GUIDANCE ON MANGANESE IN DRINKING WATER

This guidance is intended to provide strategies and resources to assist local governments, health authorities, and water system operators to assess and manage risks related to manganese in drinking water sources used for drinking water purposes, based on revisions to the Canadian Drinking Water Quality Guidelines.

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1. Introduction

This document provides supplemental guidance for drinking water officers (DWOs) on manganese in drinking water based on the 2019 Guidelines for Canadian Drinking Water Quality.

The guidance in this document focuses on three key areas:

- Background information on the health risks of manganese;
- Communication strategies for drinking water systems with elevated concentrations of manganese in treated water; and
- Manganese treatment options.

2. Background and Regulatory Framework

The 2019 Guidelines for Canadian Drinking Water Quality (GCDWQ) Guideline Technical Document for Manganese is what B.C.'s water supply systems should refer to when evaluating water from both aesthetic and health considerations. From an aesthetic perspective, elevated concentrations of manganese in drinking water are known to result in discoloured water, staining of laundry and/or plumbing fixtures. The previous GCDWQ for manganese addressed these concerns with an aesthetic objective (AO) of 0.05 mg/L, and did not consider manganese to pose any risk to human health. In the new GCDWQ, the AO has been revised to 0.02 mg/L to reduce complaints regarding discoloured water.

Based on emerging health research, the GCDWQ for manganese now also sets out a maximum acceptable concentration (MAC). The MAC has been set at 0.12 mg/L, and is based on being protective of ongoing consumption of tap water by infants, especially infants consuming formula made with tap water. Risk to other users is not as well established and likely not as significant.

Concentrations of manganese in drinking water should be compared to both the revised AO and the MAC. Exceedances of the AO which are less than the MAC can be addressed as aesthetic concerns; however, consumption of water with manganese concentrations greater than the MAC of 0.12 mg/L should be evaluated from a health perspective.

2.1 Background Manganese Concentrations

Background levels of manganese in untreated water typically range from 0.001 to 0.2 mg/L, but can be much higher in groundwater depending on the geology. A monitoring program by Health Canada from 1991 to 2014 found manganese concentrations in water from British Columbia were greater than 0.2 mg/L in 13% of samples and greater than 10 mg/L in 4% of samples. Manganese can be present as dissolved Mn(II), manganese(II) sulfate, particulate manganese oxides and hydroxides, and Mn (IV) carbonates.

In British Columbia, the Ministry of Environment & Climate Change Strategy reported that manganese was monitored at various locations including both surface and groundwater supplies between 1991 and 2014 (British Columbia Ministry of Health, 2014). Results of monitoring are presented below in Table 1.

Table 1. Historical concentrations of manganese in British Columbia water supplies (1991-2014)

Parameter	Median Concentration (mg/L)	Maximum Concentration (mg/L)	Concentration Range (mg/L)	Number of Samples (percentage)
Total Manganese	**0.008**	**139**	**>0.2**	413 of 3,593 (11.5%)
			>10	6 of 3,593 (0.2%)
Dissolved Manganese	**0.008**	**26.2**	**>0.2**	20 of 160 (12.5%)
			>10	1 of 160 (0.6%)

BC Ministry of Health (2014)

2.2 Manganese Exposure and Toxicity

The primary target of manganese toxicity is the central nervous system, followed by the reproductive system. Several epidemiological studies on manganese exposure via drinking water were reviewed by Health Canada in the development of the guidelines. The majority of the studies:

- were based on environments with elevated manganese concentrations;
- had significant confounding variables or were not sufficiently powerful to establish a dose-response relationship at low concentrations;
- were unable to confidently establish a lower threshold based on the available data.

The significant limitations of the human studies prevented their use in quantitative risk assessment, and they were instead used to select neurotoxicity as the key endpoint to use from animal studies.

