occur for various reasons, such as lack of access to more appropriate pesticides.

Once the pesticides of interest have been determined, it is then necessary to examine the type of application, the likely weather conditions, the nature of the soil and water sources, and the chemical nature of the pesticide (i.e. stability, octanol-water coefficient, binding, water solubility and, where appropriate, binding capacity to soil organic matter), to determine the risk that the chemical will reach water sources. This is discussed in Section 5 of Chapter 5.

The pesticides considered in Table A3.1 are those for which WHO has set guideline levels in drinking-water. The crops included were chosen based on the world's 30 major crops, on a harvested area basis, according to 2002 statistics from the Food and Agriculture Organization of the United Nations (FAO).

Table A3.1 only shows the known, major uses for particular pesticides. There will also be many minor uses of each pesticide, not stated in the literature because the manufacturers consider the use to be insignificant. In general, similar suites of pesticides are used on different crops in a related group. For example, many more sorghum pesticides may be used on millet than are shown in the table, and similar pesticides are likely to be used on chickpeas and cow peas. The table is also based on approved or recommended uses for each pesticide. In countries where pesticide use is poorly regulated, farmers and growers might use a much greater range of pesticides on each crop than is shown, particularly if the pesticides do not cause unacceptable damage to the crop. In particular, many insecticides could be used on a much wider range of crops than is shown, without damage to the crops (unlike herbicides). It is possible that most of the insecticides shown in Table A3.1 could be used on most of the crops shown.

For these reasons, in areas where current and past pesticide use is not well documented, pesticide analysis should be based on the best available evidence even if it is anecdotal, but should nevertheless include chemicals of greatest hazard to human health, such as insecticides.

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Table A3.1 | Association of insecticides and herbicides with crops and crop types

Crop	Insecticides	Herbicides
Cereals		
Barley	aldrin [a]; dieldrin [a]; dimethoate; lindane	chlorotoluron; cyanazine; 2,4-D; 2,4-DB; dichlorprop; isoproturon; MCPA; MCPB; mecoprop; pendimethalin
Maize	aldicarb; aldrin [a]; dieldrin [a]; carbofuran; lindane	alachlor; atrazine; cyanazine; 2,4-D; fenoprop; metalochlor; pendimethalin; simazine; terbuthylazine
Millet	1,3-dichloropropene	2,4-D
Oats	aldrin [a]; dieldrin [a]; dimethoate; lindane	cyanazine; 2,4-D; 2,4-DB; dichlorprop; MCPA; MCPB; mecoprop; pendimethalin
Rice (paddy)	carbofuran; dimethoate	2,4-D; MCPA; MCPB; molinate; pendimethalin
Rye	dimethoate; lindane	chlorotoluron; 2,4-D; 2,4-DB; dichlorprop; isoproturon; MCPA; MCPB; mecoprop; pendimethalin
Sorghum	aldicarb; carbofuran	atrazine; 2,4-D; metalochlor; pendimethalin; terbuthylazine
Wheat	aldrin [a]; dieldrin [a]; dimethoate; lindane	chlorotoluron; cyanazine; 2,4-D; 2,4-DB; dichlorprop; isoproturon; MCPA; MCPB; mecoprop; pendimethalin
Fibre crops		
Flax fibre and tow	1,3-dichloropropene	MCPA; trifluralin
Seed cotton	aldicarb; aldrin [a]; dieldrin [a]; carbofuran; dimethoate; endrin [a]	alachlor; cyanazine; metalochlor; pendimethalin; trifluralin

