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NGWA Best Suggested Practice

Reducing Problematic Concentrations of Iron and Manganese in Residential Water Well Systems

Introduction

As a benefit to members of the National Ground Water Association, this document provides the water well system professional (WWSP) with basic knowledge and suggested practices. Because of varying geologic conditions and other factors, it is not practical to develop a totally prescriptive guideline.

There are references throughout this document to public health standards in the United States; other nations may have different standards, and standards may change.

Sometimes the concentrations of select constituents will prove to be unacceptably high even after careful site selection and well construction, or after cleaning an existing well. The WWSP can recommend cost-effective water treatment options to mitigate such problems. For instance, it may be less expensive for the consumer to install an appropriate water treatment technology to remove or lower concentrations of a contaminant than to replace or deepen an existing well or to use a more expensive drilling technology to emplace a new well. On the other hand, if a water intake area in an existing well has to be replaced or an aquifer lined off, economics will probably dictate that a new water well be constructed. Such decisions are site-specific and, thus, based on careful analysis by the WWSP.

- Section 1 offers background on the health effects from excessive levels of iron or manganese and the related regulatory responses.
- Section 2 is guidance about how geologic conditions and land-use settings may affect the concentrations of iron or manganese in groundwater.
- Section 3 provides a description of well location and construction methodologies related to minimizing the presence of iron or manganese. Generally, all construction and maintenance practices must comply with local and state requirements.
- Section 4 deals with water sampling methods and water treatment options.

national ground water association®

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Definitions

contaminant:
Any physical, chemical, biological, or radiological substance or matter in water that has an adverse impact.

iron (Fe):

A silvery-gray, lustrous metal, it makes up about 5% of the earth's crust, usually in an oxidized form.

manganese (Mn):
A gray-white metal, it resembles iron in appearance. It is hard, very brittle, and easily oxidized. It comprises only about 0.1% of the earth's crust, primarily as manganese dioxide.

maximum contaminant level (MCL):
Under the U.S. Safe Drinking Water Act, the maximum allowable concentration of some contaminants in surface water or groundwater to be used in the drinking water supply.

microgram:
A unit of mass equal to 1/1,000,000 of a gram (1×10^{-6}), or 1/1000 of a milligram. Expressed as μg.

milligram:
A unit of mass equal to one thousandth (1×10^{-3}) of a gram. Expressed as mg.

point-of-entry (POE) treatment device:
A treatment device applied to the drinking water entering a house or building to reduce the contaminants in the water distributed throughout the house or building.

precipitation:
The removal of a substance from a solution by increasing the concentration above its saturation point.

residential water well system:
The well system used by a private household, including the well, pumping equipment, and treatment equipment, if needed.

secondary maximum contaminant level (SMCL):
The U.S. Environmental Protection Agency has established National Secondary Drinking Water Regulations that set non-mandatory water quality standards for 15 contaminants. EPA does not enforce these "secondary maximum contaminant levels" or "SMCLs." They are established only as guidelines to assist public water systems in managing their drinking water for aesthetic considerations such as taste, color, and odor. These contaminants are not considered to present a risk to human health at the SMCL.

1. Iron and Manganese in Groundwater

Iron normally exists in groundwater in the soluble ferrous (Fe^{2+}) form, in concentrations as high as 15 mg/L. Manganese may be found in groundwater in concentrations above 10 mg/L.

The effects that are associated with iron and manganese contamination can be grouped into two categories: aesthetic and physical.

Aesthetic effects are undesirable tastes or odors. Iron in quantities greater than 0.3 mg/L in drinking water can cause an unpleasant metallic taste. Elevated levels of iron in drinking water can also cause a rusty color that can stain laundry, toilet bowls, sinks, and other surfaces in contact

with the water. Manganese levels above 0.05 mg/L can also produce unpleasant tastes and cause black staining. Discolored water is one of the most frequent consumer complaints about drinking water.

Physical effects are damages to water equipment and reduced effectiveness of treatment for other contaminants that may present added costs to operations for water utilities. The problems of staining and precipitation from iron and manganese are more problematic in water well systems than are issues of corrosion.

Manganese-bearing minerals are common in rocks and soils. As a result, it is also commonly found in groundwater. Detection levels in groundwater of the United States generally fall below public health levels of concern. Manganese may exist in large concentrations in organic material, since it is a plant nutrient. The greatest exposure to manganese is usually from food.

Concentrations of manganese in natural waters are generally 0.02 mg/L or less. The largest amounts of it are found in acidic waters and it begins to precipitate as the water becomes more alkaline. In alkaline groundwater, manganese most commonly occurs as manganous bicarbonate.

Manganese is an essential nutrient at low doses. Adverse health effects can be caused by over-exposure, with recent studies indicating a possible link to cancer. Children exposed to high concentrations of manganese in groundwater-supplied drinking water performed worse on tests of intellectual functioning than children with lower exposures, according to 2010 research. Manganese deficiency in humans is thought to be rare because manganese is present in many common foods, according to the U.S. EPA.