A lowest observed adverse effect limit (LOAEL) of 25 mg Mn/kg-bw/d was established based on two studies of neurological effects in rats. A tolerable daily intake of 0.025 mg/kg-bw/d was then calculated for humans using an uncertainty factor of 1000 [for interspecies variation (x10), intraspecies variation (x10), and use of a LOAEL rather than a NOAEL (x10)]. Neurological effects in laboratory animals were found in other studies at concentrations as low as 0.106 mg/kg-bw/d, but these endpoints were not selected due to study limitations. There are additional limitations when extrapolating to infant human exposure associated with Health Canada's assumption that half of manganese exposure is from drinking water, as well as differences in bioavailability between different age groups and species. These uncertainties are reflected in the differences in other international health-based limits for manganese in drinking water, which range from 0.1 mg/L (Minnesota) to 0.5 mg/L (Australia).

While there is no evidence to conclude that detectable differences in health will be present at concentrations less than the MAC, the available evidence does suggests that measureable neurological impacts may be possible when infants and children are chronically exposed to manganese concentrations greater than the MAC. Based on the precautionary approach adopted by Health Canada and the high degree of uncertainty and limitations of the available information, the guideline of 0.12 mg/L should be interpreted as being protective of ongoing exposure to all infants relying solely on formula made with tap water. Health impacts in other human groups with decreased exposure or sensitivity to manganese might not be significant until drinking water concentrations are much higher. The amount of manganese transferred from an expecting mother to her baby is not fully understood, however, it is expected that manganese absorption and excretion would be managed by the mother's body.

2.3 Previous Recommendations

In areas of BC with naturally elevated concentrations of manganese, there is the potential for regular or seasonal occurrences of elevated manganese in water. Based on the previous recommendations from Health Canada, manganese was not believed to be toxic at palatable concentrations in drinking water. For small water systems with limitations on the ability to remove manganese, many communities were advised in the past that water with manganese levels above the AO was safe to drink.

This approach may no longer be appropriate based on the current understanding of manganese toxicity. For existing drinking water systems that have elevated concentrations of manganese in their water, the following sections contain options for evaluating and communicating risk.

2.4 Evaluating Risk

In determining whether increased manganese in drinking water is a health hazard and the need to advise on mitigation, drinking water officers should look at:

The magnitude of the exceedance above the MAC - Marginal short-term exceedances indicate a need for further evaluation, but may not require any immediate actions. Chronic exceedances slightly above the MAC likely require, at a minimum, notification that infants should not consume formula made with tap water and consideration of options for mitigating manganese concentrations. Concentrations exceeding 0.3 mg/L warrant consideration of risks to a broader population and may require short-term mitigation. Concentrations in this magnitude would also exceed less conservative international guidelines from the US EPA and WHO which would indicate further potential health risks to other groups in addition to bottle-fed infants.

Trends in manganese concentration - Whether there is a single occurrence, periodic/seasonal occurrence, a persistent problem, or an increasing trend. Manganese concentrations can be significantly influenced by environmental conditions. Since the drinking water guideline is based on chronic exposure, individual isolated short term exceedances are not likely to require action. Ongoing elevated trends in manganese concentration may indicate a change in source water or watershed conditions and could be associated with changes to water chemistry or the presence of co-contaminants and warrant significant consideration.

Who the users of the systems are – The MAC is based on toxicity to bottle-fed infants. Water systems supplying sensitive populations, such as schools, hospitals, or daycares should be considered at greater risk than communities comprised of adults or those that have access to other sources of drinking water.

What potential actions can be taken to mitigate risks – Risks can be mitigated by using various treatment technologies to reduce the concentration of manganese in the water. Boiling water is not an effective form of treatment for manganese reduction. Boiling water can increase the concentration of dissolved, and therefore absorbable, manganese in drinking water. Switching to an alternate source or bottled water is also an option.

3. Communicating Risk

The type and extent of communication of risks to human health from manganese depend on the degree of human exposure and the severity of the health risk. A template for messaging is included as an Appendix to this document, however individual water supply systems may have unique challenges and therefore it may be appropriate to create community specific messaging for systems that do not meet the MAC.