Crop	Insecticides	Herbicides
Fruits		
Apples	1,2-dichloropropane[a]; 1,3-dichloropropene; dimethoate; lindane; methoxychlor[a]	2,4-D; pendimethalin; simazine
Bananas	aldicarb; carbofuran	simazine
Citrus fruits	aldicarb; dimethoate	metolachlor; pendimethalin; simazine; trifluralin
Grapes	1,2-dichloropropane[a]; 1,3-dichloropropene; carbofuran; dimethoate; lindane; methoxychlor[a]	2,4-D; metolachlor; pendimethalin; simazine; terbuthylazine; trifluralin
Oilcrops		
Coconuts		2,4,5-T
Groundnuts in shell	aldicarb; carbofuran; 1,2-dichloropropane; 1,3-dichloropropene; ethylene dibromide	alachlor; 2,4-DB; MCPB; metalochlor; pendimethalin; trifluralin
Oil palm fruit		simazine; 2,4,5-T; terbuthylazine
Olives	1,2-dichloropropane[a]; 1,3-dichloropropene	simazine; terbuthylazine
Rapeseed	carbofuran; lindane	alachlor; cyanazine; simazine; trifluralin
Soybeans	aldicarb; carbofuran	alachlor; cyanazine; 2,4-DB; metalochlor; pendimethalin; trifluralin
Sunflower seed	carbofuran; lindane	alachlor; metalochlor; pendimethalin; trifluralin
Pulses		
Beans (dry)	aldicarb; 1,2-dichloropropane[a]; 1,3-dichloropropene; dimethoate; lindane; methoxychlor[a]	cyanazine; pendimethalin; simazine; terbuthylazine; trifluralin
Chickpeas	dimethoate	cyanazine; MCPA; MCPB; pendimethalin; simazine; terbuthylazine; trifluralin
Cow peas (dry)	1,2-dichloropropane[a]; 1,3-dichloropropene; dimethoate; methoxychlor[a]	cyanazine; MCPA; MCPB; pendimethalin; simazine; terbuthylazine; trifluralin

Crop	Insecticides	Herbicides
Roots and tubers		
Cassava	dimethoate	metolachlor; pendimethalin
Potatoes	aldicarb; aldrin[a]; carbofuran; 1;2-dichloropropane; 1,3-dichloropropene; dieldrin; endrin[a]; ethylene dibromide; dimethoate	cyanazine; MCPA; metalochlor; pendimethalin; terbuthylazine
Sweet potatoes	aldicarb; 1,2-dichloropropane; 1,3-dichloropropene; methoxychlor[a]	
Sugar crops		
Sugar-beet	aldicarb; carbofuran; 1,2-dichloropropane; 1,3-dichloropropene; ethylene dibromide; dimethoate; lindane	metalochlor; trifluralin
Sugar-cane	aldicarb; carbofuran	alachlor; atrazine; cyanazine; 2,4-D; fenoprop; metalochlor; simazine; terbuthylazine; trifluralin
Vegetables		
Cabbages	1,2-dichloropropane[a]; 1,3-dichloropropene; dimethoate; lindane; methoxychlor[a]	metolachlor; trifluralin
Onions	1,2-dichloropropane[a]; 1,3-dichloropropene; lindane	trifluralin
Tomatoes	1,2-dichloropropane[a]; 1,3-dichloropropene; dimethoate; lindane; methoxychlor[a]	trifluralin
Other crops		
Cocoa beans	dimethoate; lindane	simazine; terbuthylazine
Coffee (green)	aldicarb; carbofuran; dimethoate	simazine; terbuthylazine
Natural rubber		simazine; 2,4,5-T; terbuthylazine

[a] Superseded pesticides (materials believed to be no longer manufactured or marketed for crop protection use).

appendix 4

Practical comments on selected parameters

Introduction

This appendix gives some practical comments on selected chemicals and parameters, based on broad experience worldwide. It may be used as a supporting document for risk-management planning; however, it provides general guidance only, and the comments provided should be considered in this light. In addition to chemicals of health concern, this appendix also includes other chemicals and physical parameters that may give rise to consumer complaints or act as indicators of other chemicals of concern listed in the World Health Organization's (WHO) *Guidelines for Drinking-water Quality* (WHO, 2004; WHO, 2006). It also comments on monitoring of treated water. As noted in Chapter 3, monitoring is only one part of risk management, and the resources required need to be considered carefully, because monitoring of final drinking-water may not be the most cost-effective approach.

The WHO guidelines provide additional information for most of the parameters discussed below.

Adipates and phthalates

Adipates and phthalates are widely used in industry, and are widespread in the environment. They are encountered in raw surface water and may be found (usually at low concentrations) in treated drinking-water. Few countries have considered it necessary to set standards for these substances, and they are not usually monitored routinely.

Adipates and phthalates are used in the manufacture of polyacrylamides and water treatment resins. They are extremely difficult to analyse in water at trace concentrations. Control of these substances is through specifications on product quality and on the way that the products are used in contact with water.

