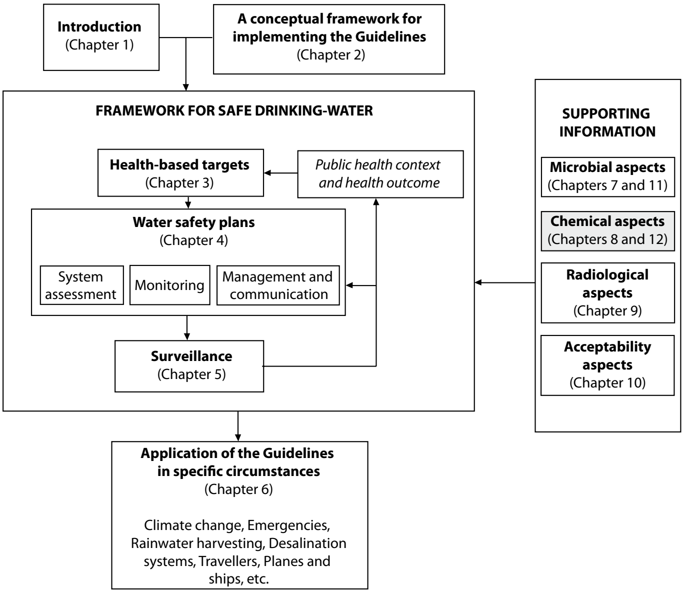
8

Chemical aspects



Most chemicals arising in drinking-water are of health concern only after extended exposure of years, rather than months. The principal exception is nitrate. Typically, changes in water quality occur progressively, except for those substances that are discharged or leach intermittently to flowing surface waters or groundwater supplies from, for example, contaminated landfill sites.

In some cases, there are groups of chemicals that arise from related sources—for example, disinfection by-products (DBPs)—and it may not be necessary to set standards for all of the DBPs for which there are guideline values. If chlorination is practised, the trihalomethanes (THMs) and haloacetic acids (HAAs) will be the main DBPs. If bromide is present, brominated as well as chlorinated DBPs will be produced. Maintaining THM and HAA concentrations below the guideline values by controlling precursor compounds will provide adequate control over other chlorination by-products.

Several of the inorganic elements for which guideline values have been established are recognized to be essential elements in human nutrition. No attempt has been made here at this time to define a minimum desirable concentration of such substances in drinking-water, although the issue of nutritional essentiality is considered during the guideline development process.

Fact sheets for individual chemical contaminants are provided in chapter 12. For those contaminants for which a guideline value has been established, the fact sheets include a brief toxicological overview of the chemical, the basis for guideline derivation, treatment performance and analytical limit of detection. More detailed chemical reviews are available (http://www.who.int/water_sanitation_health/water-quality/guidelines/chemicals/en/).

8.1 Chemical hazards in drinking-water

A few chemical contaminants have been shown to cause adverse health effects in humans as a consequence of prolonged exposure through drinking-water. However, this is only a very small proportion of the chemicals that may reach drinking-water from various sources.

The lists of chemicals addressed in these Guidelines do not imply that all of these chemicals will always be present or that other chemicals not addressed will be absent.

The substances considered here have been assessed for possible health effects, and guideline values have been established only on the basis of health concerns. Additional consideration of the potential effects of chemical contaminants on the acceptability (i.e. taste, odour and appearance) of drinking-water to consumers is included in chapter 10. Some substances of health concern have effects on the acceptability of drinking-water that would normally lead to rejection of the water at concentrations significantly lower than those of health concern. For such substances, no formal guideline value is usually proposed, but a health-based value (see section 8.2) may be needed, for instance, in order to assist in judging the response required when problems are encountered and in some cases to provide reassurance to health authorities and consumers with regard to possible health risks.

Regulators are required to establish health-based targets that must be met through water safety plans. In the case of chemical contaminants, these are normally based on the guideline value, which is, in turn, based on health-related end-points. In this case, the guideline value and the local water quality target are similar, but not necessarily identical, because the latter value may need to be adjusted to take into account local sociocultural, economic and environmental/geological circumstances, as indicated in section 2.6. Guideline values provide a benchmark for the development of local water quality targets for chemicals (usually a national standard expressing a maximum allowable concentration). Guideline values may not directly reflect the target of 10^{-6} disability-adjusted life year (DALY),as these are frequently derived based on evidence indicating a no-adverse effect or negligible risk level. Some guideline values are based on extrapolation of the risk of cancer from exposures at which this can be measured to low exposures where measurement is currently not possible.

In section 2.6, it is stated that “In developing national drinking-water standards based on these Guidelines, it will be necessary to take account of a variety of environmental, social, cultural, economic, dietary and other conditions affecting potential exposure. This may lead to national standards that differ appreciably from these Guidelines.” This is particularly applicable to chemical contaminants, for which there

It is important that chemical contaminants be prioritized so that the most important in the country or local region are considered for inclusion in national standards and monitoring programmes.

is a long list, and setting standards for, or including, all of them in monitoring programmes is neither feasible nor desirable.

The probability that any particular chemical may occur in significant concentrations in any particular setting must be assessed on a case-by-case basis. The presence of certain chemicals may already be known within a particular country, but others may be more difficult to assess.

In most countries, whether developing or industrialized, water sector professionals are likely to be aware of a number of chemicals that are present in significant concentrations in some drinking-water supplies. A body of local knowledge that has been built up by practical experience over a period of time is invaluable. Hence, the presence of a limited number of chemical contaminants in drinking-water is usually already known in many countries and in many local systems. Significant problems, even crises, can occur, however, when chemicals posing high health risk are widespread but their presence is unknown, because their long-term health effect is caused by chronic exposure as opposed to acute exposure. Such has been the case of arsenic in groundwater in Bangladesh and West Bengal, India, for example.

For many contaminants, there will be exposure from sources other than drinking-water, and this may need to be taken into account when setting, and considering the need for, standards. It may also be important when considering the need for monitoring. In some cases, drinking-water will be a minor source of exposure, and controlling levels in water will have little impact on overall exposure. In other cases, controlling a contaminant in water may be the most cost-effective way of reducing exposure. Drinking-water monitoring strategies should therefore not be considered in isolation from other potential routes of exposure to chemicals in the environment.

The scientific basis for each of the guideline values is summarized in chapter 12. This information is important in helping to adapt guideline values to suit national requirements or for assessing the health significance of a contaminant that is of a higher concentration than the guideline value.

Chemical contaminants in drinking-water may be categorized in various ways; however, the most appropriate is to consider the primary source of the contaminant—that is, to group chemicals according to where control may be effectively exercised. This aids in the development of approaches that are designed to prevent or minimize contamination, rather than those that rely primarily on the measurement of contaminant levels in final waters.

In general, approaches to the management of chemical hazards in drinking-water vary between those where the source water is a significant contributor (with control effected, for example, through source water selection, pollution control, treatment or blending) and those from materials and chemicals used in the production and distribution of drinking-water (controlled by process optimization or product specification). In these Guidelines, chemicals are therefore divided into five major source groups, as shown in Table 8.1.

Table 8.1 Categorization of source of chemical constituents

Source of chemical constituents	Examples of sources
Naturally occurring	Rocks, soils and the effects of the geological setting and climate; eutrophic water bodies (also influenced by sewage inputs and agricultural runoff)
Industrial sources and human dwellings	Mining (extractive industries) and manufacturing and processing industries, sewage (including a number of contaminants of emerging concern), solid wastes, urban runoff, fuel leakages
Agricultural activities	Manures, fertilizers, intensive animal practices and pesticides
Water treatment or materials in contact with drinking-water	Coagulants, DBPs, piping materials
Pesticides used in water for public health	Larvicides used in the control of insect vectors of disease

Categories may not always be clear-cut. The group of naturally occurring contaminants, for example, includes many inorganic chemicals that are found in drinking-water as a consequence of release from rocks and soils by rainfall, some of which may become problematical where there is environmental disturbance, such as in mining areas.

8.2 Derivation of chemical guideline values and health-based values

In order for a particular chemical constituent to be evaluated to determine whether a guideline value or health-based value should be derived, one of the following criteria must be satisfied:

- 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), which coordinates the testing and evaluation of pesticides for public health, including those applied directly to drinking-water for control of insect vectors of disease.

Guideline values are derived for many chemical constituents of drinking-water. A guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption. A number of provisional guideline values have been established at concentrations that are reasonably achievable through practical treatment approaches or in analytical laboratories; in these cases, the guideline value is above the concentration that would normally represent the calculated health-based value. Guideline values are also designated as provisional when there is a high degree of uncertainty in the toxicological and health data (see also section 8.2.5).

For some chemicals, no formal guideline value is proposed, on the grounds that occurrence is only at concentrations well below those that would be of concern for health. Establishing a formal guideline value for such substances could encourage some Member States to incorporate the value into their national standards when this is neither necessary nor appropriate. However, to provide guidance for Member States should the chemical be found in drinking-water or in source water in the hazard identification phase of developing a WSP, a health-based value has been determined.

In addition, health-based values for acute exposures are now being developed for a small number of substances that may be implicated in emergency situations as a result of a spill, usually to surface water sources. The derivation of these acute health-based values is explained in section 8.7.5.

There are two principal sources of information on health effects resulting from exposure to chemicals that can be used in deriving guideline values. The first and preferred source is studies on human populations. However, the availability of such studies for most substances is limited, owing to the ethical barriers to conducting human toxicological studies and the lack of quantitative information on the concentration to which people have been exposed or on simultaneous exposure to other agents. However, for a few substances, such studies are the primary basis on which guideline values are developed. The second and most frequently used source of information is toxicological studies using laboratory animals. The limitations of toxicological studies include the relatively small number of experimental animals used and the relatively high doses administered, which create uncertainty as to the relevance of particular findings to human health. This uncertainty stems from the need to extrapolate the results from experimental animals to humans and to the low doses to which human populations are usually exposed. In most cases, the study used to derive the guideline value is supported by a range of other studies, including human data, and these are also considered in carrying out a health risk assessment.

In order to derive a guideline value to protect human health, it is necessary to select the most suitable study or studies. Data from well-conducted studies, where a clear dose–response relationship has been demonstrated, are preferred. Expert judgement, applied against criteria described in section 8.2.4, is exercised in the selection of the most appropriate studies from the range of information available. Safety or uncertainty factors using standard risk assessment principles are included to provide conservative guideline values that are considered to be protective.

8.2.1 Approaches taken

Two approaches to the derivation of guideline values are used: one for "threshold chemicals" and the other for "non-threshold chemicals" (mostly genotoxic carcinogens).

It is generally considered that the initiating event in the process of genotoxic chemical carcinogenesis is the induction of a mutation in the genetic material (deoxyribonucleic acid [DNA]) of somatic cells (i.e. cells other than ova or sperm) and that there is a theoretical risk at any level of exposure (i.e. no threshold). In contrast, there are carcinogens that are capable of producing tumours in experimental animals or humans without exerting a genotoxic activity, but acting through an indirect mechanism. It is generally believed that a demonstrable threshold dose exists for non-genotoxic carcinogens.

In deriving guideline values for carcinogens, consideration is given to the potential mechanisms by which the substance may cause cancer, in order to decide whether a threshold or non-threshold approach should be used (see sections 8.2.2 and 8.2.3).

The evaluation of the potential carcinogenicity of chemical substances is usually based on long-term laboratory animal studies. Sometimes data are available on carcinogenicity in humans, mostly from occupational exposure.

On the basis of the available evidence, the International Agency for Research on Cancer (IARC) categorizes chemical substances with respect to their potential carcinogenic risk into the following groups:

Group 1:	the agent is carcinogenic to humans
Group 2A:	the agent is probably carcinogenic to humans
Group 2B:	the agent is possibly carcinogenic to humans
Group 3:	the agent is not classifiable as to its carcinogenicity to humans
Group 4:	the agent is probably not carcinogenic to humans

According to IARC, these classifications represent a first step in carcinogenic risk assessment, which leads to a second step of quantitative risk assessment where possible. In establishing guideline values for drinking-water, the IARC evaluation of carcinogenic compounds, where available, is taken into consideration.

8.2.2 Threshold chemicals

For most kinds of toxicity, it is believed that there is a dose below which no adverse effect will occur. For chemicals that give rise to such toxic effects, a tolerable daily intake (TDI) should be derived as follows, using the most sensitive end-point in the most relevant study, preferably involving administration in drinking-water:

$$\text{TDI} = \frac{\text{NOAEL or LOAEL or BMDL}}{\text{UF and/or CSAF}}$$

where:

NOAEL = no-observed-adverse-effect level
LOAEL = lowest-observed-adverse-effect level
BMDL = lower confidence limit on the benchmark dose
UF = uncertainty factor
CSAF = chemical-specific adjustment factor

The guideline value (GV) is then derived from the TDI as follows:

$$\text{GV} = \frac{\text{TDI} \times \text{bw} \times \text{P}}{\text{C}}$$

where:

bw = body weight (see below)
P = fraction of the TDI allocated to drinking-water
C = daily drinking-water consumption (see below)

Tolerable daily intake

The TDI is an estimate of the amount of a substance in food and drinking-water, expressed on a body weight basis (milligram or microgram per kilogram of body weight), that can be ingested over a lifetime without appreciable health risk, and with a margin of safety.

