PHYSICAL AND CHEMICAL CHARACTERISTICS FACT SHEET

Manganese

(Public consultation draft July 2024)

Guideline

Based on aesthetic considerations, the concentration of manganese in drinking water should not exceed 0.05 mg/L, measured at the customer's tap. Water authorities are encouraged to keep manganese concentrations as low as possible, preferably below 0.02 mg/L.

Based on health considerations, the concentration of manganese in drinking water should not exceed 0.1 mg/L.

General description

Manganese is present in the environment in the divalent (Mn(II)), tetravalent (Mn(IV)), and heptavalent (Mn(VII)) states. Most of the divalent compounds are soluble in water. Manganese can occur in particulate, colloidal and dissolved forms in surface water (WHO 2022). The most common tetravalent compound, manganese dioxide, is insoluble; however, the heptavalent permanganate is soluble. The most common form of manganese in groundwater is Mn(II) due to the low levels of dissolved oxygen.

Manganese is principally used in the manufacture of iron, steel and alloys. Manganese compounds are used in cleaning, bleaching and disinfectant products and potassium permanganate may be used to treat potable water (see Chapter 8 and the Fact Sheet in Part V on Potassium permanganate). Manganese may also be present as an impurity in chemicals used to treat drinking water (e.g. ferric chloride and ferric sulfate; see Fact Sheets in Part V on Drinking water treatment chemicals).

Uncontaminated rivers and streams generally have low concentrations of manganese, ranging from 0.001 mg/L to 0.2 mg/L (WHO 2022). High concentrations may occur in polluted rivers or under anoxic conditions such as at the bottom of deep reservoirs or lakes, or in groundwater.

At concentrations exceeding 0.05 mg/L, manganese may impart an undesirable taste to water and stain plumbing fixtures and laundry (USEPA 2024a). Even at concentrations of 0.02 mg/L, where an increase in consumer complaints is common, manganese may form a coating on pipes that can slough off as a black ooze (see Fact Sheets in Part V on Potassium permanganate and Colour, WHO

2022). Some nuisance microorganisms can concentrate manganese and give rise to taste, odour and turbidity problems in distribution systems (see Section 5.7).

Manganese oxides that have accumulated in the distribution system can be released into the drinking water supply following physical or hydraulic disturbances or changes to water chemistry (e.g. changes in pH, temperature, chlorine residual, and source water type/blending). Physical and hydraulic disturbances most often release particulate manganese and can cause discoloured water and consumer complaints. Chemical releases can go unnoticed however if manganese occurs in a soluble form (Health Canada 2019, WHO 2021).

Oxidised forms of manganese (e.g. permanganate) can interfere with the commonly used DPD (diethyl-phenylenediamine) method for determining chlorine residual, potentially resulting in an overestimation of the chlorine residual (see Information Sheet 1.4 on Chloramines).

Manganese can be found in many foods at varying concentrations. High concentrations (up to 5 mg/100 g) may be found in nuts, tea leaves, legumes, grains and some fruits (EFSA 2023). Manganese may also be used as a plant fertiliser (micronutrient for plants).

Typical values in Australian drinking water

In major Australian reticulated drinking water supplies, manganese concentrations have been found up to 0.8 mg/L, with typical concentrations less than 0.03 mg/L. Mean concentrations of manganese in reticulated drinking water supplies measured below 0.03 mg/L across urban and regional Western Australia and in Northern Territory town centres (Water Corporation 2023, Power and Water Corporation 2023). Manganese concentrations measured in drinking water derived from the six major Melbourne storage reservoirs following primary treatment processes were in the range 0.0001–0.0138 mg/L during 2022 (Melbourne Water 2023).

Manganese in treated drinking water may accumulate and deposit as oxides in distribution system pipes and, if disturbed physically or chemically, can result in higher levels of manganese at the tap (Health Canada 2019, WHO 2021).