Algal toxins

Blue-green algae (cyanobacteria) can occur in surface water bodies used for water supply Some species of cyanobacteria contain toxins of concern to human health (e.g. microcystins), and these can be released when algal cell walls are ruptured. There is a wide range of potential toxins and it appears that not all of the possible toxins have been identified.

Toxins such as microcystin LR and associated substances can be very difficult to analyse at low concentrations in water. Therefore, it is preferable to control blue-green algae by preventing algal blooms in source waters. There are treatment options for microcystin LR and related substances, but these require careful assessment; for example, it is particularly important to ensure that algal cells are removed.

Blooms of blue-green algae occur in appropriate weather conditions in still or slow-flowing bodies of water with high phosphorus concentrations that either occur naturally or are from a number of possible human-made sources.

Every effort should be made to prevent blooms forming, and this is the primary management approach. Where there are heavy algal blooms, it is best to consider an alternative source of water unless appropriate treatment is available.

Aluminium (Al)

Aluminium is one of the most common elements in the Earth's crust; it occurs in a large variety of minerals in almost all geological environments. Aluminium from natural sources is therefore often found in raw waters, but only soluble forms of aluminium are likely to reach drinking-water. One of the major potential sources is aluminium salts, which are widely used as coagulants in drinking-water treatment.

Although there is no health-based guideline value for aluminium, high concentrations reaching distribution systems can result in deposits of aluminium flocs, which can cause subsequent problems of dirty water. Concentrations can normally be maintained below 0.2 mg/L, and 0.1 mg/L should be achievable in well-run large treatment works. Monitoring is normally carried out in final water from the treatment works, but control is best achieved by optimizing coagulation and filtration, and by using operational monitoring for parameters such as turbidity.

Ammonia (NH_3)

Ammonia is not of direct health concern but can compromise disinfection efficiency because it exerts a significant chlorine demand, reacting rapidly with chlorine.

Although ammonia is not toxic at concentrations generally found in water, its presence in raw water often indicates that the water is contaminated by sewage, by leachate from waste-disposal sites or by animal waste from agricultural activities. Ammonia may also occur naturally in groundwater from peaty sediments, or in slow-moving or stagnant surface water bodies that contain a lot of organic matter and are poorly aerated.

Ammonia is occasionally found in distribution systems where chloramine is used as a residual disinfectant, if the process of producing chloramine is not sufficiently well controlled. Monitoring could be carried out in the final water from the treatment works, but other parameters (e.g. free chlorine) are normally considered to be more important.

Antimony (Sb)

High concentrations of antimony may occur in acidic drainage from mining areas, in groundwater known to contain high concentrations of arsenic, and in groundwater in active volcanic areas.

Antimony is not usually found in significant concentrations in drinking-water. Concerns that antimony–tin solders would be widely used in place of lead solders have not materialized. Should monitoring be required, this would normally need to be at the tap unless a specific source of antimony in raw water is identified.

Arsenic (As)

Arsenic naturally occurs in a number of geological environments, but is particularly associated with sulfide-containing minerals; principally, arsenopyrite precipitated from hydrothermal fluids in metamorphic environments. It is also formed in low-temperature sedimentary environments under reducing conditions. Major alluvial and deltaic plains and inland basins composed of young sediments (quaternary, thousands to tens of thousands of years old) are particularly prone to developing groundwater arsenic problems (World Bank, 2005). Although the mechanism for the mobilization of arsenic remains unclear, the presence of reducing (anaerobic) conditions in the affected aquifer has been recognized as a key risk factor for high-arsenic groundwater. Slow groundwater movement also appears to be important (World Bank, 2005). As a consequence, high arsenic concentrations in groundwater do not necessarily correspond with areas where rock or sediment has the highest arsenic levels; rather, they occur where chemical conditions are most suitable for mobilization, usually reducing conditions. This is particularly important when planning the drilling of tubewells.

Concentrations of arsenic can be significant, and major health effects can occur due to exposure through drinking-water. Therefore, arsenic has been included in the list of “must consider” chemicals noted in Chapter 2. It is especially important to consider arsenic before establishing a new drinking-water source.

The concentrations of arsenic are usually, but not always, stable. Where concentrations are likely to be stable (i.e. deep groundwater), monitoring would normally only need to take place infrequently. Where water supplies for populations are subject to treatment to remove arsenic, samples are normally best taken at the treatment works, where the frequency of monitoring should be sufficient to ensure that the process is effective.