Acceptable daily intakes (ADIs) are established for food additives and pesticide residues that occur in food for necessary technological purposes or plant protection reasons. For chemical contaminants, which usually have no intended function in drinking-water, the term "tolerable daily intake" is more appropriate than "acceptable daily intake", as it signifies permissibility rather than acceptability.

Over many years, the Joint Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Expert Committee on Food Additives (JECFA) and the Joint FAO/WHO Meeting on Pesticide Residues (JMPR) have developed certain principles in the derivation of ADIs (FAO/WHO, 2009). These principles have been adopted, where appropriate, in the derivation of TDIs used in developing guideline values for drinking-water quality.

As TDIs are regarded as representing a tolerable intake for a lifetime, they are not so precise that they cannot be exceeded for short periods of time. Short-term exposure to levels exceeding the TDI is not a cause for concern, provided the individual's intake averaged over longer periods of time does not appreciably exceed the level set. The large uncertainty factors generally involved in establishing a TDI (see below) serve to provide assurance that exposure exceeding the TDI for short periods is unlikely to have any deleterious effects upon health. However, consideration should be given to any potential acute effects that may occur if the TDI is substantially exceeded for short periods of time.

No-observed-adverse-effect level and lowest-observed-adverse-effect level

The NOAEL is defined as the highest dose or concentration of a chemical in a single study, found by experiment or observation, that causes no detectable adverse health effect. Wherever possible, the NOAEL is based on long-term studies, preferably of ingestion in drinking-water. However, NOAELs obtained from short-term studies and studies using other sources of exposure (e.g. food, air) may also be used.

If a NOAEL is not available, a LOAEL may be used, which is the lowest observed dose or concentration of a substance at which there is a detectable adverse health effect. When a LOAEL is used instead of a NOAEL, an additional uncertainty factor is normally applied (see below).

Benchmark dose

Increasingly, the preferred approaches for the derivation of TDIs/ADIs for threshold effects include the benchmark dose (BMD) or the lower confidence limit on the benchmark dose (BMDL) (IPCS, 1994). When appropriate data for mathematical modelling of dose–response relationships are available, BMDLs are used as alternatives to NOAELs in the calculation of health-based guideline values. In such a case, use of the BMDL could eliminate the need for application of an additional uncertainty factor to the LOAEL. The BMDL is the lower confidence limit of the dose that

Table 8.2 Source of uncertainty in derivation of guideline values

Source of uncertainty	Uncertainty factor
Interspecies variation (extrapolating from experimental animals to humans)	1–10
Intraspecies variation (accounting for individual variations within humans)	1–10
Adequacy of studies or database	1–10
Nature and severity of effect	1–10

produces a small increase (e.g. 5% or 10%) in the level of adverse effects. The BMDL is derived on a quantitative basis using data from the entire dose–response curve for the critical effect rather than from a single dose at the NOAEL or LOAEL and accounts for the statistical power and quality of the data (IPCS, 2009).

Uncertainty factors

The application of uncertainty or safety factors has been traditionally and successfully used in the derivation of ADIs and TDIs for food additives, pesticides and environmental contaminants. The derivation of these factors requires expert judgement and careful consideration of the available scientific evidence.

In the derivation of guideline values, uncertainty factors are applied to the NOAEL, LOAEL or BMD/BMDL for the response considered to be the most biologically significant.

In relation to exposure of the general population, the NOAEL or BMD/BMDL for the critical effect in experimental animals is normally divided by an uncertainty factor of 100. This comprises two 10-fold factors, one for interspecies differences and one for interindividual variability in humans (Table 8.2). Extra uncertainty factors may be incorporated to allow for database deficiencies and for the severity or irreversibility of effects.

Factors lower than 10 are used, for example, for interspecies variation when humans are known to be less sensitive than the experimental animal species studied. Inadequate studies or databases include those where a LOAEL is used instead of a NOAEL and studies considered to be shorter in duration than desirable. Situations in which the nature or severity of effect might warrant an additional uncertainty factor include studies in which the end-point is malformation of a fetus or in which the end-point determining the NOAEL is directly related to possible carcinogenicity. In the latter case, an additional uncertainty factor is usually applied for carcinogenic compounds for which the guideline value is derived using a TDI approach rather than a theoretical risk extrapolation approach.

For substances for which the uncertainty factors are greater than 1000, guideline values are designated as provisional in order to emphasize the higher level of uncertainty inherent in these values. A high uncertainty factor indicates that the guideline value may be considerably lower than the concentration at which health effects would actually occur in a real human population. Guideline values with high uncertainty are more likely to be modified as new information becomes available.

The selection and application of uncertainty factors are important in the derivation of guideline values for chemicals, as they can make a considerable difference in the values set. For contaminants for which there is sufficient confidence in the database, the guideline value is derived using a small uncertainty factor. For most contaminants, however, there is greater scientific uncertainty, and a relatively large uncertainty factor is used. The use of uncertainty factors enables the particular attributes of the chemical and the data available to be considered in the derivation of guideline values.

Use of chemical-specific adjustment factors instead of uncertainty factors

Approaches to the derivation of TDIs are increasingly being based on understanding of a chemical's mode of action in order to reduce reliance on default assumptions. This approach provides a departure from the use of default uncertainty factors (such as a simple 10 for interspecies variation and 10 for intraspecies variation) and relies on the use of quantitative toxicokinetic and toxicodynamic data to derive CSAFs for use in interspecies and intraspecies extrapolations (IPCS, 2005). Previously, CSAFs were called "data-derived uncertainty factors". The part of the CSAF approach that is at present best developed is the use of physiologically based pharmacokinetic models to replace the default values for extrapolation between species and between differing routes of exposure (e.g. inhalation to oral).

Relative source allocation

Drinking-water is usually not the only source of human exposure to the chemicals for which guideline values have been derived. In many cases, the exposure to or intake of chemical contaminants from drinking-water is much lower than that from other sources, such as food, air and consumer products. Some consideration of the proportion of the ADI or TDI that may be attributed to different sources is therefore needed in developing guideline values and risk management strategies. This approach ensures that total daily intake from all sources (including drinking-water containing concentrations of the chemical at or near the guideline value) does not exceed the ADI or TDI.

Wherever possible or in an ideal situation, derivation of guideline values uses data on the proportion of total daily intake normally ingested in drinking-water (based on mean levels in food, drinking-water, consumer products, soil and air), or data on intakes estimated on the basis of physical and chemical properties of the substances of concern. As the primary sources of exposure to chemicals are generally food (e.g. pesticide residues) and water, it is important to quantify, whenever possible, the exposures from both sources. To inform this process, it is desirable to collect as much high-quality data as possible on food intake in different parts of the world as possible. The data collected can then be used to estimate the proportion of the intake that comes from food and the proportion that comes from drinking-water. However, for most contaminants, data from the various exposure sources, most notably food and drinking-water, are available only from developed countries.

In the absence of adequate exposure data or where documented evidence is available regarding widespread presence in one or more of the other media (i.e. air, food, soil or consumer products), the normal allocation of the total daily intake to drinking-water is 20% (floor value), which reflects a reasonable level of exposure based on broad experience, while still being protective (Krishnan & Carrier, 2013). This value reflects a change from the previous allocation of 10%, which was found to be excessively conservative. As chemicals are progressively reassessed, overall exposure will be reconsidered, and a change in the default allocation factor from 10% to 20% will be made, if appropriate. Therefore, not all older guideline values reflect this change. In some circumstances, there is clear evidence that water is the main (and possibly only) source of exposure, such as for some of the DBPs; the allocation in such cases may be as high as 80% (ceiling value), which still allows for some exposure from other sources (Krishnan & Carrier, 2013). Where chemical and context-specific allocation factors can be developed using exposure data or models, the allocation factor applied should still be bounded by the floor and ceiling values (i.e. 20–80%).

For pesticides, even when available food exposure data suggest that exposure via this route is minimal, the default allocation factor of 20% is used to account for the fact that available food exposure data do not generally include information from developing countries, where exposure via this route may be higher.

A detailed explanation of the reasoning behind the choice of allocation factor is an essential component of the evaluation. This assists Member States in making appropriate decisions about incorporating or adapting guideline values into national standards where local circumstances need to be taken into account. It also provides assistance in making decisions regarding potential risks when a guideline value is exceeded. As a general principle, efforts should be made to keep contaminant concentrations as low as possible and not allow increases up to the guideline value.

Although the values chosen are, in most cases, sufficient to account for additional routes of intake (i.e. inhalation and dermal absorption) of contaminants in water, under certain circumstances (e.g. limited ventilation), authorities may wish to take inhalation and dermal exposure into account in adapting the guideline values to local conditions (see section 8.2.9).

Some elements are essential for human nutrition. In developing guideline values and in considering allocation factors, it is necessary to take into account the recommended minimum daily intake and exposures from food and to ensure that the allocation does not result in an apparent conflict with essentiality.

Default assumptions

There is variation in both the volume of water consumed daily and the body weight of consumers. It is therefore necessary to apply some assumptions in order to determine a guideline value. The default assumption for consumption by an adult is 2 litres of water per day, whereas the default assumption for body weight is 60 kg.

In some cases, the guideline value is based on children, where they are considered to be particularly vulnerable to a particular substance. In this event, a default intake of 1 litre is assumed for a body weight of 10 kg; where the most vulnerable group is considered to be bottle-fed infants, an intake of 0.75 litre is assumed for a body weight of 5 kg.

Significant figures

The calculated ADI or TDI is used to derive the guideline value, which is usually rounded to one significant figure. In calculating the guideline value, the unrounded ADI or TDI value should be used.

The guideline value is generally rounded to one significant figure to reflect the uncertainty in, for example, experimental animal toxicity data, exposure assumptions made and the uncertainty factors selected. In a few cases, rounding to two significant figures is appropriate because the practical impact of rounding depends on the units; for example, rounding from 1.5 to 2.0 µg/L has less influence on treatment requirements than rounding from 1.5 to 2.0 mg/L. These are considered on a case-by-case basis.

The general rounding rule for mid-way values (x.5) is to round up, in line with common convention. Examples for rounding to one significant figure are as follows: 1.25 becomes 1, 0.73 becomes 0.7 and 1.5 becomes 2.

8.2.3 Non-threshold chemicals

In the case of compounds considered to be genotoxic carcinogens, guideline values are normally determined using a mathematical model. Although several models exist, the linearized multistage model is generally adopted. Other models are considered more appropriate in certain cases. These models compute an estimate of risk at a particular level of exposure, along with upper and lower bounds of confidence on the calculation, which may include zero at the lower bound. Guideline values are conservatively presented as the concentrations in drinking-water associated with an estimated upper-bound excess lifetime cancer risk of 10^{-5} (or one additional case of cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). This value does not equate to the number of cases of cancer that will be caused by exposure to the substance at this level. It is the maximum potential risk, taking into account large uncertainties. It is highly probable that the actual level of risk is less than this, even approaching zero, but risks at low levels of exposure cannot be experimentally verified. The recognition that the cancer risk may approach zero or be indistinguishable from zero stems from the uncertainties associated with mechanisms of carcinogenesis, including the role of the chemical in the cancer process and the possibility of detoxification and repair mechanisms. Member States may consider that a different level of hypothetical risk is more appropriate to their circumstances, and values relating to risks of 10^{-4} or 10^{-6} additional cancer cases over a lifetime of exposure may be determined by respectively multiplying or dividing the guideline value by 10.

The mathematical models used for deriving guideline values for non-threshold chemicals cannot be verified experimentally, and they do not usually take into account a number of biologically important considerations, such as pharmacokinetics, pre-systemic and metabolic detoxification, DNA repair or protection by the immune system. They also assume the validity of a linear extrapolation of very high dose exposures in test animals to very low dose exposures in humans. As a consequence, the models used are conservative (i.e. err on the side of caution). The guideline values derived using these models should be interpreted differently from TDI-derived values because of the lack of precision of the models. Moderate short-term exposure to levels exceeding the guideline value for non-threshold chemicals does not significantly affect the risk.

8.2.4 Data quality

The following factors were taken into account in assessing the quality and reliability of available information:

- Oral studies are preferred (in particular, drinking-water studies), using the pure substance with appropriate dosing regime and a good quality clinical biochemistry and histopathology.

- The database should be sufficiently broad that all potential toxicological end-points of concern have been identified.
- The quality of the studies is such that they are considered reliable; for example, there has been adequate consideration of confounding factors in epidemiological studies.
- There is reasonable consistency between studies; the end-point and study used to derive a guideline value do not contradict the overall weight of evidence.
- For inorganic substances, there is some consideration of speciation in drinking-water.
- There is appropriate consideration of multimedia exposure in the case of epidemiological studies.

In the development of guideline values, existing international approaches are carefully considered. In particular, previous risk assessments developed by the International Programme on Chemical Safety (IPCS) in Environmental Health Criteria monographs and Concise International Chemical Assessment Documents, IARC, JMPR and JECFA are reviewed. These assessments are relied upon except where new information justifies a reassessment, but the quality of new data is critically evaluated before it is used in any risk assessment. Where international reviews are not available, other sources of data are used in the derivation of guideline values, including published reports from peer-reviewed open literature, national reviews recognized to be of high quality, information submitted by governments and other interested parties and, to a limited extent, unpublished proprietary data (primarily for the evaluation of pesticides).

