

Discussion of Water Treatment Systems

Please find below a discussion of three water treatment options

• Option 1:

Continued use of potassium permanganate and manganese greensand filtration for turbidity, iron, and manganese reduction in combination with chlorine dioxide for primary disinfection and chloramines for secondary disinfection.

• Option 2:

Use of pyrolucite filtration for turbidity, iron, and manganese reduction in combination with ozone for oxidation and primary disinfection and chloramines for secondary disinfection.

• Option 3:

Use of biological treatment for iron, ammonia, and organics reduction followed by reverse osmosis for manganese, sulphate, total dissolved solids, and hardness reduction. Continue use of free chlorine for primary and secondary disinfection.

With any development, there are factors other than cost that are just as important in judging the overall “value” of the development. For this comparison, factors such as final water quality, ability to meet future guidelines, sustainability, and ease of operation are considered in addition to capital, operation, and maintenance costs.

OPTION 1 – MANGANESE GREENSAND

Traditionally, the approach to groundwater treatment in Saskatchewan has often been aeration and or chemical oxidation and minimal detention followed by manganese greensand filtration, as this is the most familiar and often the most economical solution, from the perspective of capital investment.

Manganese greensand is manufactured by coating small particles of iron silicate mineral with manganous sulphate and potassium permanganate. This creates iron and manganese oxides on the sand grains which gives manganese greensand the ability to adsorb soluble

iron and manganese, speed up the oxidation process, and act as a filter. Therefore, manganese greensand takes advantage of the adsorptive capacity of manganese dioxide. The downside is that because of the small size of the media, the sites between the media can become filled by solid particles quite quickly which results in substantially short filter runs. When the amount of precipitate is large, a layer of crushed anthracite coal is usually used to top the manganese greensand in order to reduce the particle loading on the exchange medium.

In recent years, the use of manganese greensand became so popular that it eventually led to a demand that was greater than production capability, resulting in spot shortages and long lead times. One synthetic product, often referred to by the trade name of Greensand Plus, uses a special-density silica sand instead of an iron silicate as its base. The result is an alternate media that is an exact replacement for manganese greensand.

Both manganese greensand and Greensand Plus need to be regenerated using either chlorine or potassium permanganate. There are two methods of regeneration: 1) continuous, and 2) intermittent. Continuous regeneration is commonly employed. This allows the chlorine or potassium permanganate to act as an oxidizer which in turn reduces the load of soluble iron and manganese on the media's adsorption sites. It also avoids the down time that intermittent regeneration requires. Assuming the test results from the distribution system indicate the presence of trihalomethanes, potassium permanganate would need to be used as potassium permanganate reacts very little with organics.

Although manganese greensand filtration with continuous regeneration has proven itself to be an effective treatment process if properly operated, the use of potassium permanganate has several disadvantages. It is difficult to handle as it comes as a powder, is very corrosive, stains nearly everything purple, and forms manganese particulates which need to be removed by filtration to avoid the accumulation of deposits in the distribution system. Potassium permanganate also cannot be used a primary or secondary disinfectant due to the doses that would be required and its ability to turn the water pink if overdosed. Finally, in recent years, there have been issues surrounding the availability of potassium permanganate from chemical suppliers that has significantly increased the cost of the chemical.

As potassium permanganate cannot function as a primary or secondary disinfectant, an alternate primary and secondary disinfectant must be used. Chlorine dioxide is not as effective against viruses as ozone or other chlorine-based technologies. However, it does not react with organics to form trihalomethanes or haloacetic acids. Chlorine dioxide also does not react with ammonia to create chloramines and can provide a prolonged residual. As a result, chlorine dioxide has proved economical and effective for treating waters high in ammonia or organic nitrogen once iron and manganese has been removed. However, chlorine dioxide is not frequently used as a secondary disinfectant due to taste and odour complaints and its tendency to break down into the inorganic disinfection by-products, chlorate and chlorite, which may pose human health risks.

OVERVIEW

Finished Water Quality

Manganese greensand filtration will reduce iron, manganese, arsenic, hydrogen sulphide, and turbidity; but will not reduce ammonia, organics, sulphate, total dissolved solids, or hardness. Whether chlorine dioxide is used for secondary disinfection or chlorine is added to form chloramines, residual manganese greensand ammonia may lead to biological nitrification in the distribution system. As organic reduction of the presence of organics and nitrifying bacteria in the distribution system may contribute to biofilm growth, increasing the potential for test results indicating the presence of coliforms or background colonies.

