Chapter 6 Physical and chemical quality of drinking water

6.1 Introduction

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

6.2 Physical quality of drinking water

6.2.1 AN OVERVIEW OF PHYSICAL CHARACTERISTICS

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

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

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

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

6.2.2 APPROACH USED IN DERIVATION OF GUIDELINES VALUES FOR PHYSICAL CHARACTERISTICS

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

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

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

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

6.3 Chemical quality of drinking water

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

6.3.1 INORGANIC CHEMICALS

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

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

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

6.3.2 ORGANIC COMPOUNDS

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

- disinfection byproducts
- other organic compounds.

Disinfection byproducts

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

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

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

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

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

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

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

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

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

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

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

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

Other organic compounds

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

6.3.3 PESTICIDES

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

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

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

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

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

Guideline values

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

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

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

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

Health values

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

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

6.3.4 APPROACH USED IN DERIVATION OF GUIDELINE VALUES FOR CHEMICALS

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

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

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

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

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

Chemicals fall into two categories based on health effects:

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

Sources of data used

Human data

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

Animal data

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

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

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

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

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

Derivation of guideline values for substances for which a threshold exists

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

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

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

In using this equation, it is necessary to make assumptions about the amount of water consumed per day, the average body weight and the proportion of total intake that can be attributed to water consumption, and to decide on an appropriate safety factor. Clearly the figures selected will all affect the guideline value, and varying one or more of them could raise or lower the resultant value by a factor of 10 or more. Any guideline value will thus have a degree of 'fuzziness' surrounding it; however, the assumptions made in calculating these guideline values are generally very conservative, and always err on the side of safety.

Animal dose

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

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

Human weight

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

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

Proportion of intake from water

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

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

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

Volume of water consumed

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

Safety factor

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

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

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

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

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

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

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

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

Interaction between chemicals

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

6.4 Differences between Australian and WHO guideline values

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

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

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

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

6.5 References

IARC (International Agency for Research on Cancer) (1991). IARC monographs on the evaluation of carcinogenic risks to humans: chlorinated drinking water; chlorination byproducts; some other halogenated compounds; cobalt and cobalt compounds. WHO, IARC, 52, Lyons.

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