PHYSICAL AND CHEMICAL CHARACTERISTICS
FACT SHEETS

Chlorine dioxide
Chlorite
Chlorate

(Public consultation draft - April 2026)

GUIDELINE

Chlorine dioxide: Based on aesthetic considerations (taste and odour), the concentration of chlorine dioxide in drinking water should not exceed 0.4 mg/L. No health-based guideline value is set for chlorine dioxide.

Chlorite: Based on health considerations, the concentration of chlorite in drinking water should not exceed 0.8 mg/L.

Chlorate: Based on health considerations, the concentration of chlorate in drinking water should not exceed 0.8 mg/L.

Action to reduce the formation of chlorite and chlorate is encouraged, but must not compromise disinfection, as nondisinfected water poses significantly greater risk than chlorite and chlorate. Water suppliers should be aware that implementing new guideline values for disinfection by-products may take additional time and resources, particularly where further treatment or infrastructure changes are required, and should be done in consultation with the relevant health authority or drinking water regulator.

GENERAL DESCRIPTION

Chlorine dioxide (ClO_2) (CAS 10049-04-4) is used as a disinfectant for drinking water supplies, typically as an alternate disinfectant to chlorine. It is particularly effective in the control of manganese-reducing bacteria. When added to water, it dissociates into chlorite (ClO_2^-) (CAS 14998-27-7) and, to a lesser extent, chlorate (ClO_3^-) (CAS 14866-68-3). Studies have shown that approximately 70% of the applied chlorine dioxide will eventually form chlorite, while about 10% will form chlorate (Health Canada 2008). Chlorine dioxide is usually generated on site due to handling and transportation difficulties.

Chlorine dioxide is used commercially as a bleaching agent in paper production, paper pulp, and cleaning and tanning of leather. Chlorite is used in the production of paper, textiles and straw products, and in the manufacture of waxes, shellacs and varnishes. Acidified sodium chlorite is also used in food sanitation (WHO 2016). Chlorate and its salts, most notably sodium chlorate, are powerful oxidisers and have been used in herbicide and defoliant formulations, as well as in the manufacture of dyes, matches, and explosives. Sodium chlorate and sodium chlorite are used in the production of chlorine dioxide (WHO 2016).

Chlorite enters drinking water mainly as a by-product of using chlorine dioxide for disinfection. Chlorite is also present in hypochlorite solutions as an intermediate between hypochlorite and chlorate, the formation of which is influenced by factors such as temperature, presence of transition metals such as iron and copper, and the age of the solution (WHO 2016).

Chlorate is generated by the dissociation of hypochlorite solutions, which are used for disinfection of drinking water. Use of such solutions has become more common in Australia in recent years as use of chlorine gas has declined due to work health and safety considerations. As hypochlorite solutions age 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 amount of chlorate added to the treated water (WHO 2016).

Chlorate levels can be minimised by restricting storage times for hypochlorite solutions and storing the solutions under cool, dark conditions out of direct sunlight, where the temperature does not exceed 27°C (AWWA 2018). Additional measures include using fresh, high-quality hypochlorite, avoid mixing old and new solutions, and careful dilution of the hypochlorite solution to slow down the rate of conversion to chlorate (WHO 2016).

The taste and odour threshold for chlorine dioxide in water has been reported to range from 0.2 to 0.4 milligrams per litre (mg/L) (WHO 2016). No data are available on taste and odour thresholds for chlorite and chlorate.

Overseas water treatment plants that use hypochlorite as a disinfectant report a median chlorate concentration of approximately 0.1 mg/L. In comparison, plants using chlorine dioxide report a median chlorate concentration of approximately 0.13 mg/L (US EPA 2006). Chlorate concentrations above 1 mg/L have been reported when hypochlorite was used, but such high concentrations would be unusual unless hypochlorite is stored under adverse conditions (WHO 2022).

Where hypochlorite or chlorine dioxide is used as a disinfectant, the major route of environmental exposure to chlorite and chlorate is expected to be through drinking water (WHO 2016).