Ability to Meet Future Regulations

The combination of potassium permanganate, chlorine dioxide, and chloramines should reduce trihalomethane and haloacetic acids formation which are the two disinfection byproducts currently regulated. However, the chlorine dioxide process forms the specific byproducts chlorite and chlorate. While not currently regulated by Saskatchewan Environment, Health Canada has set a maximum acceptable concentration for chlorite of 1 mg/L and chlorate of 1 mg/L. The United States Environmental Protection Agency has set a maximum residual disinfection level for chlorine dioxide of 0.8 mg/L and the maximum contaminant level for chlorite of 1.0 mg/L. The chlorine dioxide dosage cannot exceed 1.4 mg/L to limit the total combined concentration of chlorine dioxide, chlorate, and chlorite to a maximum of 1.0 mg/L.

The formation of n-nitrosodimethylamine and other nitrosamines are also of concern. Nitrosamines are currently included on Health Canada's Drinking Tap Water Survey and in the United States Environmental Protection Agency's *Unregulated Contaminant Monitoring Rule 2*. These two studies require public water systems to gather occurrence data of n-nitrosodimethylamine levels in the finished water and distribution systems. This data will be used as support in regulatory assessment and decisions. N-nitrosodimethylamine is already regulated in many states and Ontario and Quebec.

Sustainability

Manufacturing of manganese greensand and potassium permanganate both require manganese dioxide; therefore, this process has sustainability issues with regard to the long-term availability of manganese dioxide ore. In addition, the manufacturing of manganese greensand depends on the availability of an iron silicate and has already incurred issues of greater demand than production capability resulting in the development of a replacement media. There have also been availability issues with potassium permanganate.

Ease of Operations

Oxidation and filtration via manganese greensand has become the most widely used method for the removal of dissolved iron and manganese in recent years because of its relative ease of operation, low maintenance, low energy requirements, and reliability. However, potassium permanganate is toxic and irritating to the skin and mucous membranes, requires long contact time, and can turn the water pink if overdosed. Although, chlorine dioxide is easy to generate, generator efficiency and optimization difficulties can cause excess chlorine to be fed which has the potential to form disinfection by-products. Not as complex as ozone disinfection, a higher level of maintenance and operator skill is required when compared to free chlorine disinfection. If chlorine dioxide is not used as a secondary disinfectant, chlorine will still need to be carefully dosed in order to form the desired monochloramine for disinfection within the distribution system.

Without reducing ammonia or organics, the distribution system is more prone to biofilm growth and will require more frequent flushing and should be shock chlorinated on a regular basis.

OPTION 2 – PYROLUCITE FILTRATION

Manganese dioxide is a naturally found ore used as a filter media in water treatment systems to reduce iron, manganese, hydrogen sulphide, and for the co-precipitation-filtration of arsenic. Pyrolucite is not designed to reduce organics, ammonia, or other items that are present in most Saskatchewan raw water supply including lead, total alkalinity, total dissolved solids, and total hardness; nor will it help reduce biofilm growth from occurring in the distribution system.

Soluble manganese and iron attach to adsorption sites on the media. Once oxidized into their particulate form, iron and manganese solids free themselves of the adsorption sites and the particles become caught in the spaces between the media. With any type of granular filtration, water quality tends to degrade as the filter runs to completion. The end of the filter run is indicated either by the plugging up of the filter due to the accumulation of solids, or contaminant breakthrough is detected. The filter is then taken out of service and cleaned by backwashing with clean water. High levels of iron and manganese will require more frequent backwashing.

Manganese dioxide ore is very heavy, weighing 1900 kg/m³. Because pyrolucite is so heavy, backwash rates in the order of 61 m³/hr/m² to 73 m³/hr/m² are required to adequately expand the filter bed to allow for effective cleaning. The backwash flow rate required for pyrolucite is 2.5 times greater than the flow rate required for cleaning other manganese dioxide coated media such as manganese greensand. Assuming the backwash pump was originally designed for the flow rates required by manganese greensand, one of the reasons the current processes may not be adequately treating the water is that with insufficient backwash flow rates, the media has become permanently fouled and ineffective.