Iron and manganese are virtually always found together in water supplies. These elements are extremely close in chemical characteristics, and as a result form very similar chemical compounds in water. Since iron is more abundant in the earth's crust, groundwater sources typically have about 10 times more iron than the concentration of manganese.

The U.S. EPA has not established a federally enforceable regulation either for iron or for manganese, but has set what the agency calls secondary maximum contaminant levels (SMCLs) of 0.30 mg/L for iron and 0.05 mg/L for manganese. The SMCL is intended as a guideline for states. States may establish higher or lower levels depending on the local conditions.

2. Geologic Settings and Land Uses

Iron and manganese found in groundwater are generally naturally occurring. The presence of either in groundwater depends on the rock and soil types in the area.

A 2009 U.S. Geological Survey study of groundwater used by residential water wells reported the following findings related to iron and manganese.

"Iron and manganese were each detected in about half of the wells [sampled]. USEPA SMCLs [secondary maximum contaminant levels] for iron and manganese were established to prevent poor water taste and the staining of laundry and plumbing fixtures (U.S. Environmental Protection Agency, 1992). Concentrations of iron were greater than the SMCL of 300 µg/L in 19 percent of wells, and concentrations of manganese were greater than the SMCL of 50 µg/L in 21 percent of wells. The elevated concentrations occurred throughout the United States; such concentrations were found in samples from nearly all principal aquifers. Iron and manganese are common elements in most aquifer materials but are mobilized under certain geochemical conditions, such as low dissolved oxygen concentrations and low pH.

"Values or concentrations of pH, dissolved solids, iron, and manganese in samples collected prior to any in-home treatment were individually outside the ranges defined by USEPA secondary maximum contaminant levels (SMCLs) in 15 to 21 percent of wells," the Survey study reported.

3. Well Location and Construction Methodologies

If testing confirms that the groundwater exceeds the MCL for iron and/or manganese, the homeowner has several choices:

- Explore with a qualified water well contractor the feasibility of retrofitting the well to zone off the metals-producing zones.
- Construct a new well system that isolates the likely zones of groundwater.
- Install appropriate water treatment technology.

Iron and manganese problems are most likely to develop in water from wells with high pH and low oxygen. Problems occur when this type of water is pumped to the surface. The chemical equilibrium is changed upon exposure to the atmosphere, often resulting in precipitation that causes staining and potential fouling, including of the well intake or the water distribution system.

Some types of bacteria derive their energy by reacting with soluble forms of iron and manganese. These organisms are usually found in waters that have high levels of the metals in solution. The reaction changes iron and manganese from a soluble form into a less soluble form, thus causing precipitation and accumulation of red (iron) or black (manganese) gelatinous material (slime). Masses of these can clog plumbing and water treatment equipment. They also slough off in globs that stain laundry. Bacterial reactions with iron or manganese do not cause any additional precipitation compared to normal exposure to oxygen. However, precipitation caused by bacteria occurs faster and tends to concentrate staining, thus making it more apparent.

Mixing groundwater of differing iron and manganese levels within the same well is not recommended. Some local and state regulations prohibit interconnection of multiple aquifers within the same well.

As access to an uncontaminated source of water should be safeguarded, it is better to focus on other alternatives and uniquely deal with the problem each time it occurs. It is not possible to know at what level a contaminant will be found to be harmful in the future.

If the groundwater exceeds the iron or manganese SMCL, a qualified water well contractor can determine if it is pragmatic to retrofit the well to zone off the zones. If this does not result in levels of iron or manganese consistently below the SMCL, then it may be necessary to construct a new well system that isolates the likely iron-producing or manganese-producing zones of groundwater, or to install appropriate water treatment technology.

4. Groundwater Analyses and Water Treatment Methodologies

Testing water for iron and manganese in areas where iron and manganese are a concern is an important strategy for residential water well system owners. For more information on groundwater sampling and testing, NGWA has developed separate Best Suggested Practices for these topics.

Typical Iron and Manganese Testing Costs

Testing for these contaminants typically costs $10 to $50, depending on location. It is essential that samples being tested utilize a laboratory qualified to test for iron or manganese consistent with local, state, or federal requirements.

Iron and Manganese Treatment Choices

There are several readily available options to well owners to effectively treat iron and manganese in their drinking water. Not all water treatment technologies are appropriate for household use.

The two most commonly used treatment methods for reducing iron and manganese levels in drinking water include (1) ion exchange and (2) oxidation and filtration.

Ion exchange is a physical-chemical process in which ions are exchanged between a solution phase and solid resin phase.

Ion exchange technology is commonly used for household point of entry (POE) water softening (cation exchange). For iron and manganese removal, strong acid cation resin can be used in cases where the water has a pH close to neutral.

This means that a standard household water softener may effectively remove iron and manganese at concentrations of up to 2 mg/L; however, to minimize iron and manganese fouling of the resin, the unit will have to be regenerated more frequently. In sizing the softener, each mg/L of iron should be considered equivalent to 50 to 85 mg/L of hardness.

Oxidation and filtration involves oxidation of the iron from the soluble ferrous (Fe^{2+}) form to the insoluble ferric (Fe^{3+}) form, and manganese from the soluble manganous (Mn^{2+}) form to the insoluble manganic (Mn^{4+}) form, followed by filtration to remove them.