The goal of health authority communication with the water supplier is to ensure that the supplier understands health authority expectations regarding:

- risk communication to the public, and
- drinking water system plans to meet the MAC

Water suppliers should consult with health authorities on appropriate messaging. Communication between the water supplier and the users of drinking water from the water supply system should:

- Describe the situation and the reason for the message:
    - what the source of water is and why it is at risk;
    - whether an aesthetic objective (AO) or a maximum acceptable concentration (MAC) was not met;
    - the risks associated with consuming drinking water that does not meet the standards or guidelines
    - Actions that consumers can take to reduce the risk (e.g. use alternate water supplies, support water system improvements);
- Identify the area(s) and population(s) affected;
- Explain what the water system is doing to address the risks and to resolve the situation:
    - where the water system is in the process of resolving the situation;
    - what the plans and timelines are for meeting the treatment standards
- Identify a central point of contact for information and where updates can be found as they become available.

Further messaging may be considered, such as identifying:

- subpopulations that might be particularly vulnerable such as infants;
- reference to the appropriate HealthLinkBC - #49g – Manganese in Drinking Water;
- How individuals can help share the notice with others such as communicating with neighbours, and isolated or vulnerable individuals, etc.

Communication with the general public can range from informational notices intended to educate the water user, to an advisory to take some action either to reduce or prevent exposure as in the case of "Do Not Consume" messaging.

Messaging should be specific to the situation and to the water supply system, and should use plain, non-technical language that is clear and easy to understand by the general public. Messaging should include multiple channels of communication to ensure all users, including transient users, are apprised of the situation, as well as ensuring susceptible sub-populations receive guidance as appropriate. Examples include but are not limited to website updates, annual reports, signage, and leaflets with water bills.

4. Example messaging for Public Notice

4.1 Background Information on Manganese for Consumers

Emphasis should be placed on the fact that manganese is generally naturally occurring in the source water, and may be reduced to acceptable levels through water treatment. Key points for communication:

- Manganese is a naturally occurring element that is present throughout the environment and can normally be found in many water sources.
- British Columbians can be exposed to manganese through air, food, soil, consumer products, and drinking water. The main source for most people is their diet as manganese is present in nuts, beans, fruits, and leafy green vegetables, and some types of infant formula.
- Manganese is an essential nutrient- and consuming a small amount of manganese is necessary to maintain your overall health.
- High levels of manganese can make water appear, brown, purple or black at concentrations less than the MAC.
- Water that is high in manganese can pose a risk to infants when it is used to prepare formula.

4.2 Why did the guideline change?

Messaging regarding the change made to the manganese guideline should indicate that the understanding of manganese toxicity has changed over time, and that the new guideline is based on studies that have been completed since the previous manganese guideline was established. Key points for communication:

- Until recently, elevated levels of manganese in drinking water were not considered to be a health concern.
- Manganese from drinking water is now believed to be a greater health risk than previously thought. New evidence has shown that consuming drinking water with high levels of manganese may impact the memory, attention, motor function, and the overall intellectual development of infants and young children.

4.3 Did drinking manganese in the past impact my health?

For communities with historical issues related to elevated levels of manganese in their drinking water, there may be concern regarding potential health impacts, particularly if infants have been relying on tap water. Key points for communication:

- Exposure to manganese through skin contact is not harmful. Exposure through hand washing, showering, or bathing from water with manganese is unlikely to be significant. While inhalation of manganese aerosols during showering has not been directly evaluated it is not expected to pose any risk to human health.

- The MAC is based on animal studies and includes safety factors to ensure even sensitive individuals are protected. Concentrations approaching, but remaining less than, the MAC are not associated with increased health risks in any individuals.
- Health Canada calculated the MAC assuming that people would be constantly exposed to elevated levels of manganese for long periods of time. Occasionally consuming water with manganese concentrations slightly greater than the MAC is unlikely to cause any health issues.
- Health Canada has adopted a precautionary approach due to the limitations on the available information. Manganese concentrations greater than the guideline are only representative of a potential risk to health, but do not represent measurable health impacts.
- The health effects from manganese exposure are related to neurological function, and related symptoms could include changes in behaviour, poor memory, or reduced motor function. If you have been consuming water with elevated levels of manganese and are experiencing, or have concerns regarding these issues, you should consult your family physician.