Oxidation of manganese is more difficult and takes more time than the oxidation of iron. If the manganese is not eventually oxidized into its solid form, all of the adsorption sites on the medium eventually fill up and soluble manganese will pass through the filter. For this reason, oxidants such as chlorine, potassium permanganate, or ozone are added ahead of the filter to aid in converting adsorbed soluble manganese to its solid form in order to free up those absorption sites. Using an oxidant to help free up adsorption sites on the media is referred to as regeneration. Regeneration enhances the performance of the media and prolongs media life.

Chlorine dioxide is an oxidant that reacts very little with organics, and it can be used as a primary disinfectant. However, it is estimated that 70% of a chlorine dioxide dose breaks down into chlorite, an inorganic disinfection by-product that may pose human health risks. Both Health Canada and the United States Environmental Protection Agency have set a maximum allowable concentration for chlorite of 1.0 mg/L.

OVERVIEW

Finished Water Quality

Pyrolucite filtration should reduce iron, manganese, arsenic, hydrogen sulphide, and turbidity; but will not reduce ammonia, organics, sulphate, total dissolved solids, or hardness. Residual ammonia remaining after chloramine formation can cause biological nitrification in the distribution system. With greater emphasis being put on a multi-barrier approach, water quality changes from the water treatment plant to the tap are being increasingly investigated. In groundwater systems, the confirmed presence of total coliforms or overgrowth of >200 background colonies usually indicates the distribution system is experiencing bacterial regrowth problems or infiltration. The presence of nitrifying bacteria and biofilms in drinking water certainly demonstrates a health risk.

Ability to Meet Future Regulations

Ozone is one of the most potent and effective germicides used in water treatment. It is effective against bacteria, viruses, and protozoan cysts. The combination of ozone and chloramines should reduce trihalomethane and haloacetic acids formation which are the two disinfection by-products currently regulated by Saskatchewan Environment. However, if bromide is present in the raw water or if chlorine is added as a secondary disinfectant, ozone may create other disinfection by-products including bromate, organic acids, and aldehydes. While not currently regulated by Saskatchewan Environment, Health Canada and the United States Environmental Protection Agency have a maximum acceptable limit for bromate of 0.010 mg/L.

N-nitrosodimethylamines and other nitrosamines have shown to be a by-product of a reaction between chlorine, ammonia, and certain forms organics and is thought to create a far more serious health risk than other disinfection by-products including trihalomethanes and haloacetic acids. Although federal standards for N-nitrosodimethylamines and other nitrosamines have not been set, nitrosamines are currently included on Health Canada's

Drinking Tap Water Survey and in the United States Environmental Protection Agency's *Unregulated Contaminant Monitoring Rule 2*. These two studies require public water systems to gather occurrence data of n-nitrosodimethylamine levels in the finished water and distribution systems. This data will be used as support in regulatory assessment and decisions. N-nitrosodimethylamine is already regulated in many states and Ontario and Quebec.

Sustainability

Pyrolusite, also known as manganese dioxide, is an ore mined in Australia, Burkina Faso, Brazil, Democratic Republic of the Congo, Ghana, and Gabon. Manganese dioxide is used in a number of other applications beside water treatment. The predominant application for manganese dioxide is as a component of dry cell batteries. Approximately 5,000,000 kg of manganese oxide are consumed for this application annually. At this time, there are no practical technologies for replacing manganese with other materials and the overall level and nature of manganese use is expected to remain the same in the near term. While vast quantities of manganese exist in manganese nodules on the ocean floor, attempts to find economically viable methods of harvesting manganese nodules were abandoned in the 1970s.

Pyrolucite requires a significant amount of water for cleaning. This increases the cost of pumping and treatment, as well as the amount of raw water needed to produce a given amount of treated water. Ozone generation is also very energy intensive.

Ease of Operation

Ozone is highly corrosive and unstable and must be generated on-site, is a relatively complex process, and a higher level of maintenance and operator skill is required. Ambient ozone levels in plant facilities should be monitored continuously as ozone is a highly toxic gas. Given that ozone does not create a disinfectant residual, chlorine will still need to be added at the appropriate dosage in order to form the desired monochloramine.

At chlorine:ammonia ratios of 4:1 to 6:1 dichloramine becomes predominate. Dichloramine has similar disinfectant and oxidant properties of monochloramine; however, even trace amounts of dichloramine often give objectionable tastes and odors to the water. When the chlorine:ammonia nitrogen ratio is above approximately 6:1, monochloramine, dichloramine, and chloro-organic compounds are destroyed and nitrogen trichloride is formed. Even though the chlorine dose is increased, at this chlorine:ammonia ratio the chlorine residual decreases. Nitrogen chloride is practically insoluble in water, has a very intense taste and odour, and is known for its eye irritation/tearing effects at very low concentrations.