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

Chlorine dioxide is rarely used as a disinfectant in Australian reticulated supplies. When used, the chlorite residual concentration within chlorinated systems is generally maintained between 0.2 mg/L and 0.4 mg/L.

In the absence of an Australian health-based guideline value for chlorate prior to 2026, few water utilities have reported chlorate levels, which has made it difficult to define typical chlorate concentrations throughout Australian drinking water supplies. Available data from large urban reticulated systems in South East Queensland shows chlorate concentrations up to 0.8 mg/L, with typical levels below 0.1 mg/L (Gold Coast Water 2023–2024; Seqwater 2025a - h; South East Water 2023–2024; Unitywater 2016–2024). In Tasmanian supplies, chlorate concentrations in both large urban and smaller rural systems typically range from <0.1 mg/L to 0.6 mg/L. However, a few small rural and remote systems with elevated organic matter and ammonia present in source water recorded concentrations between 0.6 mg/L and 4 mg/L, with typical values often exceeding 0.8 mg/L (TasWater 2026).

TREATMENT OF DRINKING WATER

Chlorine dioxide

Chlorine dioxide can be removed from drinking water by the addition of reducing agents such as sodium bisulfite (although some studies indicate that the chlorate concentration increases as a result), photodecomposition by exposure to sunlight, or by the use of granular activated carbon. Precise operation ("tuning"), proper maintenance and the generation technology employed with the chlorine dioxide generator have a large bearing on the chlorine dioxide production efficiency and the rate at which chlorite and other by-products are formed in drinking water (WHO 2016).

Chlorite

Chlorite can be removed from drinking water using granular activated carbon, sulfur-based reducing agents, and anion exchange (WHO 2016).

Chlorate

Once present in drinking water, chlorate is persistent and difficult to remove. There is currently no readily available, low-cost treatment to remove chlorate in drinking water. Anion exchange and reverse osmosis are possible methods, although expensive. Granular activated carbon is generally ineffective, as chlorate is reversibly adsorbed on granular activated carbon. Control of chlorate concentrations in drinking water must rely on preventing its formation in hypochlorite solutions, or its formation from chlorine dioxide (WHO 2016). Methods to control the formation of chlorate in hypochlorite solutions include: avoiding contact with transition metals such as iron, copper and nickel because they may catalyse chlorate formation; purchasing fresh, high quality hypochlorite solution; storing hypochlorite solutions in a cool area, out of direct sunlight; avoid adding new hypochlorite solution to containers containing old hypochlorite solution; and using hypochlorite solutions as soon as possible after purchase (7 days maximum storage is recommended). Further control methods include dilution and cooling of the hypochlorite solution which will slow down the rate of conversion to chlorate, noting that dilution of the hypochlorite solution will lead to the dosing of more hypochlorite solution in order to maintain disinfection targets which could result in higher chlorite and chlorate concentrations in the treated water (Bouland et al. 2005; WHO 2016).

MEASUREMENT

Quantification of chlorine dioxide in drinking water can be determined using titration or colorimetric methods (APHA et al. 2023a, b). The concentration of chlorite and chlorate in drinking water can be determined through ion chromatography. The limit of detection ranges from 0.00005 mg/L to 0.01 mg/L depending on the laboratory test method (APHA Method 4110 Part B 1992; US EPA 300 1999).

HEALTH CONSIDERATIONS

Chlorine dioxide, chlorite, and chlorate are all absorbed rapidly by the gastrointestinal tract into blood plasma and distributed to the major organs. All compounds appear to be rapidly metabolised. Chlorite and chlorate are excreted primarily in the urine in the form of chloride, with lesser amounts of chlorite and chlorate (WHO 2016).

Chlorine dioxide and chlorite

In a study with human volunteers, no adverse effects were observed after drinking water with either chlorine dioxide or chlorite concentrations up to 5 mg/L for periods of 12 weeks (Lubbers et al. 1981). The International Agency for Research on Cancer (IARC) has concluded that chlorite is not classifiable as to its carcinogenicity in humans (Group 3, no human data and inadequate evidence in animals) (IARC 1991).