Treatment of Drinking Water

Manganese concentrations in drinking water source waters may be lowered to below 0.05 mg/L by using common water treatment methods, including oxidation/filtration, adsorption/oxidation, softening/ion exchange and biological filtration (see also Section 8.3.5, Health Canada 2019, WHO 2022). Manganese levels below 0.02 mg/L can be achieved with a well operated and optimised system. However, selection of the appropriate treatment for manganese removal depends on the form of manganese present (dissolved or particulate) (Health Canada 2019, WHO 2022).

Ensuring stable water chemistry, regular maintenance to remove accumulated oxides and minimising physical or hydraulic disturbances of the distribution system are also key to limiting manganese in drinking water (Health Canada 2019, WHO 2021).

Measurement

The manganese concentration in drinking water can be determined using inductively coupled plasma atomic emission spectroscopy, inductively coupled plasma mass spectrometry and graphite furnace atomic absorption spectroscopy with detection limits ranging between 0.005–50 µg/L (APHA Method 3500-Mn, Health Canada 2019, WHO 2021, USEPA 2024b). These detection methods measure the total amount of manganese present and do not distinguish between different oxidation states (WHO 2021).

Colorimetric methods (detection limits between 10–70 µg/L) are suited to monitoring dissolved manganese in source waters and assessing treatment effectiveness (Health Canada 2019).

Health Considerations

Manganese is an essential trace element required for normal growth and development in humans (including development of the nervous system and brain), especially in early life (WHO 2021). Manganese neurotoxicity is known to occur as a result of manganese dust inhalation in occupational settings (e.g. mining and welding) over long periods (WHO 2021, Health Canada 2019).

Animal studies (such as Kern *et al.* 2010, Kern and Smith 2011, Beaudin *et al.* 2013, 2017) have shown that oral exposure to manganese affects neurological functions (both motor and learning abilities) in rats at doses of 25 mg/kg bw/day and above (WHO 2021, WHO 2022, Health Canada 2019).

Reviews by the World Health Organization (WHO) and Health Canada found that several human epidemiological studies suggest an association between exposure to manganese in drinking water and neurological effects (e.g. intellectual impairment and poorer neurobehavioural function, including memory, attention, motor function and hyperactivity). Although these epidemiological studies could not establish the level at which oral manganese intake can lead to neurotoxic effects, collectively they provide support that neurotoxicity is a critical effect in humans (WHO 2021, WHO 2022, Health Canada 2019).

Infants, especially newborns, are unable to regulate the levels of manganese in their bodies and are more susceptible to the neurotoxic effects of excess manganese (WHO 2021, WHO 2022, Health Canada 2019).

The European Food Safety Authority has established average safe dietary intake levels for manganese from all dietary sources, recommending up to 8 mg/day for adults (including pregnant and lactating women) and up to 2–7 mg/day for children depending on their age (EFSA 2023).

There is inadequate evidence to assess the potential carcinogenicity of exposure to manganese in humans. Additionally, the International Agency for Research on Cancer has not reviewed the carcinogenicity potential of any manganese compounds (WHO 2021, Health Canada 2019).

Derivation of Guideline

Aesthetic guideline

Manganese precipitates can discolour water, stain laundry, alter taste and impact consumer acceptance of drinking water. The aesthetic guideline of 0.05 mg/L at the customer's tap is based on levels that are achievable using common treatment methods, and to limit the number of customer complaints. Water authorities are encouraged to keep manganese concentrations as low as possible, preferably below 0.02 mg/L at the treatment plant.

Health-based guideline

The guideline value was developed to protect bottle-fed infants, the most sensitive population, and is therefore also considered protective of the general population.

The health-based guideline value for manganese in drinking water of 0.1 mg/L (rounded) was derived as follows:

$$0.1\ \text{mg/L} = \frac{25\ \text{mg/kg bodyweight/day} \times 7\ \text{kg} \times 0.5}{0.85\ \text{L/day} \times 1000}$$

where:

- 25 mg/kg bw/day is the lowest observed adverse effect level (LOAEL) for developmental neurotoxicity following oral exposure to manganese in neonatal rat studies (Kern et al. 2010, Kern and Smith 2011, Beaudin et al. 2013, 2017).
- 7 kg is the average weight for an infant 0–<1 years (enHealth 2012).
- 0.85 L/day is the average amount of water consumed by an infant (enHealth 2012).