8.2.5 Provisional guideline values

The use and designation of provisional guideline values are outlined in Table 8.3.

For non-threshold substances, in cases in which the concentration associated with an upper-bound excess lifetime cancer risk of 10^{-5} is not feasible as a result of inadequate analytical or treatment technology, a provisional guideline value (designated A or T, respectively) is recommended at a practicable level.

Table 8.3 Use and designation of provisional guideline values

Situations where a provisional guideline applies	Designation	
Significant scientific uncertainties regarding derivation of health-based guideline value	P	
Calculated guideline value is below the achievable analytical quantification level	A	*(Guideline value is set at the achievable quantification level)*
Calculated guideline value is below the level that can be achieved through practical treatment methods	T	*(Guideline value is set at the practical treatment level)*
Calculated guideline value may be exceeded as a result of disinfection procedures	D	*(Guideline value is set considering possible health effects and the need to maintain adequate disinfection. Adequate disinfection of drinking-water remains paramount)*

8.2.6 Chemicals with effects on acceptability

Some substances of health concern have effects on the taste, odour or appearance of drinking-water that would normally lead to rejection of water at concentrations significantly lower than those of concern for health. Such substances are not normally appropriate for routine monitoring. However, guideline values have been established for some substances that may cause taste or odour in drinking-water at concentrations much lower than the guideline values because there is such a wide range in the ability of consumers to detect them by taste or odour. For such substances, a fact sheet and health-based guideline value (see chapter 12) are presented in the usual way. In the fact sheet, the relationship between concentrations relevant to health and those relevant to the acceptability of the drinking-water is explained. In tables of guideline values, the health-based guideline values are designated with a "C". For other substances, health-based guideline values may be needed, for instance, in order to assist in judging the response that is required when problems are encountered and in some cases to provide reassurance to health authorities and consumers with regard to possible health risks.

8.2.7 Chemicals not included in the Guidelines

Additional information on many chemicals not included in these Guidelines is available from several credible sources, including WHO Environmental Health Criteria monographs and Concise International Chemical Assessment Documents (http://www.who.int/ipcs/en/), chemical risk assessment reports from JMPR, JECFA and IARC and published documents from a number of national sources, such as the United States Environmental Protection Agency. Although these information sources may not have been reviewed for these Guidelines, they have been peer reviewed and provide readily accessible information on the toxicology of many additional chemicals. They can help drinking-water suppliers and health officials decide upon the significance (if any) of a detected chemical and on the response that might be appropriate.

8.2.8 Mixtures

Chemical contaminants of drinking-water supplies are present with numerous other inorganic and organic constituents. The guideline values are calculated separately for individual substances, without specific consideration of the potential for interaction of each substance with other compounds present. Synergistic interactions between substances are usually selective and very limited, especially at the very low levels usually encountered in drinking-water. The large margin of uncertainty incorporated in the majority of the guideline values is considered to be sufficient to account for potential interactions. In addition, the majority of contaminants will not be continuously present at concentrations at or near their guideline value.

For many chemical contaminants, mechanisms of toxicity are different; consequently, there is no reason to assume that there are interactions. There may, however, be occasions when a number of contaminants with similar toxicological mechanisms are present at levels near their respective guideline values. In such cases, decisions concerning appropriate action should be made, taking into consideration local circumstances. Unless there is evidence to the contrary, it is appropriate to assume that the toxic effects of these compounds are additive.

8.2.9 Adapting guideline values to local circumstances

In order to account for the variations in exposure from different sources in different parts of the world, default values, generally between 20% and 80%, are used to make an allocation of the TDI to drinking-water in setting guideline values for many chemicals. Where relevant exposure data are available, authorities are encouraged to develop context-specific guideline values that are tailored to local circumstances and conditions. For example, in areas where the intake of a particular contaminant in drinking-water is known to be much greater than that from other sources (e.g. air and food), it may be appropriate to allocate a greater proportion of the TDI to drinking-water to derive a guideline value more suited to the local conditions.

Daily water intake can vary significantly in different parts of the world, seasonally and particularly where consumers are involved in manual labour in hot climates. Local adjustments to the daily water consumption value may be needed in setting local standards, as in the case of fluoride, for example. For most other substances, the drinking-water intake range is very small (perhaps a factor of 2–4) compared with the much larger range in the toxicological uncertainty factors; hence, no such adjustment is necessary.

Volatile substances in water may be released to the atmosphere in showering and through a range of other household activities. Under such circumstances, inhalation may become a significant route of exposure. Some substances may also be absorbed through the skin during bathing, but this is not usually a major source of uptake. For those substances that are particularly volatile, such as chloroform, the correction factor would be approximately equivalent to a doubling of exposure, which is small in relation to the uncertainties inherent in the derivation of guideline values. However, in some parts of the world, houses have a very low rate of ventilation, and authorities may wish to take inhalation exposure into account in adapting the guideline values to local conditions, although other uncertainty factors used in the quantitative assessments may render this unnecessary. Where such exposure is shown to be important for a particular substance (i.e. high volatility, low ventilation rates and high rates of showering/bathing), it may be appropriate to adjust the guideline value accordingly.

8.3 Analytical achievability

As noted above, guideline values are not set at concentrations of substances that cannot reasonably be measured. In such circumstances, provisional guideline values are set at the reasonable analytical limits.

Guidance provided in this section and in Annex 4 is intended to assist readers to select appropriate analytical methods for specific circumstances. In carrying out hazard identification and risk assessment and for verification and auditing of the water safety plan for chemical contaminants, it is usually necessary to carry out some analysis. It is important that appropriate facilities are available to ensure that suitable methods are used in carrying out chemical analysis.

Various collections of "standard" or "recommended" methods for water analysis are published by a number of national and international agencies. It is often thought that adequate analytical accuracy can be achieved provided that all laboratories use the same standard method. Experience shows that this is not always the case, as a variety of factors may affect the accuracy of the results. Examples include reagent purity, apparatus type and performance, degree of modification of the method in a particular laboratory and the skill and care of the analyst. These factors are likely to vary both between laboratories and over time in an individual laboratory. Moreover, the precision and accuracy that can be achieved with a particular method frequently depend upon the adequacy of sampling and nature of the sample ("matrix"). While it is not essential to use standard methods, it is important that the methods used are properly validated and their precision and accuracy determined before significant decisions are made based on the results. In the case of "nonspecific" variables such as taste, odour, colour and turbidity, the result is method specific, and this needs to be considered when using the data to make comparisons.

A number of considerations are important in selecting methods:

- The overriding consideration is that the method chosen is demonstrated to have the required accuracy. Other factors, such as speed and convenience, should be considered only in selecting among methods that meet this primary criterion.
- Of primary importance is the expertise and diligence of the laboratories performing the analyses. They must utilize auditable quality control and quality assurance procedures for their results to be credible. External certification is highly desirable.
- There are a number of markedly different procedures for measuring and reporting the errors to which all methods are subject. This complicates and prejudices the effectiveness of method selection, and suggestions for standardizing such procedures have been made. It is therefore desirable that details of all analytical methods are published together with performance characteristics that can be interpreted unambiguously.
- If the analytical results from one laboratory are to be compared with those from others or with a numerical standard, it is obviously preferable for them not to have any associated systematic error. In practice, this is not possible, but each laboratory should select methods whose systematic errors have been thoroughly evaluated and shown to be acceptably small.

A qualitative ranking of analytical methods based on their degree of technical complexity is given in Table 8.4 for inorganic chemicals and in Table 8.5 for organic chemicals. These groups of chemicals are separated, as the analytical methods used differ greatly. The higher the ranking, the more complex the process in terms of equipment or operation. In general, higher rankings are also associated with higher total costs.

Analytical achievabilities, based on detection limits, of the inorganic and organic chemicals for which guideline values have been established are given in Annex 4, by source category.

Table 8.4 Ranking of complexity of analytical methods for inorganic chemicals

Ranking	Example of analytical methods
1	Volumetric method, colorimetric method
2	Electrode method
3	Ion chromatography
4	High-performance liquid chromatography
5	Flame atomic absorption spectrometry
6	Electrothermal atomic absorption spectrometry
7	Inductively coupled plasma atomic emission spectrometry
8	Inductively coupled plasma mass spectrometry

Table 8.5 Ranking of complexity of analytical methods for organic chemicals

Ranking	Example of analytical methods
1	High-performance liquid chromatography
2	Gas chromatography
3	Gas chromatography–mass spectrometry
4	Headspace gas chromatography–mass spectrometry
5	Purge-and-trap gas chromatography Purge-and-trap gas chromatography–mass spectrometry

Many kinds of field test kits are available to measure the concentrations of various chemicals in water. These are generally used for compliance examinations as well as for operational monitoring of drinking-water quality. Although the field test kits have the advantage of being simple to use in non-laboratory environments and are often available at relatively low prices, their analytical accuracy is generally less than that of the methods shown in Tables 8.4 and 8.5. However, when properly used, they provide valuable tools for rapidly assessing numerous contaminants in a non-formal laboratory setting at low cost compared with commercial laboratory tests. It is therefore necessary to check the validity of the field test kit before applying it.

A brief description of the analytical methods listed in Tables 8.4 and 8.5 is provided in Annex 4.

8.4 Treatment

As noted above, where a health-based guideline value cannot be achieved by reasonably practicable treatment, then the guideline value is designated as provisional and set at the concentration that can be reasonably achieved through treatment.

Collection, treatment, storage and distribution of drinking-water involve deliberate additions of numerous chemicals to improve the safety and quality of the finished drinking-water for consumers (direct additives). In addition, water is in constant contact with pipes, valves, taps and tank surfaces, all of which have the potential to impart additional chemicals to the water (indirect additives). The chemicals used in water treatment or from materials in contact with drinking-water are discussed in more detail in section 8.5.4.

Table 8.6 Ranking of technical complexity and cost of water treatment processes

Ranking	Examples of treatment processes
1	Simple chlorination Plain filtration (rapid sand, slow sand)
2	Prechlorination plus filtration Aeration
3	Chemical coagulation Process optimization for control of DBPs
4	Granular activated carbon treatment Ion exchange
5	Ozonation
6	Advanced oxidation processes Membrane treatment

8.4.1 Treatment performance

Treatment performance varies according to local conditions and circumstances. The ability to achieve a guideline value within a drinking-water supply depends on a number of factors, including:

- the concentration of the chemical in the raw water;
- control measures employed throughout the drinking-water system;
- nature of the raw water (groundwater or surface water, presence of natural organic matter and inorganic solutes and other components, such as turbidity);
- treatment processes already installed.

If a guideline value cannot be met with the existing system, then additional treatment may need to be considered, or water might need to be obtained from alternative sources.

The cost of achieving a guideline value will depend on the complexity of any additional treatment or other control measures required. It is not possible to provide general quantitative information on the cost of achieving individual guideline values. Treatment costs (capital and operating) will depend not only on the factors identified above, but also on issues such as plant throughput; local costs for labour, civil and mechanical works, chemicals and electricity; life expectancy of the plant; and so on. Guideline values may be progressively achieved in the long term through less capital-intensive non-treatment options, such as through agreements with land users to reduce application of chemicals (fertilizers, pesticides, etc.)

A qualitative ranking of treatment processes based on their degree of technical complexity is given in Table 8.6. The higher the ranking, the more complex the process in terms of plant or operation. In general, higher rankings are also associated with higher costs.

Annex 5 summarizes the treatment processes that are capable of removing chemical contaminants of health significance. The tables in Annex 5 include only those chemicals, by source category, for which some treatment data are available and for which guideline values have been established.

The tables in Annex 5 are provided to help inform decisions regarding the ability of existing treatment to meet guidelines and what additional treatment might need to be installed. They have been compiled on the basis of published literature, which includes mainly laboratory experiments, some pilot plant investigations and relatively few full-scale studies of water treatment processes. Consequently:

- Many of the treatments outlined are designed for larger treatment plants and may not necessarily be appropriate for smaller treatment plants or individual-type treatment. In these cases, the choice of technology must be made on a case-by-case basis.
- The information is probably "best case", as the data would have been obtained under laboratory conditions or with a carefully controlled plant for the purposes of experimentation.
- Actual process performance will depend on the concentration of the chemical in the raw water and on general raw water quality. For example, chlorination and removal of organic chemicals and pesticides using activated carbon or ozonation will be impaired if there is a high concentration of natural organic matter.
- For many contaminants, potentially several different processes could be appropriate, and the choice between processes should be made on the basis of technical complexity and cost, taking into account local circumstances. For example, membrane processes can remove a broad spectrum of chemicals, but simpler and cheaper alternatives are effective for the removal of most chemicals.
- It is normal practice to use a series of unit processes (e.g. coagulation, sedimentation, filtration, chlorination) to achieve desired water quality objectives. Each of these may contribute to the removal of chemicals. It may be technically and economically advantageous to use a combination of processes (e.g. ozonation plus granular activated carbon or membranes) to remove particular chemicals.
- The effectiveness of potential processes should be assessed using laboratory or pilot plant tests on the actual raw water concerned. These tests should be of sufficient duration to identify potential seasonal or other temporal variations in contaminant concentrations and process performance.
- These treatment technology characterizations are estimates and are not comprehensive, but are intended to provide some indications of the types of technologies that have shown greater or lesser capabilities for removing the indicated chemicals from drinking-water.