4.4 What should I do if there are high levels of manganese in my drinking water?

If you have drinking water with high levels of manganese, the following actions are recommended:

- Water with high levels of manganese can have a purple, brown, or blackish colour; however, a better indicator is discolouration of fixtures such as kettles or toilet tanks. Manganese may also facilitate the growth of manganese bacteria which may form black-brown (manganese) slime and produce a foul odor that may be mistaken for sewage contamination. Testing for manganese should be considered as a first step if the above properties are observed. Manganese can cause discoloured water at concentrations that are still safe to drink. Regardless, as a precaution, it is recommended that you avoid drinking discoloured water, or using it to prepare food or infant formula.
- Infants should not consume tap water or formula prepared with tap water if the manganese concentrations are greater than the MAC of 0.12 mg/L. An alternate source such as bottled water should be used.
- Children and adults are less sensitive to manganese than infants, and may be able to safely consume drinking water with concentrations of manganese slightly above the MAC for short periods of time.
- If you have concerns regarding high levels of manganese in your drinking water, you can switch to other sources of drinking water, such as bottled water until such time that mitigation measures are in place for your water supply system.

4.5 Can our treatment system be upgraded to remove manganese?

Water suppliers may wish to consider sharing information on why upgrades are required, the types of upgrades being considered, the capital and operating costs of the upgrades and expected timelines for construction. In areas where it is known that manganese can exceed the MAC based on naturally occurring conditions, it may be appropriate to discuss options for treatment plant upgrades over an extended period of time because *the infrastructure of many water supply systems predates current treatment expectations.* Health Authorities have been engaging water suppliers to make continuous improvements to meet treatment expectations; however improvements to infrastructure often take considerable time to complete due to financial, technical and logistical challenges.

5. Technical Treatment Details

5.1 Manganese Chemistry

Selection of an appropriate treatment system for manganese is dependent on the chemistry of the source water and water within the drinking water system. Treatment for manganese removal is often done in conjunction with treatment for iron removal, however, it is more difficult to remove manganese than iron. .

Manganese can exist in several oxidation states: Mn(II) is soluble and appears clear in water, Mn(III) and Mn(IV) are insoluble oxides, and Mn(VII) is a soluble ion that appears purple. The species of manganese present is controlled by the oxidation/reduction potential and pH of the source water, as well as the presence of other parameters that can form manganese compounds.

Treatment of manganese is generally accomplished by reducing the solubility of manganese, typically by oxidizing the highly soluble Mn(II) species to the Mn(III) or Mn(IV) species which precipitate as solid oxides (referred to as MnO_x). The oxidation process is influenced by the amount of iron present in the treatment system, as iron is preferentially oxidized under most conditions. Adsorption/desorption processes can also occur in treatment systems as negatively charged MnO_x compounds can adsorb Mn(II) and catalyze further oxidation of Mn(II).

5.2 Municipal Scale Treatment

Selection of an appropriate treatment system for manganese depends on the form of manganese present in the source water. Mn(II) is often the most common form in source water that requires treatment; however, the levels of pH and dissolved oxygen (DO) in the source water could result in a combination of dissolved and solid manganese being present.

Dissolved manganese can be removed through source water control, oxidation/physical separation, absorption/oxidation, biological filtration, and precipitative softening (Health Canada, 2019). Manganese oxides can exist as both particulate (large solids) and colloidal (small particle) forms. While particulate can be more easily removed through sedimentation or filtration, the colloidal particles may require the addition of a coagulant (Health Canada, 2019).

5.2.1 Source Water Control

Manganese concentrations can vary significantly between different groundwater intake wells, and altering intake flow rates (blending) from multiple wells is a method that can be used to optimize concentrations of manganese entering a treatment plant (Health Canada, 2019). A similar option for surface water would be the use of a variable depth intake.