A number of agents are used to accomplish oxidation of iron and manganese. These include oxygen, chlorine, potassium permanganate, ozone, certain catalytic media that oxidize and filter in one step, and new electrolytic oxygenation technology.

Oxygen – The water to be treated is pumped through a Venturi tube that draws air into the water stream. It may then enter a pneumatic storage tank to allow the oxygen in the air to oxidize the iron and manganese. The air-saturated water is then directed to another vessel where excess air is vented to the atmosphere and the oxidized iron and manganese start to precipitate. The water stream then enters a media filter tank that completes the process. Because of the slow rate of manganese oxidation, this process is generally not considered practical for manganese removal.

Chlorine – Typically, sodium hypochlorite (bleach) is fed into the incoming water, utilizing a tank and metering pump system. The chlorine oxidizes iron and manganese to their insoluble forms and they are removed with a downstream media filter.

Potassium permanganate ($KMnO_4$) – As with chlorine, this liquid effectively oxidizes iron and manganese to enable the oxidized material to be removed by filtration.

Ozone – This powerful oxidant is a gas and must be generated on site, and injected into the water through a Venturi tube (as with the oxygen agent) prior to filtration.

The following chart summarizes the performance of these oxidizing agents for the treatment of iron and manganese.

Oxidizing Chemicals Comparison

Iron: Fe^{+2} to Fe^{+3}	**Quantity***	**pH**
Oxygen (O_2)	0.14	>7.5
Chlorine (Cl_2)	0.64	>7.0
Potassium Permanganate ($KMnO_4$)	0.94	6–9
Ozone (O_3)	0.86	6.5–7.5
Manganese: Mn^{+2} to Mn^{+4}		
Oxygen (O_2)	0.29	>9.5
Chlorine (Cl_2)	1.29	>8.5
Potassium Permanganate ($KMnO_4$)	1.92	>7.0
Ozone (O_3)	0.87	>8.0

* Quantity (mg/L) of oxidizing chemical required to oxidize 1 mg/L of metal.

Oxidizing media – There are two media commonly available that will oxidize and filter out iron and manganese in one step. These are manganese greensand and manganese dioxide.

There are a number of base materials utilized in manganese greensand constructions, which are then chemically coated with manganese oxide deposits.

Manganese greensand will both oxidize and filter out the insoluble iron and manganese oxides in one step. It must be backwashed at three to four times its normal service rate and regenerated with potassium permanganate to restore its oxidizing properties. In many cases, it works most effectively with a continuous feed of potassium permanganate; however, since this chemical is hazardous and the liquid solution must be prepared fresh weekly, it can present safety and handling problems. Additionally, for optimum performance, the feedwater pH must be above 7.5. In some cases, using manganese greensand as the filter media following the other oxidizing technologies has proven to be effective.

Manganese dioxide, which is similar to manganese greensand, is obtained from mines and does not require regeneration, but does require the high pH and backwash rates of greensand treatment.

Electrolytic oxygen generation – A new development is the electrolytic generation of oxygen from water itself. As the feedwater flows past, special electrodes produce small "microbubbles," which readily oxidize iron and manganese, and the precipitants can then be removed utilizing standard filtration media.

In all cases, iron and manganese removal involves POE treatment only.

The following table compares the treatment technologies in regards to efficiency and costs.

Treatment Technology (POE only)			
	Removal Performance	**Capital Cost**	**Operating Cost**
Ion Exchange:	Excellent (up to 2 ppm)	≤ $1,000	≤ $500/yr
Oxidation/Filtration			
Oxygen (Iron):	Good	≤ $3,000	≤ $100/yr
Oxygen (Manganese):	Not Effective		
Chlorine:	Good	≤ $3,000	≤ $100/yr
Potassium Permanganate:	Limited/Poor	≤ $3,000	≤ $500/yr
Ozone:	Excellent	> $3,000	≤ $100/yr
Oxidizing Media:	Good	≤ $1,000	≤ $500/yr
Electrolytic Oxygen Generation:	Excellent	> $3,000	≤ $500/yr

There are voluntary performance testing programs for POE treatment systems, such as those of the Water Quality Association and NSF International, although there may not be systems listed that have been evaluated for their effectiveness in dealing with iron or manganese. A contractor should determine if the technology being provided to the customer has been voluntarily submitted for performance testing.

The contractor should recognize that each manufacturer may have unique operation and maintenance expectations to assure the long-term treatment performance of its equipment. The contractor should discuss these expectations with the treatment equipment customer and make certain it is understood who holds responsibility for adhering to the manufacturer's expectations.

Following installation of a treatment device, water quality should again be tested to verify the operation of the device. After that, water should be tested at least annually to confirm treatment effectiveness. A maintenance agreement for such devices is highly recommended.

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Disclaimer:
This publication is a collaborative effort to try to set forth best suggested practices on this topic but individual situations and local conditions may vary, so members and others utilizing this publication are free to adopt differing standards and approaches as they see fit. The Association assumes no liability or responsibility for the contents of the publication.

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