A brief description of the various treatment processes referred to in Table 8.6 is included in Annex 5.

8.4.2 Process control measures for disinfection by-products

All chemical disinfectants produce inorganic or organic DBPs that may be of concern.

The principal DBPs formed during chlorination are THMs, HAAs, haloketones and haloacetonitriles, as a result of chlorination of naturally occurring organic precursors such as humic substances. Monochloramine produces lower THM concentrations than chlorine but produces other DBPs, including cyanogen chloride.

In attempting to control DBP concentrations, it is of paramount importance that the efficiency of disinfection is not compromised and that a suitable residual level of disinfectant is maintained throughout the distribution system.

Chlorine and ozone oxidize bromide to produce hypohalous acids, which react with precursors to form brominated THMs. A range of other DBPs, including aldehydes and carboxylic acids, may also be formed. Of particular concern is bromate, formed by the oxidation of bromide. Bromate may also be present in some sources of hypochlorite, but usually at concentrations that will give rise to levels in final water that are below the guideline value.

The main by-products from the use of chlorine dioxide are chlorite ion, which is an inevitable decomposition product, and chlorate ion. Chlorate is also produced in hypochlorate as it ages.

The basic strategies that can be adopted for reducing the concentrations of DBPs are:

- changing the process conditions (including removal of precursor compounds prior to application);
- using a different chemical disinfectant with a lower propensity to produce by-products with the source water;
- using non-chemical disinfection;
- removing DBPs prior to distribution.

Changes to process conditions

The formation of THMs during chlorination can be reduced by removing precursors prior to contact with chlorine—for example, by installing or enhancing coagulation (this may involve using higher coagulant doses or lower coagulation pH values than are applied conventionally). DBP formation can also be reduced by lowering the applied chlorine dose; if this is done, it must be ensured that disinfection is still effective.

The pH value during chlorination affects the distribution of chlorinated by-products. Reducing the pH lowers the THM concentration, but at the expense of increased formation of HAAs. Conversely, increasing the pH reduces HAA production but leads to increased THM formation.

The formation of bromate during ozonation depends on several factors, including concentrations of bromide and ozone and the pH. It is not practicable to remove bromide from raw water, and it is difficult to remove bromate once formed, although granular activated carbon filtration has been reported to be effective under certain circumstances. Bromate formation can be minimized by using lower ozone dose, shorter contact time and a lower residual ozone concentration. Operating at lower pH (e.g. pH 6.5) followed by raising the pH after ozonation also reduces bromate formation, and addition of ammonia can also be effective. Addition of hydrogen peroxide can either increase or decrease bromate formation, depending on the point at which it is applied and local treatment conditions.

Changing disinfectants

It may be feasible to change disinfectant in order to achieve guideline values for DBPs. The extent to which this is possible will be dependent on the raw water quality and installed treatment (e.g. for precursor removal).

It may be effective to change from chlorine to monochloramine to provide a secondary disinfectant residual within distribution, in order to reduce THM formation and subsequent development within the distribution system. Although monochloramine provides a more stable residual within distribution, it is a less powerful disinfectant and should not be used as a primary disinfectant.

Chlorine dioxide can be considered as a potential alternative to both chlorine and ozone disinfection, although it does not provide a residual effect, as chlorine would. The main concerns with chlorine dioxide are with the residual concentrations of chlorine dioxide and the by-products chlorite and chlorate. These can be addressed by controlling the dose of chlorine dioxide at the treatment plant.

Non-chemical disinfection

Ultraviolet (UV) irradiation or membrane processes can be considered as alternatives to chemical disinfection. UV is particularly effective at inactivating *Cryptosporidium*, which is extremely resistant to chlorination. Neither of these provides any residual disinfection, and it may be considered appropriate to add a small dose of a persistent disinfectant such as chlorine or monochloramine to act as a preservative during distribution.

Removing DBPs prior to distribution

It is technically feasible to remove DBPs prior to distribution; however, this is the least attractive option for controlling DBP concentrations. Strategies for DBP control include source control, precursor removal, use of alternative disinfectants and removal of DBPs by technologies such as air stripping, activated carbon, UV light and advanced oxidation. These processes would need to be followed by a further disinfection step to guard against microbial contamination and to ensure a residual concentration of disinfectant within distribution.

8.4.3 Treatment for corrosion control

Corrosion is the partial dissolution of the materials constituting the treatment and supply systems, tanks, pipes, valves and pumps. In certain circumstances, all water can be corrosive. Corrosion may lead to structural failure, leaks, loss of capacity and deterioration of chemical and microbial water quality. The internal corrosion of pipes and fittings can have a direct impact on the concentration of water constituents, including lead and copper. Corrosion control is therefore an important aspect of the management of a drinking-water system for safety.

Corrosion control involves many parameters, including the concentrations of calcium, bicarbonate, carbonate and dissolved oxygen, as well as pH. The detailed requirements differ depending on water quality and the materials used in the distribution system. The pH controls the solubility and rate of reaction of most of the metal species involved in corrosion reactions. It is particularly important in relation to the formation of a protective film at the metal surface. For some metals, alkalinity (carbonate and bicarbonate) and calcium (hardness) also affect corrosion rates.

Characterizing corrosivity

Most of the indices that have been developed to characterize the corrosion potential of waters are based on the assumption that water with a tendency to deposit a calcium carbonate scale on metal surfaces will be less corrosive. The Langelier index is the difference between the actual pH of a water and its "saturation pH", this being the pH at which a water of the same alkalinity and calcium hardness would be at equilibrium with solid calcium carbonate. Waters with a positive Langelier index are capable of depositing calcium carbonate scale from solution.

There is no corrosion index that applies to all materials, and corrosion indices, particularly those related to calcium carbonate saturation, have given mixed results. The parameters related to calcium carbonate saturation status are, strictly speaking, indicators of the tendency to deposit or dissolve calcium carbonate (calcite) scale, not indicators of the "corrosivity" of a water. For example, there are many waters with a negative Langelier index that are non-corrosive and many with a positive Langelier index that are corrosive. Nevertheless, there are many documented instances of the use of saturation indices for corrosion control based on the concept of laying down a protective "eggshell" scale of calcite in iron pipes. In general, waters with high pH, calcium and alkalinity are less corrosive, and this tends to be correlated with a positive Langelier index. However, these calcium carbonate precipitation indices are not necessarily considered to be good corrosion predictors for copper systems.

The ratio of the chloride and sulfate concentrations to the bicarbonate concentration (Larson ratio) has been shown to be helpful in assessing the corrosiveness of water to cast iron and steel. A similar approach has been used in studying zinc dissolution from brass fittings—the Turner diagram.

Water treatment for corrosion control

To control corrosion in water distribution networks, the methods most commonly applied are adjusting pH, increasing the alkalinity or hardness or adding corrosion inhibitors, such as polyphosphates, silicates and orthophosphates. The quality and maximum dose to be used should be in line with specifications for such water treatment chemicals. Although pH adjustment is an important approach, its possible impact on other aspects of water supply technology, including disinfection, must always be taken into account.

It is not always possible to achieve the desired values for all parameters. For example, the pH of hard waters cannot be increased too much, or softening will occur. The application of lime and carbon dioxide to soft waters can be used to increase both the calcium concentration and the alkalinity to at least 40 mg/l as calcium carbonate.

More detailed information on the corrosion of various metals commonly used in water treatment and distribution systems can be found in Annex 5.

8.4.4 Household treatment

The chemicals of greatest health concern in some natural waters are usually excess natural fluoride, nitrate/nitrite and arsenic.

Some commercial water treatment technologies are available for small applications for the removal of chemical contaminants. For example, anion exchange using activated alumina or iron-containing products will effectively reduce excess fluoride concentrations. Bone char has also been used to reduce fluoride concentrations. Arsenic is also removed by anion exchange processes similar to those employed for fluoride. Nitrates and nitrates, which are frequently present due to sewage contamination or agricultural runoff, are best managed by protecting the source water from contamination. They are difficult to remove, although disinfection will oxidize nitrite, the more toxic form, to nitrate. In addition, disinfection will sanitize the water and reduce the risk of gastrointestinal infection, which is a risk factor for methaemoglobinaemia caused by excess nitrate/nitrite exposure of infants up to approximately 3–6 months of age.

Cation exchange water softening is widely used in homes to remove excess hardness due to high calcium or magnesium, and it can also remove metals including iron and radium.

Synthetic and natural organic chemicals can be removed by granular activated carbon or carbon block technologies. The treatment systems must be well managed and replaced regularly, because their effectiveness is eventually lost, depending upon the types of contaminating chemicals and their concentrations in the water. Reverse osmosis technologies have general applicability for removal of most organic and inorganic chemicals; however, there is some selectivity, and also there is a significant amount of water wastage when low-pressure units are used in small-volume applications.

8.5 Guideline values for individual chemicals, by source category

8.5.1 Naturally occurring chemicals

There are a number of sources of naturally occurring chemicals in drinking-water. All natural water contains a range of inorganic and organic chemicals. The former derive from the rocks and soil through which water percolates or over which it flows. The latter derive from the breakdown of plant material or from algae and other microorganisms that grow in the water or on sediments. Most of the naturally occurring chemicals for which guideline values have been derived or that have been considered for guideline value derivation are inorganic. Only one, microcystin-LR, a toxin produced by cyanobacteria or blue-green algae, is organic. Cyanobacteria (see also section 11.5) occur widely in lakes, reservoirs, ponds and slow-flowing rivers. Many species are known to produce toxins, or "cyanotoxins", which are of concern for health. Cyanotoxins vary in structure and may be found within cells or released into water. There is wide variation in the toxicity of recognized cyanotoxins (including different structural variants within a group, such as microcystins), and it is likely that further toxins remain unrecognized, so control of blooms is the preferred control option.

The approach to dealing with naturally occurring chemicals will vary according to the nature of the chemical and the source. For inorganic contaminants that arise from rocks and sediments, it is important to screen possible water sources to determine whether the source is suitable for use or whether it will be necessary to treat the

Table 8.7 Naturally occurring chemicals for which guideline values have not been established

Chemical	Reason for not establishing a guideline value	Remarks
Bromide	Occurs in drinking-water at concentrations well below those of health concern	
Chloride	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Hardness	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Hydrogen sulfide	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Iron	Not of health concern at levels causing acceptability problems in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Manganese	Not of health concern at levels normally causing acceptability problems in drinking-water. However, there are circumstances where manganese may remain in solution at higher concentrations in some acidic or anaerobic waters, particularly groundwater	May affect acceptability of drinking-water (see chapter 10)
Molybdenum	Occurs in drinking-water at concentrations well below those of health concern	
pH	Not of health concern at levels found in drinking-water	An important operational water quality parameter
Potassium	Occurs in drinking-water at concentrations well below those of health concern	
Sodium	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Sulfate	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Total dissolved solids	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)

water to remove the contaminants of concern along with microbial contaminants. In some cases, where a number of sources may be available, dilution or blending of the water containing high levels of a contaminant with a water containing much lower levels may achieve the desired result.

A number of the most important chemical contaminants (i.e. those that have been shown to cause adverse health effects as a consequence of exposure through drinking-water) fall into the category of naturally occurring chemicals. Some naturally occurring chemicals have other primary sources and are therefore discussed in other sections of this chapter.

Guideline values have not been established for the naturally occurring chemicals listed in Table 8.7 for the reasons indicated in the table. Fact sheets are included in chapter 12.

Guideline values have been established for the naturally occurring chemicals listed in Table 8.8, which meet the criteria for inclusion. Fact sheets are included for each in chapter 12.

8.5.2 Chemicals from industrial sources and human dwellings

Chemicals from industrial sources can reach drinking-water directly from discharges or indirectly from diffuse sources arising from the use and disposal of materials and

Table 8.8 Guideline values for naturally occurring chemicals that are of health significance in drinking-water

	Guideline value		
Chemical	**µg/l**	**mg/l**	**Remarks**
Inorganic			
Arsenic	10 (A, T)	0.01 (A, T)	
Barium	1300	1.3	
Boron	2400	2.4	
Chromium	50 (P)	0.05 (P)	For total chromium
Fluoride	1500	1.5	Volume of water consumed and intake from other sources should be considered when setting national standards
Selenium	40 (P)	0.04 (P)	
Uranium	30 (P)	0.03 (P)	Only chemical aspects of uranium addressed
Organic			
Microcystin-LR	1 (P)	0.001 (P)	For total microcystin-LR (free plus cell-bound)

A, provisional guideline value because calculated guideline value is below the achievable quantification level; P, provisional guideline value because of uncertainties in the health database; T, provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

products containing the chemicals. In some cases, inappropriate handling and disposal may lead to contamination (e.g. degreasing agents that are allowed to reach groundwater). Some of these chemicals, particularly inorganic substances, may also be encountered as a consequence of natural contamination, but this may also be a by-product of industrial activity, such as mining, that changes drainage patterns. Many of these chemicals are used in small industrial units within human settlements, and, particularly where such units are found in groups of similar enterprises, they may be a significant source of pollution. Petroleum oils are widely used in human settlements, and improper handling or disposal can lead to significant pollution of surface water and groundwater. Where plastic pipes are used, the smaller aromatic molecules in petroleum oils can sometimes penetrate the pipes where they are surrounded by earth soaked in the oil, with subsequent pollution of the local water supply.