Animal studies have shown that when female rats are exposed to chlorine dioxide in drinking water, the offspring experience changes in thyroid hormones and impaired neurobehavioural development (WHO 2016).

The most consistent finding with chlorite, seen in other animal studies, is oxidative stress resulting in changes in red blood cells, including some studies indicating specific damage to the membrane of the red blood cells (WHO 2016).

A two-generation study of rats exposed to chlorite found that the offspring in these groups had reduced responses to auditory startle stimuli and altered liver weights (CMA 1997; TERA 1998). These findings were considered to be an appropriate point of departure to derive a health-based guideline value for chlorite in Australian drinking water. Other effects seen at higher doses of chlorite (70 and 300 mg/L) included lower body weight, reduced survival of offspring and lower red blood cell counts (CMA 1997).

Chlorate

Poisoning in humans resulting from oral exposure to high toxic doses of chlorate (upwards of 11-23 mg of chlorate per kilogram body weight [mg chlorate/kg bw]) is characterised by haematological and renal toxicity. The formation of methaemoglobin is a prominent adverse effect, and individuals with pre-existing blood conditions or those with kidney disease are particularly sensitive (EFSA 2015).

Like perchlorate, chlorate is proposed to competitively inhibit iodine uptake in the thyroid. Iodine uptake in the thyroid is a key step in the synthesis of thyroid hormones and its inhibition may result in the disruption of the thyroid hormone synthesis leading to the development of hypothyroid symptoms. However, no human studies on the inhibition of iodine uptake by chlorate exist. These assumptions are made due to the chemical similarity and mode of action of perchlorate and chlorate, and that there are several observations in humans on the effects of exposure to perchlorate (EFSA 2015).

A human volunteer study lasting 12 weeks showed no clear treatment-related effects after daily ingestion of 500 mL of water containing a concentration of 5 mg/L of sodium chlorate equivalent to 0.036 mg chlorate/kg bw per day (/day) (Lubbers et al. 1981).

Experimental animal studies that assess the effects of subchronic or chronic exposure to chlorate show the most sensitive effects take place upon the thyroid.

In a 90-day study in rats (McCauley et al. 1995), pituitary lesions (vacuolisation in the cytoplasm of the pars distalis) and thyroid gland colloid depletion were observed in both the mid- and high-dose chlorate groups of both sexes. A no-observed-adverse-effect level (NOAEL) of 30 mg chlorate/kg bw/day was identified based on thyroid gland colloid depletion at the next higher dose of 100 mg/kg bw per day (McCauley et al. 1995).

In a 2-year carcinogenicity study in rats and mice (NTP 2005), incidences of minimal to mild thyroid gland follicular cell hypertrophy were significantly increased in male and female rats exposed to 500 mg sodium chlorate/L or greater. Hyperplasia of the bone marrow in rats and hyperplasia of the bone marrow and granulosa cell hyperplasia of the ovary in mice were also observed. The study concluded that there was some evidence of carcinogenic activity in male and female rats based on increased incidences of thyroid gland neoplasms, equivocal evidence of carcinogenic activity in female mice based on marginally increased incidences of pancreatic islet neoplasms, and no evidence of carcinogenic activity in male mice (NTP 2005). IARC has not classified the carcinogenicity of chlorate.

Recent assessments of chlorate in drinking water by the US EPA and WHO identified NTP (2005) as the best available assessment of exposure to chlorate in drinking water based on experimental animal data of carcinogenicity. Both agencies used benchmark dose modelling to determine a critical endpoint for thyroid effects (US EPA 2006, 2016; WHO 2008, 2016).

DERIVATION OF GUIDELINE

i) Chlorine dioxide:

A health-based guideline value has not been established for chlorine dioxide because of its rapid hydrolysis to chlorite and chlorate. The guideline values for chlorite and chlorate are adequately protective for potential toxicity from chlorine dioxide (the NOAEL of 2.9 mg/kg bw/day used to derive the tolerable daily intake for chlorite is similar to the lowest NOAELs observed for effects of chlorine dioxide on neurobehavioural and neurological development and on thyroid hormone levels). The taste and odour threshold for chlorine dioxide in water is 0.4 mg/L (WHO 2022).