Manganese in groundwater sources can also be oxidized by raising the redox potential in the aquifer by injecting aerated water into the aquifer through recharge wells. However, this option can raise concerns about altering the natural aquifer geochemistry and permeability.

Aeration to increase levels of DO in surface waters can be beneficial to reduce the concentration of Mn(II). There are several physical and chemical aeration options, and the amount of DO required will depend on the volume of water, existing DO levels, and oxygen demand of the underlying sediment (Health Canada, 2019). Control is needed to avoid destratification of the water body which can cause other water quality issues.

5.2.2 Chemical Oxidation

If dissolved Mn(II) is the primary form of manganese present in source water, direct oxidation to precipitate manganese as MnO_x followed by physical separation is an effective treatment strategy. The effectiveness of this treatment is based on several factors, including pH, reduction potential, temperature, reaction time, alkalinity, and total oxidant demand in the source water. Oxidation can also be influenced by the presence of other compounds such as iron, sulphide, nitrate, ammonia, and organic compounds (Brandhuber et al., 2013).

Different combinations of oxidants and physical separation methods are available. Typical chemical oxidants include permanganate (MnO_4^-), chlorine dioxide (ClO_2), and ozone (O_3). Chlorine and oxygen can also be used under high pH conditions. Oxidant doses generally must be greater than stoichiometric ratios in order to meet source water oxidant demand and to achieve an adequate oxidation of manganese (Knocke et al., 1990a). Iron is easier to oxidize than manganese and oxidant demand from iron must be satisfied before oxidation of manganese will occur at any pH.

When using permanganate, chlorine dioxide, and ozone to oxidize Mn(II), colloidal particles less than 1 µm can be created. This occurs more often under low hardness conditions as calcium and manganese ions help to destabilize and aggregate colloids. It is recommended that oxidants be added prior to coagulation/flocculation processes so that colloidal particles can be removed thorough conventional sedimentation and filtration processes.

Oxidation/filtration methods typically remove between 80 to 99% of manganese and are able to achieve treated water concentrations less than 0.04 mg/L (Health Canada, 2019).

5.2.2.1 Permanganate

Permanganate is supplied as either sodium permanganate ($NaMnO_4$) or potassium permanganate ($KMnO_4$). $NaMnO_4$ is being used at an increasing number of facilities as it can be purchased as a concentrated solution rather than a dry product (Health Canada, 2019). Oxidation of Mn(II) occurs rapidly under a wide range of temperature and pH conditions in water with low (<3 mg/L) dissolved organic carbon (DOC). The stoichiometric dosage is 1.9 mg $KMnO_4$ per mg Mn(II) but the required dosage will increase based on the source water oxidant demand. Permanganate is not as effective under conditions less than 5 °C and pH less than 5.5. Under ideal conditions permanganate can reduce concentrations by greater than 80% resulting in concentrations less than 0.045 mg/L (Health Canada, 2019).

Oxidation with permanganate requires precise optimization otherwise there may be remaining permanganate in the treated water, resulting in consumer complaints about the water colour. Optimization requires oxidation/reduction potential measurements to determine the necessary permanganate feed.

5.2.2.2 Chlorine Dioxide

Chlorine dioxide can oxidize Mn(II) to Mn(IV), and is best suited for source waters that do not have a high oxidant demand (Tobiason et al., 2008). Chlorine dioxide oxidation has reduced efficiency at low temperatures (less than 5°C) and pH levels (less than 5.5) (Knocke et al., 1990a). Kohl and Medlar (2006) reported removal efficiencies of 81-95%, achieving treated water concentrations as low as 0.001 mg/L.

The stoichiometric dosage is 2.45 mg ClO_2 per mg Mn(II); however, during the oxidation reaction chlorine dioxide is not completely reduced to Cl^- and instead forms chlorite (ClO_2^-). Chlorite will react with free chlorine to form chlorate, which is difficult to remove. As chlorate and chlorite have health based drinking water quality guidelines, it is recommended that the chlorine dioxide feed be limited to less than 1.2 mg/L (Health Canada, 2019).