A number of chemicals can reach water as a consequence of disposal of general household chemicals; in particular, a number of heavy metals may be found in domestic wastewater. Where wastewater is treated, these will usually partition out into the sludge. Some chemicals that are widely used both in industry and in materials used in a domestic setting are found widely in the environment (e.g. di(2-ethylhexyl)-phthalate), and these may be found in water sources, although usually at low concentrations.

Some chemicals that reach drinking-water from industrial sources or human settlements have other primary sources and are therefore discussed in other sections of this chapter. Where latrines and septic tanks are poorly sited, these can lead to contamination of drinking-water sources with nitrate (see section 8.5.3).

Identification of the potential for contamination by chemicals from industrial activities and human dwellings requires assessment of activities in the catchment and of

Table 8.9 Chemicals from industrial sources and human dwellings for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Beryllium	Rarely found in drinking-water at concentrations of health concern
Cyanide	Occurs in drinking-water at concentrations well below those of health concern, except in emergency situations following a spill to a water source
1,3-Dichlorobenzene	Available data inadequate to permit derivation of health-based guideline value
1,1-Dichloroethane	Available data inadequate to permit derivation of health-based guideline value
1,1-Dichloroethene	Occurs in drinking-water at concentrations well below those of health concern
Di(2-ethylhexyl)adipate	Occurs in drinking-water at concentrations well below those of health concern
Hexachlorobenzene	Occurs in drinking-water at concentrations well below those of health concern
Methyl tertiary-butyl ether	Any guideline that would be derived would be significantly higher than concentrations at which methyl tertiary-butyl ether would be detected by odour
Monochlorobenzene	Occurs in drinking-water at concentrations well below those of health concern, and health-based value would far exceed lowest reported taste and odour threshold
Nitrobenzene	Rarely found in drinking-water at concentrations of health concern
Petroleum products	Taste and odour will in most cases be detectable at concentrations below those of health concern, particularly with short-term exposure
Trichlorobenzenes (total)	Occur in drinking-water at concentrations well below those of health concern, and health-based value would exceed lowest reported odour threshold
1,1,1-Trichloroethane	Occurs in drinking-water at concentrations well below those of health concern

the risk that particular contaminants may reach water sources. The primary approach to addressing these contaminants is prevention of contamination by encouraging good practices. However, if contamination has occurred, then it may be necessary to consider the introduction of treatment.

Guideline values have not been established for the chemicals listed in Table 8.9 for the reasons indicated in the table. Fact sheets for each are included in chapter 12.

Guideline values have been established for the chemicals listed in Table 8.10, which meet all of the criteria for inclusion. Fact sheets for each are included in chapter 12.

8.5.3 Chemicals from agricultural activities

Chemicals are used in agriculture on crops and in animal husbandry. Nitrate may be present as a consequence of tillage when there is no growth to take up nitrate released from decomposing plants, from the application of excess inorganic or organic fertilizer and in slurry from animal production. Most chemicals that may arise from

Table 8.10 Guideline values for chemicals from industrial sources and human dwellings that are of health significance in drinking-water

	Guideline value		
Chemicals	**µg/l**	**mg/l**	**Remarks**
Inorganic			
Cadmium	3	0.003	
Mercury	6	0.006	For inorganic mercury
Organic			
Benzene	10[a]	0.01[a]	
Carbon tetrachloride	4	0.004	
1,2-Dichlorobenzene	1000 (C)	1 (C)	
1,4-Dichlorobenzene	300 (C)	0.3 (C)	
1,2-Dichloroethane	30[a]	0.03[a]	
1,2-Dichloroethene	50	0.05	
Dichloromethane	20	0.02	
Di(2-ethylhexyl)phthalate	8	0.008	
1,4-Dioxane	50[a]	0.05[a]	Derived using TDI approach as well as linear multistage modelling
Edetic acid	600	0.6	Applies to the free acid
Ethylbenzene	300 (C)	0.3 (C)	
Hexachlorobutadiene	0.6	0.0006	
Nitrilotriacetic acid	200	0.2	
Pentachlorophenol	9[a] (P)	0.009[a] (P)	
Styrene	20 (C)	0.02 (C)	
Tetrachloroethene	40	0.04	
Toluene	700 (C)	0.7 (C)	
Trichloroethene	20 (P)	0.02 (P)	
Xylenes	500 (C)	0.5 (C)	

C, concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints; P, provisional guideline value because of uncertainties in the health database

[a] For non-threshold substances, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional case of cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

agriculture are pesticides, although their presence will depend on many factors, and not all pesticides are used in all circumstances or climates. Contamination can result from application and subsequent movement following rainfall or from inappropriate disposal methods.

Some pesticides are also used in non-agricultural circumstances, such as the control of weeds on roads and railway lines. These pesticides are also included in this section.

Table 8.11 Chemicals from agricultural activities excluded from guideline value derivation

Chemical	Reason for exclusion
Amitraz	Degrades rapidly in the environment and is not expected to occur at measurable concentrations in drinking-water supplies
Chlorobenzilate	Unlikely to occur in drinking-water
Chlorothalonil	Unlikely to occur in drinking-water
Cypermethrin	Unlikely to occur in drinking-water
Deltamethrin	Unlikely to occur in drinking-water
Diazinon	Unlikely to occur in drinking-water
Dinoseb	Unlikely to occur in drinking-water
Ethylene thiourea	Unlikely to occur in drinking-water
Fenamiphos	Unlikely to occur in drinking-water
Formothion	Unlikely to occur in drinking-water
Hexachlorocyclohexanes (mixed isomers)	Unlikely to occur in drinking-water
MCPB[a]	Unlikely to occur in drinking-water
Methamidophos	Unlikely to occur in drinking-water
Methomyl	Unlikely to occur in drinking-water
Mirex	Unlikely to occur in drinking-water
Monocrotophos	Has been withdrawn from use in many countries and is unlikely to occur in drinking-water
Oxamyl	Unlikely to occur in drinking-water
Phorate	Unlikely to occur in drinking-water
Propoxur	Unlikely to occur in drinking-water
Pyridate	Not persistent and only rarely found in drinking-water
Pyriproxyfen	Unlikely to occur in drinking-water[b]
Quintozene	Unlikely to occur in drinking-water
Toxaphene	Unlikely to occur in drinking-water
Triazophos	Unlikely to occur in drinking-water
Tributyltin oxide	Unlikely to occur in drinking-water
Trichlorfon	Unlikely to occur in drinking-water

[a] 4-(4-chloro-o-tolyloxy)butyric acid.
[b] The use of pyriproxyfen as a larvicide for public health purposes is discussed further in section 8.6.

Guideline values have not been established for the chemicals listed in Table 8.11, as a review of the literature on occurrence or credibility of occurrence in drinking-water has shown evidence that the chemicals do not occur in drinking-water.

Guideline values have not been established for the chemicals listed in Table 8.12 for the reasons indicated in the table. However, health-based values and, in some cases, acute health-based values have been developed for a number of these pesticides in order to provide guidance to Member States when there is a reason for local concern such as an emergency or spill situation (for further information on guideline values and health-based values, see section 8.2). Fact sheets for each are included in chapter 12.

Table 8.12 Chemicals from agricultural activities for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Ammonia	Occurs in drinking-water at concentrations well below those of health concern
Bentazone	Occurs in drinking-water or drinking-water sources at concentrations well below those of health concern
Carbaryl	Occurs in drinking-water at concentrations well below those of health concern
1,3-Dichloropropane	Available data inadequate to permit derivation of health-based guideline value
Dichlorvos	Occurs in drinking-water or drinking-water sources at concentrations well below those of health concern
Dicofol	Unlikely to occur in drinking-water or drinking-water sources[a]
Diquat	Occurs in drinking-water or drinking-water sources at concentrations well below those of health concern
Endosulfan	Occurs in drinking-water at concentrations well below those of health concern
Fenitrothion	Occurs in drinking-water at concentrations well below those of health concern
Glyphosate and AMPA[b]	Occur in drinking-water at concentrations well below those of health concern
Heptachlor and heptachlor epoxide	Occur in drinking-water at concentrations well below those of health concern
Malathion	Occurs in drinking-water at concentrations well below those of health concern
MCPA[c]	Occurs in drinking-water or drinking-water sources at concentrations well below those of health concern
Methyl parathion	Occurs in drinking-water at concentrations well below those of health concern
Parathion	Occurs in drinking-water at concentrations well below those of health concern
2-Phenylphenol and its sodium salt	Occurs in drinking-water at concentrations well below those of health concern
Propanil	Readily transformed into metabolites that are more toxic; a guideline value for the parent compound is considered inappropriate, and there are inadequate data to enable the derivation of guideline values for the metabolites

[a] Although dicofol does not fulfil one of the three criteria for evaluation in the Guidelines, a background document has been prepared, and a health-based value has been established, in response to a request from Member States for guidance.
[b] Aminomethylphosphonic acid.
[c] (2-Methyl-4-chlorophenoxy)acetic acid.

Guideline values have been established for the chemicals listed in Table 8.13, which meet the criteria for inclusion (see section 8.2). Fact sheets for each are included in chapter 12.

Guideline values and health-based values are protective against health effects resulting from lifetime exposure. Small exceedances for short periods would not normally constitute a health emergency. In the event of a spill, a higher allocation of the ADI to drinking-water could be justified. Alternatively, in cases where acute health-based values have been derived, normally based on JMPR evaluations, these may provide useful guidance (for further information, see section 8.7.5).

Routine monitoring of pesticides is generally not considered necessary. Member States should consider local usage and potential situations such as spills in deciding whether and where to monitor. In the event that monitoring results show levels above the guideline value or health-based value on a regular basis, it is advisable that a plan be developed and implemented to address the situation.

As a general principle, efforts should be made to keep the concentration of pesticides in water as low as possible, and to not allow concentrations to increase up to the guideline value or health-based value.

8.5.4 Chemicals used in water treatment or from materials in contact with drinking-water

Chemicals used in water treatment and chemicals arising from materials in contact with water may give rise to contaminants in the final water.

Some substances are deliberately added to water in the course of treatment (direct additives), some of which may be inadvertently retained in the finished water

Table 8.13 Guideline values for chemicals from agricultural activities that are of health significance in drinking-water

	Guideline value		
Chemical	**µg/l**	**mg/l**	**Remarks**
Non-pesticides			
Nitrate (as NO_3^-)	50 000	50	Based on short-term effects, but protective for long-term effects
Nitrite (as NO_2^-)	3 000	3	Based on short-term effects, but protective for long-term effects
Pesticides used in agriculture			
Alachlor	20[a]	0.02[a]	
Aldicarb	10	0.01	Applies to aldicarb sulfoxide and aldicarb sulfone
Aldrin and dieldrin	0.03	0.000 03	For combined aldrin plus dieldrin
Atrazine and its chloro-*s*-triazine metabolites	100	0.1	
Carbofuran	7	0.007	
Chlordane	0.2	0.000 2	
Chlorotoluron	30	0.03	
Chlorpyrifos	30	0.03	
Cyanazine	0.6	0.000 6	
2,4-D[b]	30	0.03	Applies to free acid
2,4-DB[c]	90	0.09	
1,2-Dibromo-3-chloropropane	1[a]	0.001[a]	
1,2-Dibromoethane	0.4[a] (P)	0.000 4[a] (P)	
1,2-Dichloropropane	40 (P)	0.04 (P)	
1,3-Dichloropropene	20[a]	0.02[a]	
Dichlorprop	100	0.1	
Dimethoate	6	0.006	
Endrin	0.6	0.000 6	
Fenoprop	9	0.009	
Hydroxyatrazine	200	0.2	Atrazine metabolite
Isoproturon	9	0.009	
Lindane	2	0.002	
Mecoprop	10	0.01	
Methoxychlor	20	0.02	
Metolachlor	10	0.01	

Table 8.13 (continued)

	Guideline value		
Chemical	**µg/l**	**mg/l**	**Remarks**
Molinate	6	0.006	
Pendimethalin	20	0.02	
Simazine	2	0.002	
2,4,5-T[d]	9	0.009	
Terbuthylazine	7	0.007	
Trifluralin	20	0.02	

P, provisional guideline value because of uncertainties in the health database

[a] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

[b] 2,4-Dichlorophenoxyacetic acid.

[c] 2,4-Dichlorophenoxybutyric acid.

[d] 2,4,5-Trichlorophenoxyacetic acid.

(e.g. salts, coagulant polymer residues or monomers). Chloramine and chlorine disinfectant residuals, for example, are deliberate additives, and their presence confers a benefit. Others, such as DBPs, are generated during chemical interactions between disinfectant chemicals and substances normally in water (Table 8.14). Chlorination by-products and other DBPs may also occur in swimming pools, from which exposure by inhalation and skin absorption will be of greater importance (WHO, 2006).