Additional and more detailed information on arsenic can be obtained from World Bank (2005) and WHO-UN (no date).

Asbestos

Asbestos can arise from natural sources and from asbestos cement pipe. Exposure to asbestos fibres through drinking-water is not considered to cause health effects in humans; also, the analysis is difficult and expensive.

Barium (Ba)

High concentrations of barium may occur in groundwater in areas with granitic rocks, felsic metamorphic rocks or sedimentary rocks. Concentrations may be high where groundwater contains little or no sulfate (generally where chloride is the dominant anion). There is no evidence to date that exposure to barium through drinking-water has caused health effects in consumers. Should monitoring be required, it would normally be most appropriate at the treatment works or the source.

Beryllium (Be)

Beryllium is primarily found in effluent from specialist metalworking. No formal guideline value has been proposed in the WHO guidelines because beryllium is considered unlikely to occur in drinking-water. It is, therefore, unusual for monitoring to be required.

Boron (B)

Boron concentrations may commonly exceed drinking-water guideline values in groundwater in areas with granitic or volcanic rocks. In areas where there are large accumulations of evaporites, boron concentrations may be high, but in these areas water is sometimes too saline for drinking without advanced drinking-water treatment (e.g. desalination). Boron can also result from wastewater discharges.

Boron is very difficult to remove from water and is not usually encountered at concentrations of concern. Should monitoring be required, this is likely to be infrequent and at the treatment works or the source.

Bromate

See disinfectants and disinfection by-products.

Cadmium (Cd)

Cadmium is a heavy metal with similar chemical properties to zinc, but is much less common in the environment than zinc. Cadmium occurs in igneous rocks and some sedimentary rocks, and is generally associated with zinc ore minerals like sphalerite, and with a range of copper ore minerals. Traces of cadmium are often present in artificial fertilizers, and this heavy metal may accumulate in soils in areas that have been used for agriculture for long periods.

Concentrations of cadmium in water are only likely to be of health concern in environments where pH is less than 4.5.

Other cadmium sources can include solder, galvanized pipes and metal fittings, pollution from disposal of cadmium-containing materials and from mining operations (see Chapter 7). However, concentrations of cadmium in drinking-water above the guideline value are unusual.

Chloride

Chloride can originate from natural and human-made sources, such as sewage and industrial effluents. Where salt is used for de-icing, chloride can contaminate groundwater through road drainage. Upland and mountain water supplies are usually low in chlorides, whereas, concentrations are generally higher in rivers and groundwater. The main operational issue for chloride is its ability to increase the corrosiveness of water, particularly in low alkalinity water. High concentrations of chloride may result in a detectable taste in water, but consumer acceptability varies widely depending on the form of chloride (e.g. $NaCl$, KCl and $CaCl_2$). Should monitoring be necessary, this would usually be at the treatment works. The frequency would depend on the variability in the source water, but would normally be low.

Chlorinated alkanes and alkenes

Chlorinated alkanes are usually found as contaminants only in groundwater. They are generally present due to careless use or disposal to the soil surface of the chlorinated alkanes used as solvents in industrial processes. These chemicals do not degrade readily in groundwater and can be present for long periods. An assessment of whether such solvents are used in the catchment would be appropriate before considering a monitoring programme.

Chlorinated alkenes are similar to chlorinated alkanes. The two chlorinated solvents most frequently found in groundwater are trichloroethene and tetrachloroethene. Although not used as a solvent, 1,2-dichloroethene may be found due to the breakdown of other alkenes. Vinyl chloride may occur as a breakdown product of other chlorinated alkenes, but is most likely to be found in water as a consequence of the leaching from polyvinyl chloride (PVC) water pipes, which contain high residuals of vinyl chloride. This chemical is usually best controlled through product specifications.

Chlorinated benzenes

Chlorinated benzenes are widely used in industry and are sometimes encountered in drinking-water from surface sources. They usually give rise to taste and odour problems at concentrations below the health-based guideline value, where one has been proposed.

Chlorite and chlorate

See disinfectants and disinfection by-products

Chromium (Cr)

High concentrations of chromium may occur naturally in groundwater in areas with mafic or ultramafic volcanic or metamorphic rocks (i.e. rocks that consist mainly of ferromagnesian minerals with no quartz).