5.2.2.3 Ozone

Ozone can oxidize Mn(II) but is less effective for achieving treated water concentrations less than 0.02 mg/L (Brandhuber et al., 2013; Tobiason et al., 2008). The stoichiometric dosage requirement for oxidation is 0.87 mg O_3 per mg Mn(II), but the actual dosage required may be 2 to 5 times greater depending on the alkalinity and DOC of the source water (Knocke et al., 1990a). Increasing alkalinity promotes direct oxidation of Mn(II) by O_3 and can reduce the effect of higher DOC concentrations.

While ozone can be effective under certain conditions, a high natural oxidant demand can result in a required dose sufficient to oxidize manganese to Mn(VII), which can discolour water (Gregory and Carlson, 2003).

5.2.2.4 Chlorine and Oxygen

Direct chemical oxidation of Mn(II) by chlorine and oxygen can also be used; however, this treatment is only effective under alkaline (pH between 8 and 9) conditions, due to slow reaction kinetics and high dosage requirements (Brandhuber et al., 2013).

5.2.3 Physical Separation

Physical separation methods include: coagulation/flocculation, sedimentation, dissolved air flotation, granular media filtration, and low pressure membrane filtration (Health Canada, 2019). The effectiveness of the selected physical separation method is dependent on: conversion of manganese to a particulate form, particle size and location in the treatment system where they are generated, and if the manganese oxides are present as particulate or colloidal solids (Health Canada, 2019).

5.2.4 Oxidation/Physical Separation

MnO_x is capable of adsorbing and retaining Mn(II) due to its negative charge. The MnO_x surface also acts as a catalyst for oxidation of Mn(II) (Health Canada, 2019). Filter media which can adsorb Mn(II) include: manganese greensand, pyrolusite, and conventional filters with MnO_x coatings (Health Canada, 2019). Dosing with an oxidant is still required prior to contact with the filter media in order to maintain MnO_x adsorption sites. These processes can achieve concentrations less than 0.015 mg/L (Brandhuber et al., 2013).

5.2.4.1 Manganese Greensand

Traditional manganese greensand is processed from glauconite and coated with a manganese base material (Sommerfeld, 1999). Greensand has an effective size of 0.03 to 0.35 mm and is effective at capturing small particles (Health Canada, 2019); however, it often requires pressure filtration due to higher head loss compared to silica. Greensand filters are suited to groundwater systems with iron and manganese concentrations less than 5 mg/L (Kohl and Medlar, 2006). Groundwater treatment plants using greensand have been able to achieve 86 to 100% manganese removal from source water concentrations between 0.35 and 0.52 mg/L, with treated water concentrations less than 0.020 mg/L (Kohl and Medlar, 2006).

Potassium permanganate or chlorine is typically used as the oxidant, and is applied to the raw water prior to contact with the greensand filter. Potassium permanganate oxidizes Mn(II) so it can be physically removed with the remaining Mn(II) adsorbed onto the filter media, with excess oxidant to regenerate adsorption sites. Lower doses of permanganate with chlorine (0.5 to 1.0 mg/L) are then used to regenerate the filter media and avoid discolouration of treated water from permanganate (Health Canada, 2019).

5.2.4.2 Pyrolusite

Pyrolusite is the mineral form of MnO_2, and filters are typically a blend of pyrolusite and sand (Health Canada, 2019). Chlorine is typically added prior to treatment to continuously regenerate the pyrolusite media (Health Canada 2019). Limited information is available on pyrolusite filtration; however, a review by Kohl and Medlar (2006) determined that treated water could achieve concentrations ranging from 0.001 to 0.024 mg/L.