Other chemicals, such as lead or copper from pipes or brass taps and chemicals leaching from coatings, may be taken up from contact with surfaces during treatment or distribution (indirect or unintentional additives).

Some chemicals used in water treatment (e.g. aluminium) or in materials in contact with drinking-water (e.g. styrene) have other principal sources and are therefore discussed in detail in other sections of this chapter.

Many of these additives, both direct and indirect or unintentional, are components of processes for producing safe drinking-water. The approach to monitoring and management is preferably through control of the material or chemical. It is important to optimize treatment processes and to ensure that such processes remain optimized in order to control residuals of chemicals used in treatment and to control the formation of DBPs. Inadvertent contamination caused by poor quality materials is best controlled by applying specifications governing the composition of the products themselves rather than by setting limits on the quality of finished water, whereas contamination due to the inappropriate use of additives can be addressed by guidance on use. Similarly, regulations on the quality of pipe can avoid possible contamination of water by leachable materials. Control of contamination from in situ applied coatings requires suitable codes of practice on their application in addition to controls on the composition of materials.

Numerous national and third-party evaluation and approval systems for additives and materials for contact with drinking-water exist throughout the world; however,

Table 8.14 Disinfection by-products present in disinfected waters (based on IPCS, 2000)

Disinfectant	Significant organohalogen products	Significant inorganic products	Significant non-halogenated products
Chlorine/ hypochlorous acid (hypochlorite)	THMs, HAAs, haloacetonitriles, chloral hydrate, chloropicrin, chlorophenols, *N*-chloramines, halofuranones, bromohydrins	Chlorate (mostly from hypochlorite use)	Aldehydes, cyanoalkanoic acids, alkanoic acids, benzene, carboxylic acids, *N*-nitrosodimethylamine
Chlorine dioxide		Reduced primarily to chlorite, chlorate and chloride in drinking-water, and to chlorite and chloride upon ingestion; the provisional guideline values for chlorite and chlorate are protective for potential toxicity from chlorine dioxide	Unknown
Chloramine	Haloacetonitriles, cyanogen chloride, organic chloramines, chloramino acids, chloral hydrate, haloketones	Nitrate, nitrite, chlorate, hydrazine	Aldehydes, ketones, *N*-nitrosodimethylamine
Ozone	Bromoform, monobromoacetic acid, dibromoacetic acid, dibromoacetone, cyanogen bromide	Chlorate, iodate, bromate, hydrogen peroxide, hypobromous acid, epoxides, ozonates	Aldehydes, ketoacids, ketones, carboxylic acids
Sodium dichloroisocyanurate	As for chlorine/ hypochlorous acid (hypochlorite)		Cyanuric acid

many countries do not have or operate such systems. Governments and other organizations should consider establishing or adapting additive management systems and setting product quality standards and guidance on use that would apply to determining acceptable water contact products. Ideally, harmonized standards between countries or reciprocal recognition would reduce costs and increase access to such standards (see also section 1.2.9).

Guideline values have not been established for the chemicals listed in Table 8.15 for the reasons indicated in the table. Fact sheets for each are included in chapter 12.

Guideline values have been established for the chemicals listed in Table 8.16, which meet the criteria for inclusion. Fact sheets for each are included in chapter 12.

Indicator substances for monitoring chlorination by-products

Although guideline values have been established for a number of chlorination by-products, data from drinking-water supplies indicate that THMs and HAAs are adequate as indicators of the majority of chlorination by-products. The most appropriate means of controlling chlorination by-products is to remove the organic precursors, which are largely of natural origin. Measurement of THMs and, if appropriate, HAAs (e.g. where water is chlorinated at a low pH) can be used to optimize treatment efficiency and to establish the boundaries of other operational parameters that can be used to monitor treatment performance. In these circumstances, monitoring frequencies of other chlorination by-products can be reduced. Although total organohalogen does not correlate well with either THMs or HAAs, it is a measure of total chlorination by-products and may be another potential indicator for operational purposes.

Table 8.15 Chemicals used in water treatment or materials in contact with drinking-water for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Disinfectants	
Chlorine dioxide	Reduced primarily to chlorite, chlorate and chloride in drinking-water, and to chlorite and chloride upon ingestion; the provisional guideline values for chlorite and chlorate are protective for potential toxicity from chlorine dioxide
Dichloramine	Available data inadequate to permit derivation of health-based guideline value
Iodine	Available data inadequate to permit derivation of health-based guideline value, and lifetime exposure to iodine through water disinfection is unlikely
Silver	Available data inadequate to permit derivation of health-based guideline value
Trichloramine	Available data inadequate to permit derivation of health-based guideline value
Disinfection by-products	
Bromochloroacetate	Available data inadequate to permit derivation of health-based guideline value
Bromochloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Chloral hydrate	Occurs in drinking-water at concentrations well below those of health concern
Chloroacetones	Available data inadequate to permit derivation of health-based guideline values for any of the chloroacetones
2-Chlorophenol	Available data inadequate to permit derivation of health-based guideline value
Chloropicrin	Available data inadequate to permit derivation of health-based guideline value
Cyanogen chloride	Occurs in drinking-water at concentrations well below those of health concern
Dibromoacetate	Available data inadequate to permit derivation of health-based guideline value
2,4-Dichlorophenol	Available data inadequate to permit derivation of health-based guideline value
Formaldehyde	Occurs in drinking-water at concentrations well below those of health concern
Monobromoacetate	Available data inadequate to permit derivation of health-based guideline value
MX[a]	Occurs in drinking-water at concentrations well below those of health concern
Trichloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Contaminants from treatment chemicals	
Aluminium	A health-based value of 0.9 mg/l could be derived, but this value exceeds practicable levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants: 0.1 mg/l or less in large water treatment facilities and 0.2 mg/l or less in small facilities

Table 8.15 (continued)

Chemical	Reason for not establishing a guideline value
Contaminants from pipes and fittings	
Asbestos	No consistent evidence that ingested asbestos is hazardous to health
Dialkyltins	Available data inadequate to permit derivation of health-based guideline values for any of the dialkyltins
Fluoranthene[b]	Occurs in drinking-water at concentrations well below those of health concern
Inorganic tin	Occurs in drinking-water at concentrations well below those of health concern
Zinc	Not of health concern at levels found in drinking-water[c]

[a] 3-Chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone.

[b] See fact sheet on polynuclear aromatic hydrocarbons.

[c] May affect acceptability of drinking-water (see chapter 10).

Table 8.16 Guideline values for chemicals used in water treatment or materials in contact with drinking-water that are of health significance in drinking-water

	Guideline value[a]		
Chemical	**µg/l**	**mg/l**	**Remarks**
Disinfectants			
Chlorine	5 000 (C)	5 (C)	For effective disinfection, there should be a residual concentration of free chlorine of ≥ 0.5 mg/l after at least 30 min contact time at pH < 8.0. A chlorine residual should be maintained throughout the distribution system. At the point of delivery, the minimum residual concentration of free chlorine should be 0.2 mg/l.
Monochloramine	3 000	3	
Sodium dichloroisocyanurate	50 000	50	As sodium dichloroisocyanurate
	40 000	40	As cyanuric acid
Disinfection by-products			
Bromate	10[a] (A, T)	0.01[a] (A, T)	
Bromodichloromethane	60[a]	0.06[a]	
Bromoform	100	0.1	
Chlorate	700 (D)	0.7 (D)	
Chlorite	700 (D)	0.7 (D)	
Chloroform	300	0.3	
Dibromoacetonitrile	70	0.07	
Dibromochloromethane	100	0.1	
Dichloroacetate	50[a] (D)	0.05[a] (D)	
Dichloroacetonitrile	20 (P)	0.02 (P)	

Table 8.16 (continued)

	Guideline value[a]		
Chemical	**µg/l**	**mg/l**	**Remarks**
Monochloroacetate	20	0.02	
N-Nitrosodimethylamine	0.1	0.0001	
Trichloroacetate	200	0.2	
2,4,6-Trichlorophenol	200[a] (C)	0.2[a] (C)	
Trihalomethanes			The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1
Contaminants from treatment chemicals			
Acrylamide	0.5[a]	0.0005[a]	
Epichlorohydrin	0.4 (P)	0.0004 (P)	
Contaminants from pipes and fittings			
Antimony	20	0.02	
Benzo[*a*]pyrene	0.7[a]	0.0007[a]	
Copper	2000	2	Staining of laundry and sanitary ware may occur below guideline value
Lead	10 (A, T)	0.01 (A, T)	
Nickel	70	0.07	
Vinyl chloride	0.3[a]	0.0003[a]	

A, provisional guideline value because calculated guideline value is below the achievable quantification level; C. concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints; D, provisional guideline value because disinfection is likely to result in the guideline value being exceeded; P, provisional guideline value because of uncertainties in the health database; T, provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source control, etc.

[a] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional case of cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

In all circumstances, disinfection efficiency should not be compromised in trying to meet guidelines for DBPs, including chlorination by-products, or in trying to reduce concentrations of these substances.

Contaminants from storage and generation of hypochlorite solutions

Sodium hypochlorite solutions slowly decompose—more rapidly at warmer temperatures—to produce chlorate and chlorite ions. As the solution ages and the available chlorine concentration decreases, it is necessary to dose more product to achieve the desired residual chlorine concentration, with a consequent increase in the amounts of chlorate and chlorite added to the treated water. The decomposition of solid calcium hypochlorite is much slower, and consequently contamination is less likely to be significant. However, if calcium hypochlorite solutions are prepared and stored before use, then decomposition to form chlorate and chlorite would also occur.

Sodium hypochlorite is manufactured by electrolysing sodium chloride dissolved in water, which would naturally also contain small concentrations of sodium bromide. This results in the presence of bromate in the sodium hypochlorite solution and will contribute bromate to the treated water. The quality and acceptability of sodium hypochlorite will partly be a function of the concentration of the bromate residue. Industrial-grade product may not be acceptable for drinking-water applications. The sodium bromide naturally present in sodium chloride will also be oxidized to form bromate in systems using on-site electrochemical generation of hypochlorite.

Contaminants from use of ozone and chlorine dioxide

The use of ozone can lead to elevated bromate concentrations through oxidation of bromide present in the water. As a general rule, the higher the bromide concentration in the water, the more bromate that is produced.

Chlorine dioxide solutions can contain chlorate as a result of reactions that compete with the desired reaction for generation of chlorine dioxide. Chlorite ion is an inevitable decomposition product from the use of chlorine dioxide; typically, 60–70% of the applied dose is converted to chlorite in the treated water.

8.5.5 Chemicals of emerging concern

Pharmaceuticals

Pharmaceuticals can be introduced into water sources in sewage by excretion from individuals using these chemicals, from uncontrolled drug disposal (e.g. discarding drugs into toilets) and from agricultural runoff from livestock manure. They have become chemicals of emerging concern to the public because of their potential to reach drinking-water.

The specific types of pharmaceuticals and their metabolites in water sources can differ between countries or regions depending on social, cultural, technological and agricultural factors. Urban and rural areas may exhibit important differences in the occurrence and concentrations of these chemicals as a result of different usage patterns. The local physical and chemical characteristics of source waters can also affect the occurrence levels of pharmaceuticals by influencing their natural degradation.

Most occurrence data in drinking-water and source water have resulted from targeted investigations, rather than from systematic monitoring. Advancements in the sensitivity and accuracy of detection technologies and methodologies have led to increasing detection of trace amounts of pharmaceuticals, ranging from concentrations in the nanogram per litre to low microgram per litre range (although largely less than 0.1 μg/l) in drinking-water, surface water and groundwater. Higher concentrations of these contaminants are found in wastewater treatment effluents or wastewater discharges from poorly controlled manufacturing facilities.

The concentrations of pharmaceuticals found in drinking-water are typically orders of magnitude less than the lowest therapeutic doses. Therefore, exposure to individual compounds in drinking-water is unlikely to have appreciable adverse impacts on human health. Formal guideline values are therefore not proposed in these Guidelines.

Routine monitoring for pharmaceuticals in drinking-water and additional or specialized drinking-water treatment to reduce the concentrations of pharmaceuticals in drinking-water are not considered necessary. However, where local circumstances indicate a potential for elevated concentrations of pharmaceuticals in drinking-water, investigative monitoring and surveys of impacted water sources can be undertaken to assess possible exposure. If undertaken, these surveys should be quality assured and should target pharmaceuticals that are of local significance—i.e. those that are commonly prescribed and used or manufactured locally. Based on the risk assessment, screening values can be developed to assess the potential risks from exposure through drinking-water, and possible control measures could be considered within the context of water safety plans. Practical difficulties with implementing monitoring programmes include lack of standardized sampling and analysis protocols, high costs and limited availability of technologies needed to detect the diverse range of pharmaceuticals that may be present.

Effective treatment of pharmaceuticals depends on the physicochemical properties of the specific compounds. Typically, conventional treatment processes are less effective than advanced treatment processes for the removal of many organic compounds, particularly those that are more water soluble.

Preventive measures, such as rational drug use and education of prescribers and the public to reduce disposal and discharges to the environment, will likely reduce human exposure.

Further information is available in *Pharmaceuticals in drinking-water* (see Annex 1).