Chromium is usually found in drinking-water at concentrations well below guideline values. However, it has been found at higher concentrations from industrial pollution or mining discharges (See Chapter 7). Generally, it would only require investigation for monitoring if there were indications that a problem might exist. Measurement would normally take place in final water from the treatment works.

Conductivity

Conductivity is included as an indicator parameter. The electrical conductivity of water is easily measured in the field using a conductivity electrode. It is an indirect measure of the total dissolved solids (TDS) content of water, and there is usually an approximately linear relationship between TDS and conductivity. Increasing conductivity over time in water indicates that one or more inorganic constituents are also increasing; this situation should trigger further investigations.

Copper (Cu)

Copper is usually found at very low concentrations in final drinking-water, but concentrations can increase significantly in buildings with copper pipes if the water is aggressive (dissolves metals from pipes and fittings). Concentrations are most likely to increase after the water has stood in the pipes for a few hours. Copper has been shown to cause acute gastrointestinal discomfort and nausea at concentrations above about 3 mg/L. Monitoring for copper therefore needs to take place at the tap. However, meaningful monitoring usually requires a specific strategy to be developed because concentrations will vary from property to property. High copper levels give rise to staining of sanitary ware. Unless a particular problem has been demonstrated, monitoring would not normally be considered to be necessary or would at least be infrequent.

Cyanide

Cyanide occurs naturally only in geothermal water in volcanic areas. However, it is a common contaminant in groundwater and surface water in gold mining areas, particularly near deposits of processed tailings, as a consequence of industrial discharges (see Chapter 7), and is a major cause of concern through spills.

While there is no documented evidence of health effects caused by exposure to cyanide in drinking-water in normal circumstances, potentially high concentrations from spills must be managed to prevent these concentrations penetrating drinking-water supplies.

Exposure, especially from industrial activity, would generally only be intermittent. This means that monitoring is difficult and would normally only be carried out in response to a particular incident or circumstance where cyanide was known to be present. Fish can be used as an indicator of high cyanide levels, because they are particularly sensitive to its effects.

Disinfectants and disinfection by-products

Disinfectants are usually only monitored to ensure that disinfection has taken place. Certain disinfectants, such as chlorine, are sometimes monitored at the tap or in the distribution system, as a measure of the quality in distribution. A wide range of potential by-products of disinfection may be formed in treatment, particularly if natural organic matter is present at high concentrations. The most commonly monitored by-products are the trihalomethanes (THMs) formed through chlorination; THMs are normally considered to be an adequate marker of the total disinfection by-products from chlorination. Some countries also monitor haloacetic acids, but these are difficult and expensive to analyse because of their high polarity. Bromate is sometimes measured when ozone is used, but its formation relates to bromide concentrations in the raw water and the conditions of ozonation. Analysis can be extremely difficult and monitoring is not usually considered except where standards have been set or on an infrequent basis.

When chlorine dioxide is used as a disinfectant, chlorite and chlorate are formed as by-products. These are sometimes monitored, but control can be achieved by control of the dose of chlorine dioxide applied. Chlorate may also form in significant quantities in hypochlorite that is stored for an extended period, particularly at higher ambient temperatures; again, it is best controlled by management procedures.

Dissolved oxygen

Dissolved oxygen is included as an indicator parameter. It can be measured in the field using a dissolved-oxygen electrode. The dissolved-oxygen content of water depends on its source, temperature, and chemical and biological processes taking place in the water distribution system. Therefore, measurements can only be used in a relative, not an absolute, sense. However, large declines in dissolved oxygen in a water source could indicate high levels of microbiological activity, and should trigger further sampling for microorganisms.

Dissolved oxygen is not usually a candidate for routine monitoring unless a specific problem is recognized.

Edetic acid and nitrilotriacetic acid

Edetic acid (EDTA) and nitrilotriacetic acid (NTA) have been widely used as sequestering agents for calcium and other metals. They are very soluble in water and difficult to analyse. However, they are of relatively low toxicity and are unlikely to require routine monitoring except in exceptional circumstances.