- 0.5 is a proportionality factor based on the assumption that infant formula represents the total diet for bottle-fed infants in the first few months of life and that 50% of manganese intake may be due to the water used to prepare the formula with the remaining intake due to the infant formula itself.
- 1000 is the combined safety factor applied for interspecies variation (10), intraspecies variation (10), and the use of a LOAEL rather than a NOAEL (no observed adverse effect level) (10).
- The calculated value of 0.103 mg/L is rounded to a final health-based guideline value of 0.1 mg/L as per the rounding conventions described in Chapter 6.

Review History

The fact sheet was initially endorsed in 2011. This update of the fact sheet was based on a review of the available evidence completed in 2024 (NHMRC 2024, see Administrative Report for more information).

References

APHA Method 3500-Mn Manganese. Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environment Federation. In: *Standard Methods for the Examination of Water and Wastewater* (2023). Lipps WC, Baxter TE, Braun-Howland EB, eds. APHA Press, Washington.

Beaudin SA, Nisam S, Smith DR (2013). Early life versus lifelong oral manganese exposure differently impairs skilled forelimb performance in adult rats. *Neurotoxicology and Teratology*, 38:36–45.

Beaudin SA, Strupp BJ, Strawderman M, Smith DR (2017). Early Postnatal Manganese Exposure Causes Lasting Impairment of Selective and Focused Attention and Arousal Regulation in Adult Rats. *Environmental Health Perspectives*, 125(2):230–237.

EFSA (2023). EFSA Panel on Nutrition, Novel Foods and Food Allergens. Scientific opinion on the tolerable upper intake level for manganese. *EFSA Journal*, 21(11), e8413. https://doi.org/10.2903/j.efsa.2023.8413.

enHealth (2012). *Australian Exposure Factor Guidance: Guidelines for assessing human health risks from environmental hazards*. Environmental Health Standing Committee of the Australian Health Protection Principal Committee. https://www.health.gov.au/resources/publications/enhealth-guidance-australian-exposure-factor-guide

Health Canada (2019). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Manganese. Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-manganese.html

Kern CH, Stanwood GD, Smith DR (2010). Preweaning manganese exposure causes hyperactivity, disinhibition, and spatial learning and memory deficits associated with altered dopamine receptor and transporter levels. *Synapse*, 64(5):363–378.

Kern CH, Smith DR (2011). Preweaning Mn exposure leads to prolonged astrocyte activation and lasting effects on the dopaminergic system in adult male rats. *Synapse*, 65(6):532–44.

NHMRC (2024). Evidence Evaluation Report – Manganese in drinking water. National Health and Medical Research Council.

Power and Water Corporation (2023). *Annual Drinking Water Quality Report 2022*. Power and Water Corporation, Northern Territory. https://www.powerwater.com.au/about/what-we-do/water-supply/drinking-water-quality/past-drinking-water-quality-reports (accessed 13 March 2024).

Water Corporation (2023). *Drinking Water Quality Annual Report 2022–23.* Water Corporation, Western Australia. https://www.watercorporation.com.au/About-us/Our-performance/Drinking-water-quality (accessed 19 February 2024).

WHO (2021). *Manganese in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. World Health Organization, Geneva.

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

USEPA (2024a) *Secondary Drinking Water Standards: Guidance for Nuisance Chemicals*. United States Environmental Protection Agency. https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals.

USEPA (2024b). *Analytical methods recommended for drinking water compliance monitoring of secondary contaminants*. United States Environmental Protection Agency. https://www.epa.gov/dwanalyticalmethods/approved-drinking-water-analytical-methods, (accessed 2 April 2024).

NOTE: Important general information is contained in PART II, Chapter 6