8.6 Pesticides used in water for public health purposes

The control of insect vectors of disease (e.g. dengue fever) is vital in many countries, and there are occasions when vectors, particularly mosquitoes, breed in containers used for the storage and collection of drinking-water. Although actions should be taken to prevent access of vectors to or breeding of vectors in these containers, this is not always possible or may not always be fully effective, and use of mosquito larvicides may be indicated in certain settings.

WHOPES carries out evaluations of pesticides for public health uses. There are currently seven larvicidal compounds (diflubenzuron, methoprene, novaluron, pirimiphos-methyl, pyriproxyfen, spinosad and temephos) and a bacterial larvicide (*Bacillus thuringiensis israelensis*) that have been evaluated and listed by WHOPES for the control of container-breeding mosquitoes.

While it is not appropriate to set guideline values for pesticides used for vector control, it is valuable to provide information regarding their safety in use. Formulations of pesticides used for vector control in drinking-water should strictly follow the label recommendations and should only be those approved for such use by national authorities, taking into consideration the ingredients and formulants used in making the final product. In evaluating vector control pesticides for the Guidelines, an assessment is made of the potential exposure compared with the ADI. However, exceeding the ADI does not necessarily mean that this will result in adverse health effects. The diseases spread by vectors are significant causes of morbidity and mortality. It is therefore important to achieve an appropriate balance between the intake of the pesticide from drinking-water and the control of disease-carrying insects. It is stressed that every effort should be made to keep overall exposure and the concentration of

Table 8.17 Pesticides used for public health purposes for which guideline values have not been derived

Pesticide	Reason for not establishing a guideline value
Bacillus thuringiensis israelensis (Bti)	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Diflubenzuron	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Methoprene	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Novaluron	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Permethrin	Not recommended for direct addition to drinking-water as part of WHO's policy to exclude the use of any pyrethroids for larviciding of mosquito vectors of human disease
Pirimiphos-methyl	Not recommended for use for vector control in drinking-water
Pyriproxyfen	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Spinosad	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Temephos	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water

any larvicide no greater than that recommended by WHOPES and as low as possible commensurate with efficacy.

Member States should consider the use of larvicides within the context of their broad vector control strategy. The use of larvicides should be only part of a comprehensive management plan for household water storage and domestic waste management that does not rely exclusively on larviciding by insecticides, but also includes other environmental management measures and social behaviour change. Nevertheless, it would be valuable to obtain actual data on exposure to these substances under field conditions in order to carry out a more refined assessment of margins of exposure.

In addition to the use of larvicides approved for drinking-water application to control disease vector insects, other control measures should also be considered. For example, the stocking of fish of appropriate varieties (e.g. larvae-eating mosquitofish and predatory copepods) in water bodies may adequately control infestations and breeding of mosquitoes in those bodies. Other mosquito breeding areas where water collects should be managed by draining, especially after rainfall.

Those pesticides used for public health purposes for which guideline values have not been derived are listed in Table 8.17. Dichlorodiphenyltrichlorethane (DDT) has been used for public health purposes in the past. It is being reintroduced (but not for water applications) in some areas to control malaria-carrying mosquitoes. Its guideline value is shown in Table 8.18. A summary of the product formulations and dosage rates, with corresponding exposures, is provided in Table 8.19.

Fact sheets for all larvicides considered in the Guidelines are included in chapter 12.

Table 8.18 Guideline values for pesticides that were previously used for public health purposes and are of health significance in drinking-water

Pesticides previously used for public health purposes	Guideline value	
	µg/l	mg/l
DDT and metabolites	1	0.001

8.7 Identifying local actions in response to chemical water quality problems and emergencies

It is difficult to give comprehensive guidance concerning emergencies in which chemicals cause massive contamination of the drinking-water supply, caused either by accident or by deliberate action. Most of the guideline values recommended in these Guidelines (see section 8.5 and Annex 3) relate to a level of exposure that is regarded as tolerable throughout life. Acute toxic effects are considered for a limited number of chemicals. The length of time for which exposure to a chemical far in excess of the guideline value would have adverse effects on health will depend upon factors that vary from contaminant to contaminant. In an emergency situation, the public health authorities should be consulted about appropriate action.

The exceedance of a guideline value may not result in a significant or increased risk to health. Therefore, deviations above the guideline values in either the short or long term may not necessarily mean that the water is unsuitable for consumption. The amount by which, and the period for which, any guideline value can be exceeded without affecting public health depends upon the specific substance involved, and acceptability judgements need to be made by qualified health officials. However, exceedance should be a signal:

- as a minimum, to investigate the cause with a view to taking remedial action as necessary;
- to consult the authority responsible for public health for advice on suitable action, taking into account the intake of the substance from sources other than drinking-water, the toxicity of the substance, the likelihood and nature of any adverse effects and the practicality of remedial measures.

If a guideline value is to be exceeded by a significant amount or for more than a few days, it may be necessary to act rapidly so as to ensure that health protective action is taken and to inform consumers of the situation so that they can act appropriately.

The primary aim with regard to chemical contaminants when a guideline value is exceeded or in an emergency is to prevent exposure of the population to toxic concentrations of pollutants. However, in applying the Guidelines under such circumstances, an important consideration is that, unless there are appropriate alternative supplies of drinking-water available, maintenance of adequate quantities of water is a high priority. In the case of an incident in which chemical contaminants are spilt into a source water and enter a drinking-water supply or enter a supply through treatment or during distribution, the primary aim is to minimize the risk of adverse effects without unnecessarily disrupting the use of the water supply.

Table 8.19 WHO-recommended compounds and formulations for control of mosquito larvae in container habitats[a]

Insecticide	Formulation	Dosage (mg/l)[b]	ADI (mg/kg bw)	Exposure (mg/kg bw)[c]	Use in drinking-water
Bacillus thuringiensis israelensis (Bti)[d]	WG	1–5	—	Adult: 0.17 Child: 0.5 Infant: 0.75	Can be used at recommended doses
Diflubenzuron	DT, GR, WP	0.02–0.25	0–0.02	Adult: 0.008 Child: 0.025[e] Infant: 0.0375[e]	Can be used at recommended doses
Methoprene	EC	1	0–0.09	Adult: 0.033 Child: 0.1[e] Infant: 0.15[e]	Can be used at recommended doses
Novaluron	EC	0.01–0.05	0–0.01	Adult: 0.0017 Child: 0.005 Infant: 0.0075	Can be used at recommended doses
Pirimiphos-methyl	EC	1	0–0.03	Adult: 0.033 Child: 0.1[e] Infant: 0.15[e]	Not recommended for direct application to drinking-water
Pyriproxyfen	GR	0.01	0–0.1	Adult: 0.000 33 Child: 0.001 Infant: 0.0015	Can be used at recommended doses
Spinosad	DT, GR, SC	0.1–0.5[f]	0–0.02	Adult: 0.0017 Child: 0.0052 Infant: 0.0078	Can be used at recommended doses
Temephos	EC, GR	1	0.023[g]	Adult: 0.033 Child: 0.1[e] Infant: 0.15[e]	Can be used at recommended doses

bw, body weight; DT, tablet for direct application; EC, emulsifiable concentrate; GR, granule; SC, suspension concentration; WG, water dispersible granule; WP, wettable powder

[a] WHO recommendations on the use of pesticides in public health are valid only if linked to WHO specifications for their quality control. WHO specifications for public health pesticides are available at http://who.int/whopes/quality/en. Label instructions must always be followed when using insecticides.

[b] Active ingredient for control of container-breeding mosquitoes.

[c] Exposure at the maximum dosage in drinking-water for (a) a 60 kg adult drinking 2 litres of water per day, (b) a 10 kg child drinking 1 litre of water per day and (c) a 5 kg bottle-fed infant drinking 0.75 litre of water per day.

[d] Bti itself is not considered to pose a hazard to humans through drinking-water.

[e] Consideration should be given to using alternative sources of water for small children and bottle-fed infants for a period after application, where this is practical. However, exceeding the ADI will not necessarily result in adverse effects.

[f] The maximum concentration actually achieved with the slow-release formulation of spinosad was approximately 52 µg/l.

[g] This is a TDI rather than an ADI, as JMPR considered that the database was insufficiently robust to serve as the basis for establishing an ADI for temephos. For the purposes of these Guidelines, a TDI has been calculated from the lowest oral NOAEL in the critical study identified by JMPR.

Source: Adapted from WHO/TDR (2009)

This section of the Guidelines can be used to assist evaluation of the risks associated with a particular situation and—especially if a guideline value exists or an authoritative risk assessment is available from an alternative source—support appropriate decision-making on short- and medium-term actions. The approaches proposed provide a basis for discussion between various authorities and for judging the urgency of taking further action.

Normally, a specific review of the situation will be required and should call on suitable expertise. It is important to take local circumstances into account, including the availability of alternative water supplies and exposure to the contaminant from other sources, such as food. It is also important to consider what water treatment is applied or available and whether this will reduce the concentration of the substance.

Where the nature of contamination is unknown, expert opinion should be sought as quickly as possible to identify the contaminants, to determine what actions can be taken to prevent the contaminants from entering the supply and to minimize the exposure of the population and so minimize any potential for adverse effects.

A water safety plan should include planning for response to both predictable events and undefined "emergencies". Such planning facilitates rapid and appropriate response to events when they occur (see section 4.4).

Consideration of emergency planning and planning for response to incidents in which a guideline value is exceeded, covering both microbial and chemical contaminants, is discussed in section 4.4. Broader discussion of actions in emergency situations can be found in section 6.7 and, for microbial contamination, section 7.6.

8.7.1 Trigger for action

Triggers for action may include:

- detection of a spill by, or reporting of a spill to, the drinking-water supplier;
- an alarm raised by the observation of items, such as chemical drums, adjacent to a vulnerable part of the drinking-water supply;
- the detection of a substance in the water;
- a sudden change to water treatment;
- consumer complaints (e.g. an unusual odour, taste or discoloration).

8.7.2 Investigating the situation

Each incident is unique, and it is therefore important to determine associated facts, including what the contaminant is; what the likely concentration is, and by how much the guideline value has been exceeded, if at all; and the potential duration of the incident. These are important in determining the actions to be taken.

8.7.3 Talking to the right people

In any emergency, it is important that there be good communication between the various authorities, particularly the water supplier and health authorities. It will usually be the health authorities that make the final decisions, but knowledge of the water supply and the nature of the supply is vital in making the most appropriate decisions.

In addition, timely and clear communication with consumers is a vital part of successfully handling drinking-water problems and emergencies.

Liaison with key authorities is discussed in section 4.4. It is particularly important to inform the public health authority of any exceedance or likely exceedance of a guideline value or other conditions likely to affect human health and to ensure that the public health authority is involved in decision-making. In the event of actions that require all consumers to be informed or where the provision of temporary supplies of drinking-water is appropriate, civil authorities should also be involved. Planning for these actions is an important part of the development of water safety plans. Involving the public health authorities at an early stage enables them to obtain specialist information and to make the appropriate staff available.

8.7.4 Informing the public

Consumers may be aware of a potential problem with the safety of their drinking-water because of media coverage, their own senses or informal networks. Lack of confidence in the drinking-water or the authorities may drive consumers to alternative, potentially less safe sources. Not only do consumers have a right to information on the safety of their drinking-water, but they have an important role to play in assisting the authorities in an incident by their own actions and by carrying out the necessary measures at the household level. Trust and goodwill from consumers are extremely important in both the short and long term.

The health authorities should be involved whenever a decision to inform the public of health-based concerns or advice to adopt health protection measures such as boiling of water may be required. Such guidance needs to be both timely and clear.

8.7.5 Evaluating the significance to public health and individuals

In assessing the significance of an exceedance of a guideline value, account should be taken of:

- information underpinning the guideline value derivation;
- local exposure to the substance of concern through other routes (e.g. food);
- any sensitive subpopulations;
- locally relevant protective measures to prevent the chemical from entering the source water or supply in the case of a spill.

Information underpinning guideline value derivation

The derivation of guideline values for chemical contaminants is described in section 8.2.

Most guideline values are derived by calculating a TDI or using an existing TDI or ADI. A proportion of the TDI or ADI is then allocated to drinking-water to make allowance for exposure from other sources, particularly food. This allocation is often 20%, but it may be as low as 1% or as high as 80%. In many circumstances, a review of likely local sources of exposure may identify that sources other than drinking-water are less significant than assumed and that a larger proportion of total exposure can be safely allocated to drinking-water. The fact sheets in chapter 12 and background documents on all chemicals addressed in these Guidelines (http://www.who.int/water_sanitation_health/water-quality/guidelines/chemicals/en/) provide further information on likely sources of the chemicals concerned, including their allocation factors. When rapid decision-making is required for such chemicals, it is possible to allow 100% of the TDI to come from drinking-water for a short period (e.g. a few days) while undertaking a more substantive review. In the event that there is significant exposure from other sources or exposure is likely to be for more than a few days, then it is possible to allocate more than the allocation used in the guideline value derivation, but no more than 100%.