Eh (oxidation-reduction or redox potential)

Many chemical reactions in water involve the transfer of electrons between chemical constituents. Electron transfer is measured with an electrode assembly that includes an inert metallic electrode (usually platinum). Eh is a measure of the extent to which these reactions can take place. A high positive Eh potential indicates oxidizing conditions where chemical species such as oxygen, nitrate and sulfate may be present in water. Very low negative Eh values indicate reducing conditions with no oxygen and where chemical species such as ferrous iron and hydrogen sulfide are frequently present. Very low Eh values in water are often indicative of pollution containing large amounts of organic carbon, such as leachate from septic tanks or landfill sites. Rapid changes in Eh should trigger an investigation as to the cause.

Fluoride (F)

Fluoride occurs in rocks in many geological environments. High concentrations of fluoride may occur in groundwater in areas with granitic, acid volcanic, sodium-rich (alkaline) igneous or volcanic rocks, and in some sedimentary and metamorphic terrains. Widespread dental mottling is a health indicator that water contains high concentrations of fluoride, although other sources (e.g. food) may be equally important.

Fluoride is one of the chemical contaminants that must be considered, because high fluoride levels in drinking-water are a major source of adverse human health effects in some parts of the world.

Haloacetic acids

See disinfectants and disinfection by-products

Hardness

Hardness is a natural feature of waters, reflecting calcium and magnesium, as carbonates, bicarbonates and sulfates. It is normally very stable and would only require analysis if there was concern about scale formation in distribution and in plumbing in buildings. Low hardness may be a consideration if assessing the level of plumbing-related metals in water at the tap.

Hexachlorobutadiene

Hexachlorobutadiene is widely used as an industrial chemical. It has been identified in effluent from chemical manufacturing, but has also been found as a contaminant in chlorine gas used for disinfection. Control should, therefore, be primarily through specifications on the quality of chlorine gas. Monitoring would normally be considered only if a specific problem was identified by catchment assessment.

Hydrocarbons

Aromatic hydrocarbons are used as solvents; they are found in petrol and diesel. They are not normally found in drinking-water except as a consequence of spills and or leaking storage facilities. Aromatic hydrocarbons are usually detected by taste and odour at concentrations well below the health-based guideline value. Styrene is sometimes found due to the use of certain pipeline materials (e.g. glass-reinforced plastic) that have not been cured properly. Routine monitoring is normally unnecessary, unless a potential problem has been recognized. Aromatic hydrocarbons are sometimes found, having leached from polyethylene pipes. Thus, monitoring in response to an incident or problem may be more effective at the tap rather than at the treatment works.

Polycyclic aromatic hydrocarbons (PAHs) are usually only found in drinking-water as a consequence of leaching from coal-tar linings on cast-iron water mains. The PAH of greatest concern is benzo(a)pyrene, but the most commonly encountered is fluoranthene. Benzo(a)pyrene is normally only detected at significant concentrations in water when particles of coal tar are present.

Hydrogen sulfide

Hydrogen sulfide arises in anaerobic conditions when sulfides are hydrolysed. It causes an unpleasant odour of rotten eggs at very low concentrations as it is lost to air. It is not normally monitored because it is not found in well-aerated systems. If it is detected by smell, it indicates that the system is anaerobic.

Iron (Fe)

There is no health-based guideline value for iron, although high concentrations do give rise to consumer complaints because the iron discolours aerobic waters at concentrations above about 0.3 mg/L. Iron is found in natural freshwaters and in some groundwaters. It may also be present from its use as a coagulant in water treatment or through corrosion of cast-iron water pipes. It is controlled at the treatment works by optimizing treatment, and in distribution systems by a structured programme of maintenance.

Lead (Pb)

Lead is widely dispersed in the environment, occurring in a variety of sedimentary rocks, and in felsic igneous and metamorphic rocks, where it may reach high concentrations in veins associated with hydrothermal fluids. Under pH conditions generally found in natural waters, lead has a low solubility. Concentrations of lead in water are only likely to be of significance in environments where pH is less than 4.5, and it is very rarely found in water at treatment works.

When found in drinking-water, lead usually arises from lead pipes and lead solder, mostly from plumbing in buildings. Monitoring is quite difficult and requires samples to be taken at the tap. Assessing the presence of lead pipes, or the ability of the water to dissolve lead, are the most appropriate management approaches. Monitoring is only considered if significant resources are available.