5.2.4.3 MnOx on Conventional Filter Media

MnO_x coatings on anthracite coal or silica sand media can adsorb Mn(II) in the presence of free chlorine or permanganate (Knocke et al., 1990b). Oxidation of Mn(II) across the filter continuously regenerates the MnO_x adsorption sites and these filter systems are able to sustain themselves without operator intervention (Brandhuber et al., 2013). The effectiveness of these methods depends on the number of oxidation sites, pH (6 or higher), and concentration of free chlorine (0.5 to 1.0 mg/L). Under ideal conditions MnO_x coated conventional filters can treat manganese concentrations as low as 0.015 mg/L and can be achieved from pre-filter concentrations up to 0.5 mg/L (Health Canada, 2019).

In comparison to post-filter chlorination, addition of pre-filter chlorination can result in a 10 to 50% increase in disinfection byproducts (Tobiason et al., 2008). The potential for formation of disinfection byproducts should be evaluated before consideration of this treatment method.

5.2.5 Biological Filtration

Manganese can be removed by naturally occurring bacteria present in biofilms or on filter media, which can oxidize Mn(II) to Mn(IV). The solid MnO_x compounds are then removed by filter backwashing. The performance of biological filters is influenced by the: presence of oxidizing bacteria in the source water, ability to form an active biofilm under operating conditions, acclimation period of the bacteria (14 to 100 days), and ability to maintain biological activity during stresses to the filter (Health Canada, 2019). Physical-chemical factors include: DO levels (minimum 5 mg/L), pH (equal or greater than 6.3), redox potential of the source water (300 to 400 mV), and the initial Mn(II) concentration and filter loading rates (Kohl and Dixon, 2012). The presence of ammonia, nitrate, and sulphide in the source water can significantly reduce the effectiveness of biological filters (Health Canada, 2019).

Biological filtration is best suited to groundwater sources with consistent Mn(II) concentrations and physical chemical characteristics (Brandhuber et al., 2013). Biological filtration and softening can achieve treated water manganese concentrations less than 0.03 mg/L (Health Canada, 2019).

5.2.6 Softening and Ion Exchange

Lime or soda ash softening treatments can also remove manganese by raising the pH above the solubility limit (9.5) of manganese hydroxides and carbonates (Health Canada, 2019). The elevated pH will also increase the oxidation rate of Mn(II) in the presence of DO. This is generally not a cost effective treatment method, but it can be effective if chemical softening of the source water is already being undertaken.

Mn(II) can also be removed by cation exchange in zeolite softening processes (Health Canada, 2019). Backwashing the zeolite with a brine solution will remove manganese, iron, calcium, and magnesium accumulated on the resin (Health Canada, 2019).

5.2.7 Sequestration

Chemical sequestration can be used to control aesthetic water quality problems associated with the oxidation of dissolved Mn(II) to MnO_x by binding dissolved Mn(II) so that it is not available for oxidation or precipitation. The addition of polyphosphates alone or in conjunction with chlorine is the most commonly reported method used to sequester manganese (Sommerfeld, 1999; Kohl and Medlar, 2006). Sequestration does not remove manganese from water, therefore, it should not be considered as a treatment option for drinking water systems that have manganese concentrations that are greater than the MAC.

When sequestration is used to reduce the potential for discoloured water, the potential for manganese accumulation and subsequent release in the distribution system should always be considered.

5.2.8 Other Manganese Sources and Residuals Management

Chemical addition and treatment plant processes can add manganese to water through: manganese impurities in coagulants, resolubilization of Mn(II) under anoxic conditions in sedimentation basins, and presence of dissolved manganese in recycle streams from solids processing (Tobiason et al., 2008). In cases where a treatment plant uses enhanced coagulation, manganese contamination of the ferric chloride can result in soluble manganese concentrations of up to 0.5 mg/L, with typical levels of manganese attributable to coagulant addition in surface water treatment plants ranging from 0.025 to 0.055 mg/L (Health Canada, 2019). Release from solids in sedimentation basins typically ranges from 0.01 to 0.10 mg/L with variations observed seasonally. Manganese in residuals recycle streams can range from 0.01 to 1 mg/L (Tobiason et al., 2008). Thus, while the total flow from residual processing side streams can be relatively small in comparison to the influent flow to the treatment plant the total mass loading of dissolved Mn(II) from such side streams can be quite significant. Careful sampling of dissolved Mn(II) concentrations in residuals processing side streams is strongly recommended.