In some cases, the guideline value is derived from epidemiological or clinical studies in humans. In most cases (e.g. benzene, barium), these relate to long-term exposure, and short-term exposure to concentrations higher than the guideline value are unlikely to be of significant concern; however, it is important to seek expert advice. In other cases of guideline values derived from epidemiological studies, the associated health effects are acute in nature. For example:

- The guideline value for nitrate is 50 mg/L, (as nitrate ion), to be protective of the health of the most sensitive subpopulation, bottle-fed infants. This guideline value is based on the absence of adverse health effects (methaemoglobinaemia and thyroid effects) at concentrations below 50 mg/L in epidemiological studies. Although the guideline value is based on short-term effects, it is protective for long-term effects and in other population groups, such as older children and adults. Methaemoglobinaemia is complicated by the presence of microbial contamination and subsequent gastrointestinal infection, which can increase the risk for this group significantly. Authorities should therefore be all the more vigilant that water to be used for bottle-fed infants is microbiologically safe when nitrate is present at concentrations near or above the guideline value. It is also particularly important to ensure that these infants are not currently exhibiting symptoms of gastrointestinal infection (diarrhoea). In addition, because excessive boiling of water to ensure microbiological safety can concentrate levels of nitrate in the water, care should be taken to ensure that water is heated only until the water reaches a rolling boil. In extreme situations, alternative sources of water (e.g. bottled water) can be used.
- The guideline value for copper is also based on short-term exposure but is intended to protect against direct gastric irritation, which is a concentration-dependent phenomenon. The guideline value may be exceeded, but there will be an increasing risk of consumers suffering from gastrointestinal irritation as the concentration increases above the guideline value. The occurrence of such irritation can be assessed in exposed populations.

In some cases, the guideline value is derived from a cancer risk estimate derived from studies in laboratory animals. In these cases, short-term (a few months to a year) exposure to concentrations up to 10 times the guideline value would result in only a small increase in estimated risk of cancer. Because the estimate of risk varies over a wide range, there may be no, or a very small, increase in risk. In such a circumstance, accepting a 10-fold increase in the guideline value for a short period would have no discernible impact on the risk over a lifetime. However, care would be needed to determine whether other toxicological end-points more relevant for short-term exposure, such as neurotoxicity, would become significant.

Health-based values for short-term exposures are now being developed for a small number of substances that are used in significant quantities and are frequently implicated in an emergency as a consequences of spills, usually to surface water sources. The methodology used in the derivation of these health-based values is described below.

Health-based values for use in emergencies

Health-based values for acute and short-term exposures (called acute and short-term health-based values) can be derived for any chemicals that are used in significant quantities and are involved in an emergency, such as a spill into surface water sources.

JMPR has provided guidance on the setting of acute reference doses (ARfDs) for pesticides (Solecki et al., 2005). These ARfDs can be used as a basis for deriving acute health-based values for pesticides in drinking-water, and the general guidance can also be applied to derive ARfDs for other chemicals. The JMPR ARfD is usually established to cover the whole population, and must be adequate to protect the embryo or fetus from possible in utero effects. An ARfD based on developmental (embryo/fetal) effects, which applies to women of childbearing age only, may be conservative and not relevant to other population subgroups.[1]

The ARfD can be defined as the amount of a chemical, normally expressed on a body weight basis, that can be ingested in a period of 24 hours or less without appreciable health risk to the consumer. Most of the scientific concepts applicable to the setting of ADIs or TDIs for chronic exposure apply equally to the setting of ARfDs. The toxicological end-points most relevant for a single or 1-day exposure should be selected. For ARfDs for pesticides, possible relevant end-points include haematotoxicity (including methaemoglobin formation), immunotoxicity, acute neurotoxicity, liver and kidney toxicity (observed in single-dose studies or early in repeated-dose studies), endocrine effects and developmental effects. The most relevant or adequate study in which these end-points have been determined (in the most sensitive species or most vulnerable subgroup) is selected, and NOAELs are established. The most relevant end-point providing the lowest NOAEL is then used in the derivation of the ARfD. Uncertainty factors are used to extrapolate from experimental animal data to the average human and to allow for variation in sensitivity within the human population. An ARfD derived in such a manner can then be used to establish an acute health-based value by allocating 100% of the ARfD to drinking-water, as follows:

$$\text{Acute health-based value} = \frac{\text{ARfD} \times \text{bw} \times \text{P}}{\text{C}}$$

where:

bw = body weight (60 kg for adult, 10 kg for children, 5 kg for infants)
P = fraction of the ARfD allocated to drinking-water (100%)
C = daily drinking-water consumption (2 L for adults, 1 L for children, 0.75 L for bottle-fed infants)

However, available data sets do not allow the accurate evaluation of the acute toxicity for a number of compounds of interest. If appropriate single-dose or short-term data are lacking, an end-point from a repeated-dose toxicity study can be used. This is likely to be a more conservative approach, and this should be clearly stated in the health-based value derivation.

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[1] ARfDs established for pesticides by JMPR may be found at http://apps.who.int/pesticide-residues-jmpr-database.

When a substance has been spilt into a drinking-water source, contamination may be present for a period longer than 24 hours, but is not usually present for longer than a few days. Under these circumstances, the use of data from repeated-dose toxicity studies is appropriate to derive a short-term health-based value (using the approach outlined in section 8.2.2). As the period of exposure used in these studies will often be much longer than a few days, this, too, is likely to be a conservative approach.

Where there is a need for a rapid response, and suitable data are not available to establish an ARfD but a guideline value or health-based value is available for the chemical of concern, a pragmatic approach would be to allocate a higher proportion of the ADI or TDI to drinking-water. As the ADI or TDI is intended to be protective of lifetime exposure, small exceedances of the ADI or TDI for short periods will not be of significant concern for health. In these circumstances, it would be reasonable to allow 100% of the ADI or TDI to come from drinking-water for a short period.

Assessing locally relevant sources of the substance of concern through other routes of exposure

The most useful sources of information regarding local exposure to substances through food and, to a lesser extent, air and other environmental routes are usually government departments dealing with food and environmental pollution. Other sources of information may include universities. In the absence of specific data, the Guidelines background documents consider the sources of exposure and give a generic assessment that can be used to make a local evaluation as to the potential use of a chemical and whether this would be likely to enter the food-chain. Further information is available in the supporting document *Chemical safety of drinking-water* (Annex 1).

Sensitive subpopulations

In some cases, there may be a specific subpopulation that is at greater risk from a substance than the rest of the population. These usually relate to high exposure relative to body weight (e.g. bottle-fed infants) or a particular sensitivity (e.g. fetal haemoglobin and nitrate/nitrite). However, some genetic subpopulations may show greater sensitivity to particular toxicity (e.g. glucose-6-phosphate dehydrogenase–deficient groups and oxidative stress on red blood cells). If the potential exposure from drinking-water in an incident is greater than the ADI or TDI or exposure is likely to be extended beyond a few days, then this would require consideration in conjunction with health authorities. In such circumstances, it may be possible to target action to avoid exposure of the specific group concerned, such as supplying bottled water for bottle-fed infants.

Specific mitigation measures affecting risk assessment

Such measures relate to actions taken locally or on a household basis that can have an impact on the presence of a particular contaminant. For example, the presence of a substance that is volatile or heat labile will be affected by heating the water for cooking or the preparation of beverages. Where such measures are routinely undertaken by the exposed population, the risk assessment may be modified accordingly. Alternatively, such steps can be used on a household basis to reduce exposure and allow the continued use of the supply without interruption.

8.7.6 Determining appropriate action

Determining appropriate action means that various risks will need to be balanced. The interruption of water supply to consumers is a serious step and can lead to risks associated with contamination of drinking-water stored in the household with pathogens and limiting use for purposes of hygiene and health protection. Issuing a "do not drink" notice may allow the use of the supply for hygiene purposes such as showering or bathing, but creates pressure on consumers and authorities to provide a safe alternative for drinking and cooking. In some cases, this option will be expensive and could divert resources from other, more important issues. Appropriate action will always be decided on a case-by-case basis in conjunction with other authorities, including the health protection and civil authorities, who may be required to participate in informing consumers, delivering alternative supplies or supervising the collection of water from bowsers and tankers. Responding to a potential risk to health from a chemical contaminant should not lead to an increase in overall health risk from disruption of supply, microbial contaminants or other chemical contaminants.

8.7.7 Consumer acceptability

Even though, in an emergency, supplying water that contains a substance present at higher concentrations than would normally be desirable may not result in an undue risk to health, the water may not be acceptable to consumers. A number of substances that can contaminate drinking-water supplies as a consequence of spills can give rise to severe problems with taste or odour. Under these circumstances, drinking-water may become so unpalatable as to render the water undrinkable or to cause consumers to turn to alternative drinking-water sources that may present a greater risk to health. In addition, water that is clearly contaminated may cause some consumers to feel unwell due to a perception of poor water quality. Consumer acceptability may be the most important factor in determining the advice given to consumers about whether or not the water should be used for drinking or cooking.

8.7.8 Ensuring remedial action, preventing recurrence and updating the water safety plan

The recording of an incident, the decisions taken and the reasons for them are essential parts of handling an incident. The water safety plan, as discussed in chapter 4, should be updated in the light of experience. This would include making sure that problem areas identified during an incident are corrected. Where possible, it would also mean that the cause of the incident is dealt with to prevent its recurrence. For example, if the incident has arisen as a consequence of a spill from industry, the source of the spill can be advised as to how to prevent another spill and the information passed on to other similar industrial establishments.

8.7.9 Mixtures

A spill may contain more than one contaminant of potential health concern (see section 8.2.8). Under these circumstances, it will be important to determine whether the substances present interact. Where the substances have a similar mechanism or mode of action, it is appropriate to consider them as additive. This may be particularly true of some pesticides, such as atrazine and simazine. In these circumstances, appropriate action must take local circumstances into consideration. Specialist advice should generally be sought.

8.7.10 Water avoidance advisories

Water avoidance advisories share many features with boil water advisories (see section 7.6.1), but are less common. Like boil water advisories, they are a serious measure that should be instituted only when there is evidence that an advisory is necessary to reduce a substantial public health risk. In cases where alternative sources of water are recommended, particular consideration should be given to the potential for microbial hazards in those alternative sources. Water avoidance advisories are applied when the parameter of concern is not susceptible to boiling or when risks from dermal contact or inhalation of the contaminant are also significant. Water avoidance advisories may also be issued when an unknown agent or chemical substance is detected in the distribution system. It is important that the water avoidance advisories include the information that boiling is ineffective or insufficient to reduce the risk.

As with the case of boil water advisories, water suppliers in conjunction with public health authorities should develop protocols for water avoidance advisories. Protocols should be prepared before any incident occurs and incorporated within water safety plans. Decisions to issue advisories are often made within a short period of time, and developing responses during an event can complicate decision-making, compromise communication and undermine public confidence.

In addition to the information discussed in section 4.4.3, the protocols should provide information to the general public and specific groups on the following:

- criteria for issuing and rescinding an advisory;
- activities impacted by the advisory;
- alternative sources of safe water for drinking and other domestic uses.

Protocols should identify mechanisms for the communication of water avoidance advisories. The mechanisms may vary, depending on the nature of the supply and the size of the community affected, and could include:

- media releases through television, radio and newspapers;
- telephone, e-mail and fax contact of specific facilities, community groups and local authorities;
- posting of notices in conspicuous locations;
- personal delivery;
- mail delivery.

The methods chosen should provide a reasonable assurance that all of those affected by the advisory, including residents, workers and travellers, are notified as soon as possible.

The issuing of a water avoidance advisory may be necessary, for example, following contamination—for example, chemical or radiological—as a result of accidental, natural or malicious origin that leads to:

- a significant exceedance of a guideline value, which may pose a threat to health from short-term exposure;

- concentrations of a chemical with no guideline value that may pose a threat to health from short-term exposure;
- significant odour or taste that has no identified source or that will give rise to significant public anxiety.

When issued, water avoidance advisories should provide information on the same issues included in boil water advisories (see section 7.6.1), although recommendations relating to affected uses and users will vary, depending on the nature of the problem. For example, for elevated concentrations of contaminants that are of concern only from a drinking or cooking perspective, the public could be advised to avoid using the water for drinking, food preparation, preparing cold drinks, making ice and hygienic uses, such as tooth brushing. Where the advisory applies to elevated levels of chemicals that can cause skin or eye irritation or gastrointestinal upsets, the public could be advised not to use the water for drinking, cooking, tooth brushing or bathing/showering. Alternatively, specific water avoidance advice might be issued where the contamination might affect subgroups of the population—for example, pregnant women or bottle-fed infants.

As for boil water advisories, specific advice may need to be issued for dentists, doctors, hospitals and other health-care facilities, child-care facilities, schools, food suppliers and manufacturers, hotels, restaurants and operators of public swimming pools.

Water avoidance advisories do not equate to cessation of supply; water will generally be suitable for flushing toilets and other uses, such as clothes washing. However, suitable alternative supplies of drinking-water, such as bottled water and carted or tankered water, will be required for drinking and other domestic uses.

Criteria for rescinding water avoidance advisories will generally be based on evidence that the source of elevated concentrations of hazardous contaminants has been removed, that distribution systems have been appropriately flushed and that the water is safe for drinking and other uses. In buildings, the flushing would extend to storages and internal plumbing systems.