Manganese (Mn)

Manganese occurs in groundwaters and surface waters that are low in oxygen; it often occurs with iron. When it is oxidized in aerobic waters, manganese precipitates as a black slimy deposit, which can build up in distribution to cause severe discolouration at concentrations above about 0.05 mg/L. The health-based guideline value is 0.4 mg/L. Monitoring is only likely to be required for operational reasons where a potential problem has been identified, in which case, final water from the treatment works would normally be the most appropriate sample site.

Mercury (Hg)

Mercury is a rare element in the Earth's crust. It is only relatively concentrated in some volcanic areas and in mineral deposits as a trace constituent of ores of other heavy metals. Mercury concentrations in groundwater and surface waters rarely exceed 1 µg/L.

High concentrations of mercury may occur in groundwater and surface water supplies in gold-mining areas where mercury has been used for gold extraction.

The guideline value for mercury is conservative because it is based on the provisional tolerable weekly intake (PTWI) for methylmercury, which is more toxic than mercury. Monitoring would normally only be justified if mercury were known to be present due to unusual circumstances, such as an industrial or mining discharge.

Molybdenum (Mo)

Molybdenum is a relatively rare element in the Earth's crust, but is commonly associated with base metal sulfide deposits, usually being present as the mineral molybdenite MoS_2.
High concentrations of molybdenum may occur in groundwater in mining areas where sulfide ores contain the mineral molybdenite. Monitoring would normally not be justified unless there were clear indications that high levels of molybdenum were likely to be present.

Nickel (Ni)

Nickel has a similar chemical behaviour to iron and cobalt, and commonly substitutes for iron in ferromagnesian minerals.

High concentrations of nickel may occur in groundwater in areas with mafic or ultramafic rocks. Concentrations of nickel in water from natural occurrences are only likely to be of health concern in environments where pH is less than 4.5 or where groundwater pumping has introduced oxygen into an anaerobic aquifer.

Nickel may also be released from some industrial sources (e.g. nickel plating) and from chromium plating of taps and fittings in which nickel is the base layer. A monitoring programme for nickel in drinking-water would generally only be required if a specific source of pollution were known.

Nitrate/nitrite

Naturally high nitrate concentrations may occur in groundwater in semiarid or arid areas where there is widespread termite activity, or where natural vegetation is dominated by leguminous species such as acacias. However, nitrate is usually found in groundwater and surface water due to agricultural activity or leaking effluent from on-site sanitation.

High nitrate concentrations can cause methaemoglobinaemia (blue-baby syndrome) in bottle-fed infants. This condition is also associated with the simultaneous presence of bacterial contamination. The primary approach to managing nitrate contamination is prevention, particularly for rural wells, which are the major problem with regard to methaemoglobinaemia. In particular, protection of wells from runoff from fields and siting of manure stores, pit latrines and septic tanks will help to prevent contamination with nitrate and microbial pathogens.

Nitrite has a similar action to nitrate, but is usually only found at very low concentrations. It is sometimes formed in water distribution systems when monochloramine is used as a residual disinfectant. Nitrite and nitrate need to be considered together, but monitoring for nitrite is difficult because formation will be in the distribution system. Nitrate levels in surface waters can change quite quickly, but levels in groundwater usually change very slowly unless the groundwater is heavily influenced by surface water.

Organotins

The dialkyltins can be used as stabilizers in PVC pipes. They normally leach in very low concentrations, but if control were required, this would be through product specification.

Pesticides

See Appendix 3.

pH

pH is important as an operational parameter, particularly in terms of the efficacy of chlorination or optimizing coagulation. Additionally, dissolution and mobility of metals in natural waters are greatly influenced by the pH.

Radon (Ra)

Radon is a colourless, odourless gas that is produced by the radioactive decay of radium that occurs naturally in minerals.

Groundwater may contain high concentrations of radon and its daughters in areas where bedrock naturally contains high levels of radioactivity. This includes areas with granitic rocks, and sediments with phosphate nodules or heavy mineral sand deposits. Management of radon in drinking-water is by aeration, in which case it is important that there is adequate ventilation of houses, because a significant proportion of radon in water will be lost to the atmosphere.

Selenium (Se)

Selenium has a similar chemical behaviour to sulfur, and often occurs associated with sulfide minerals in a wide range of rocks.

High concentrations of selenium may occur in groundwater in semiarid or arid areas, near known mineral deposits containing sulfide minerals of uranium and vanadium. Irrigated agriculture may substantially increase concentrations in groundwater in areas with high selenium levels in soil.