5.2.9 Distribution System Considerations

Manganese in the distribution system can accumulate as solid deposits, periodically releasing manganese into the distribution system as a result of physical or chemical disturbances (Health Canada, 2019). The initial deposition of manganese oxides can occur at treated water concentrations as low as 0.02 mg/L, and a treated water manganese concentration of <0.015 mg/L is recommended to prevent the formation of manganese deposits (Brandhuber et al., 2013). Manganese deposits are a concern as they can scavenge and become sinks for heavy metals (Dong et al., 2003), that are released during disturbances to the system at much higher concentrations.

Key distribution system management options include:

- maintaining stable water chemistry;
- minimizing the amount of manganese entering the distribution system; and
- minimizing the potential for physical/hydraulic disturbances of the system (Brandhuber et al., 2015).

5.3 Small Water Systems

Direct oxidation and MnOx coated filters can be used effectively in small water systems and can achieve very low manganese concentrations through ongoing optimization of source water and treatment system conditions. It is expected that most small water systems will use greensand filters to reduce manganese concentrations in drinking water to acceptable levels.

5.4 Residential Scale Treatment

Residential drinking water treatment devices are also an option for reducing high levels of manganese. Appropriate treatment methods for removal of manganese on a residential scale include reverse osmosis, ion exchange/water softeners, and oxidizing filters. These systems are typically installed at the point-of-entry into the home, but can also be used at the point-of-use (taps or faucets). It should be noted that boiling water may increase the concentration of dissolved manganese in drinking water and is not recommended.

Selection of a water treatment device will depend on a variety of factors, including the concentration and form of manganese, and other water related parameters such as water hardness, iron content, alkalinity, and sulphide, ammonia and dissolved organic carbon concentrations.

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Appendices

Water Quality Advisory: Elevated Manganese in Drinking Water

Do Not Use Water for Reconstituting/Preparing Infant Formula.

Key Points:

- This notice is being issued because elevated levels of manganese have been measured in the drinking water supply that serves __________________.
- Manganese in the water supply has been measured at _____ mg/L, which exceeds Health Canada's - Maximum Acceptable Concentration (MAC) of 0.12 mg/L.
- According to Health Canada, increased levels of manganese may contribute to adverse health effects on the nervous system, especially in infants. The MAC is protective of this most vulnerable population (infants and young children).
- To reduce risks, the Drinking Water Officer/ Medical Health Officer advises:
  - Water from this water supply system should not be fed to infants nor used for preparing/reconstituting infant formula.
  - Older children and adults should consider in-home water filtration or reverse osmosis systems to reduce the levels of manganese in drinking water used for drinking and cooking.
  - Water may be used for showering, bathing and other household uses without concern.

Background Information on Manganese

- Most manganese intake comes from food; however water can also be a significant contributor in our diet. Manganese is an essential nutrient, and some manganese is required for proper bodily function, however high levels of manganese in drinking water have been associated with effects on neurological development. Infants are at highest risk, particularly those who consume powdered baby formula reconstituted from water that is high in manganese.
- Because of infant's increased water consumption relative to body weight, rapid brain development, an increased ability to absorb manganese and a decreased ability to remove manganese from their bodies, another suitable source of drinking water (e.g., bottled water) should be used to reconstitute and prepare powdered infant formula. Breastfeeding is not likely to be a route of significant exposure.
- Short-term ingestion of manganese in drinking water by older children and adults at levels slightly above the MAC is not expected to result in adverse effects, however, if there are concerns, an alternate source of water should be considered.
- It is not possible to quantify health effects of past exposure to manganese in individuals, however future exposure can be managed to reduce risks of neurological effects.
- Link to HealthFile #49g – Manganese in Drinking Water , at https://www.healthlinkbc.ca/services-and-resources/healthlinkbc-files
- For further information contact: _____________________