- Chlorite:

The health-based guideline value of 0.8 mg/L (rounded) for chlorite in drinking water was determined as follows:

$$0.8\ \text{mg/L} = \frac{2.9\ \text{mg/kg bw/day} \times 70\ \text{kg} \times 0.8}{2\ \text{L/day} \times 100}$$

where

- 2.9 mg/kg bw/day is the no-effect level from a two-generation study using rats based on lowered auditory startle amplitude and altered liver weights (CMA 1997; TERA 1998).
- 70 kg is taken as the average weight of an adult.
- 0.8 is the proportion of total daily intake attributable to the consumption of water, based on the occasional use of chlorite in the food industry.
- 2 L/day is the average amount of water consumed by an adult.
- 100 is the uncertainty factor applied to the equivalent dose derived from an animal study. The uncertainty factor incorporates a factor of 10 to account for the uncertainty of extrapolating from animals to humans and a factor of 10 to account for human variability.
- The calculated value of 0.812 mg/L is rounded to a final health-based guideline value of 0.8 mg/L as per the rounding conventions described in Chapter 6.

ii) Chlorate

The health-based guideline value of 0.8 mg/L (rounded) for chlorate in drinking water was determined as follows:

$$0.8 \text{ mg/L} = \frac{0.9 \text{ mg/kg bw/day} \times 70 \text{ kg} \times 0.8}{2 \text{ L/day} \times 30}$$

where

- 0.9 mg/kg bw/day is the benchmark dose lower confidence limit (BMDL) derived on the basis of increased follicular cell hypertrophy from a chronic (2-year) carcinogenicity drinking water study in male rats (US EPA 2006, 2016; NTP 2005).
- 70 kg is taken as the average weight of an adult.
- 0.8 is a proportionality factor based on the assumption that drinking water accounts for 80% of the total daily intake of chlorate.
- 2 L/day is the average amount of water consumed by an adult.
- 30 is the uncertainty factor applied to the human equivalent dose derived from an animal study. The uncertainty factor incorporates a factor of 3 to account for the uncertainty of extrapolating from animals to humans and a factor of 10 to account for human variability.
- The calculated value of 0.84 mg/L is rounded to a final health-based guideline value of 0.8 mg/L as per the rounding conventions described in Chapter 6.

REVIEW HISTORY

This fact sheet was developed based on a review of the available evidence completed in 2021 (CDM Smith 2025a,b) (refer to the relevant Administrative Report for more information).

REFERENCES

APHA Method 4110 Part B (1992). Determination of ions by ion chromatography: ion chromatography with chemical suppression of eluant conductivity. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

APHA, AWWA, WEF (2023a). Method 4500, chlorine. In: Standard Methods for the examination of water and wastewater, 24th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. Washington, DC, American Public Health Association, American Water Works Association, Water Environment Federation, pp 4.56-4.69.

APHA, AWWA, WEF (2023b). Method 4500, chlorine dioxide. In: Standard Methods for the examination of water and wastewater, 24th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. Washington, DC, American Public Health Association, American Water Works Association, Water Environment Federation, pp 4.77-4.81.

AWWA (2018). Hypochlorites, ANSI/AWWA B300-18. American Water Works Association September 2018.

Bouland S, Duguet JP, Montiel A (2005). Evaluation of bromate ions level introduced by sodium hypochlorite during post-disinfection of drinking water. Environmental Technology. 26 (2): 121-126.

CDM Smith (2025a). Evidence Evaluation Report – Chlorate. Report prepared for the National Health and Medical Research Council. June 2025.

CDM Smith (2025b). Technical Report – Chlorate. Report prepared for the National Health and Medical Research Council. June 2025.

CMA (1997). Sodium Chlorite: drinking water rat two generation reproductive toxicity study. Chemical Manufacturers Association. Washington, DC (Quintiles Report CMA/17/96).

EFSA (2015). Risks for public health related to the presence of chlorate in food. European Food and Safety Authority. June 2014.

Gold Coast Water (2023-2024). Drinking Water Service Annual Report 2023-2024. City of Gold Coast.