High selenium concentrations are generally only found in groundwater with oxidizing conditions in arid areas (Hem, 1989). In areas where there is a large amount of organic matter in soils, selenium is generally relatively immobile in water.

Selenium is one of the few substances that have been shown to cause adverse human health effects as a consequence of exposure through drinking-water, although it is an essential element and in many parts of the world there is a deficiency. It is, therefore, important to consider selenium in developing new sources in areas where selenium is suspected. Where selenium is present, monitoring at the treatment works would be appropriate.

Silver (Ag)

Silver is not normally found at significant concentrations in drinking-water, but it is sometimes used as a bacteriastat impregnated in activated carbon used in point-of-use filters. It is very unlikely that monitoring of drinking-water would be appropriate.

Sodium (Na)

Sodium can be found in drinking-water at concentrations in excess of 20 mg/L as a consequence of the use of more saline waters. There is no indication of health effects in the general population associated with high sodium levels in drinking-water, although such water may not be suitable for bottle-fed infants. Concentrations in excess of 200 mg/L may give rise to taste problems. Routine monitoring for sodium is unlikely to be a high priority.

Sulfates

The sulfate anion ($SO4^{2-}$) is a common constituent in natural water and is usually present in at least mg/L concentrations. While WHO has decided that it is not necessary to develop a health-based drinking-water guideline value for this anion, concentrations in excess of 500 mg/L sulfate may cause a noticeable taste.

Tin (Sn)

Inorganic tin has not been found at concentrations of concern in drinking-water. No guideline value was considered necessary, and tin is not discussed further in this document.

Total dissolved solids

Total dissolved solids (TDS) primarily consist of inorganic salts. Although there are no direct health concerns, high concentrations may be objectionable through taste. Regular monitoring is not usually considered a high priority.

Tributyltin oxide

Tributyltin oxide (TBTO) was widely used as a wood preservative and antifungal agent. It is less widely used now because of its extremely high toxicity to shellfish and its potential impact on the aquatic environment. It has rarely been identified in drinking-water and therefore no health-based guideline value has been proposed. Monitoring would not normally be considered unless a specific problem had been identified.

Trihalomethanes

See disinfectants and disinfection by-products.

Uranium (U)

Uranium is widely distributed in the geological environment, but concentrations are particularly high in granitic rocks and pegmatites, and in areas where there is sulfide mineralization. The WHO provisional drinking-water guideline value for uranium is 15 µg/L but there are uncertainties regarding whether concentrations above this would be of concern. Some countries have drinking-water standards for uranium of up to 30 µg/L.

Uranium has been found in many parts of the world at concentrations in excess of 30 µg/L and so is considered a high-priority constituent.

Zinc (Zn)

Zinc is usually only found at very low concentrations in raw waters but can be increased by dissolution of zinc from galvanized pipes. Concentrations above about 3 mg/L can give rise to problems with appearance and taste of the water. A monitoring programme for zinc is unlikely to be necessary unless particular problems have been encountered.

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Index

Concern for chemical contamination of drinking water is increasing in both developing and developed countries worldwide; however, too often, effective risk management is hampered by a lack of basic information. Simple, practical tools are needed by those responsible for developing effective policies and making practical decisions in relation to water quality, to deal with the increasing use of chemicals in industry, agriculture, homes and water supply systems themselves.

In this book, an international group of experts has brought together for the first time a simple, rapid assessment methodology to assist in identifying real priorities from the sometimes bewildering list of chemicals of potential concern. Simply applied, at national or local levels, the approach allows users to identify those chemicals that are likely to be of particular concern for public health in particular settings. The methodology has been tested in the real world in a series of applications in seven countries; in any given setting, it led rapidly to the identification of a short list of priorities.

This text will be invaluable to public health authorities, those responsible for setting drinking water standards and regulations, drinking water supply surveillance agencies and water suppliers. The approaches described are universally applicable and will be of particular value in settings where information on actual chemical quality of drinking water is limited.

This document is part of the WHO response to the challenge of emerging chemical hazards in drinking-water. The now well-documented recognition of arsenic as a problem chemical in drinking water in South Asia is the best known of these emerging hazards, but is accompanied by other known and yet-to-be-recognised hazards. Applying the methodology described will help in using limited resources to best effect, responding to known concerns and identifying under-appreciated future issues.

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