Health Canada (2008). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Chlorite and Chlorate. Health Canada, Ottawa, Ontario.

IARC (1991). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: chlorinated drinking water, chlorination by-products, some other halogenated compounds, cobalt and cobalt compounds. World Health Organization, International Agency for Research on Cancer, p 52.

Lubbers JR, Chauhan S, Bianchine JR (1981). Controlled clinical evaluations of chlorine dioxide, chlorite and chlorate in man. Fundamentals and Applied Toxicology, 1:334-338.

McCauley PT, Robinson M, Daniel FB, Olson GR (1995). The effects of subchronic chlorate exposure in Sprague-Dawley rats. Drug and Chemical Toxicology 18(2,3):185-199.

NTP (2005). Technical Report on the Toxicology and Carcinogenesis Studies of Sodium Chlorate in F344/N Rats and B6C3F1 Mice. National Toxicology Program. National Institute of Health.

Seqwater (2025a). Monthly performance Reports, Water reporting zones - Brisbane – May 2025. Seqwater, Queensland.

Seqwater (2025b). Monthly performance Reports, Water reporting zones – Gold Coast – May 2025. Seqwater, Queensland.

Seqwater (2025c). Monthly performance Reports, Water reporting zones - Logan – May 2025. Seqwater, Queensland.

Seqwater (2025d). Monthly performance Reports, Water reporting zones - Moreton – May 2025. Seqwater, Queensland.

Seqwater (2025e). Monthly performance Reports, Water reporting zones - Redland – May 2025. Seqwater, Queensland.

Seqwater (2025f). Monthly performance Reports, Water reporting zones – Scenic Rim – May 2025. Seqwater, Queensland.

Seqwater (2025g). Monthly performance Reports, Water reporting zones - Somerset – May 2025. Seqwater, Queensland.

Seqwater (2025h). Monthly performance Reports, Water reporting zones – Sunshine Coast – May 2025. Seqwater, Queensland.

South East Water (2023-2024). Annual Drinking Water Quality Report 2023-2024. South East Water.

Tas Water (2026). Water quality portal. Available at https://www.taswater.com.au/community/water-quality/your-drinking-water. Accessed on 16 February 2026.

TERA (1998). Health Risk Assessment / Characterisation of the Drinking Water Disinfection By-products Chlorine Dioxide and Chlorite. Toxicology Excellence for Risk Assessment. Cincinnati OH.

Unitywater (2016-2017). Drinking Water Quality Performance Report July 2016–June 2017. Unitywater.

Unitywater (2017-2018). Drinking Water Quality Performance Report July 2017–June 2018. Unitywater.

Unitywater (2018-2019). Drinking Water Quality Performance Report 2018-2019. Unitywater.

Unitywater (2019-2020). Drinking Water Quality Performance Report 1 July 2019–30 June 2020. Unitywater.

Unitywater (2020-2021). Drinking Water Quality Performance Report 1 July 2020–30 June 2021. Unitywater.

Unitywater (2021-2022). Drinking Water Quality Performance Report 1 July 2021–30 June 2022. Unitywater.

Unitywater (2022-2023). Drinking Water Quality Performance Report 2022–2023. Unitywater.

Unitywater (2023- 2024). Drinking Water Quality Performance Report 2023-2024. Unitywater.

US EPA (1999). EPA Method 300.0, Revision 2.2. Determination of inorganic anions by ion chromatography. Washington (DC): United States Environmental Protection Agency, October (EPA-821-R-99-015).

US EPA (2006). Reregistration Eligibility Decision (RED) for Inorganic Chlorates. United States Environmental Protection Agency.

US EPA (2016). Six-Year Review 3 Technical Support Document for Chlorate. United States Environmental Protection Agency.

WHO (2008). Acidified sodium chlorite. In: Safety evaluation of certain food additives and contaminants. Prepared by the sixty-eighth meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Geneva: World Health Organization.

WHO (2016). Chlorine Dioxide, Chlorite and Chlorate in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality.

WHO (2022). Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda. World Health Organization, Geneva 2022.