Both residual ammonia and ozone can contribute to biofilm growth in the distribution system; therefore, the distribution system will require more frequent flushing and should be shock chlorinated on a regular basis.

OPTION 3 – REVERSE OSMOSIS WITH BIOLOGICAL FILTRATION PRE-TREATMENT

The use of reverse osmosis membranes for treatment of brackish ground water sources has gained widespread acceptance and within the last decade the use of membranes in the treatment of Saskatchewan groundwater sources has increased. Membranes provide exceptionally high quality water regardless of feed water variability, and an absolute barrier against waterborne pathogens making membranes an excellent technology to effectively meet current and future drinking water regulatory requirements. However, membrane fouling is a common operational issue. The introduction and accumulation of matter at the surface of the membrane often results in the requirement for increased operating pressures, frequent backwashing, and frequent cleanings.

By using biological filtration as pre-treatment for reverse osmosis membranes, the membranes are provided a biologically stable high water quality which significantly reduces membrane fouling. This in turn significantly reduces the frequency of membrane cleanings and operation and maintenance costs. Biological filtration has been and continues to be implemented as a pre-treatment prior to membranes in a number of First Nations water treatment systems in Saskatchewan. Biological filtration targets iron, arsenic, ammonium and organic carbon; reverse osmosis membranes reduce manganese, nitrates, sulphates, hardness, alkalinity, and total dissolved solids.

Biological water treatment involves the use of naturally occurring, non-pathogenic microorganisms typically found in water supplies to improve water quality. Used in Europe for some time, biological filtration is now receiving more interest in North America. Given proper environmental conditions, biological water treatment processes are well suited to treat some problems common to Saskatchewan water supplies including ammonia, arsenic, color, iron, dissolved organic carbon, manganese, and turbidity.

Expanded clay media provides a large surface area and pockets and crevasses for the microorganisms to attach to. An initial start-up or seeding period is required for each filter vessel to establish a colony of suitable micro-organisms. The length of this period is dependant on the contaminant the filter vessel is to remove and characteristics of the micro-organism which needs to be cultured. For example, iron removing micro-organisms generally require 2 to 7 days to establish a colony and nitrifying micro-organisms can take 6 to 8 weeks to establish a colony. However, recent applications have shown that taking micro-organisms from one treatment plant to another can be effective and significantly reduces the initial seeding period.

Different species of micro-organisms use different constituents in the water as source of energy for growth and reproduction. Each species may thrive in different conditions, often measured by pH, temperature, and dissolved oxygen. Therefore, biological treatment most often occurs in multiple stages or filter vessels.

While water makes its way through the system, micro-organisms use the contaminants in the water for food and energy in a process called biological oxidation. This allows high levels of contaminants like hydrogen sulphide, iron, arsenic, ammonia, dissolved organic carbon, colour, and turbidity to be reduced without using chemical oxidants. Biological oxidation occurs very rapidly, which allows for high filter loading rates and a small plant footprint.

As the water flows through the filters, micro-organisms are constantly growing and reproducing as contaminants are continuously being digested. Additional particulate and colloidal matter is also reduced through filtration or entrapment within the excreted polymers of the attached organisms. Solids retention on biological filters is often 3 to 5 times greater than conventional oxidation filtration processes; however, eventually, there is an excess of micro-organisms and particles and the water flow begins to slow down. This affects only the flow of water, not water quality. Therefore, the process results in consistently high-quality water. Biofilters often run for periods of 1 week to 1 month between backwashes, resulting in less wastewater than most other filtration technologies.

During backwash, the filters are cleaned with water and gentle air scour in order to remove excess micro-organisms and built up particulates or solids. Backwash water must be unchlorinated and in some cases, untreated water can be used. The backwashing process is more of a rinsing or flushing and the low back wash rates required and rapid filter ripening following backwash increase the water production efficiency of the treatment plant. Micro-organisms remain attached to the filter media in the system even after backwashing, which allows the system to run continuously for an indefinite period of time, so as long as backwashing is carried out on a regular basis and no biocides or harsh oxidants are introduced.

In most cases, the wastewater can be sent directly to the municipal sewer system or to a holding tank where the solids can settle before final disposal. Unless chemical pH adjustment is required, there are no process chemical residues in the backwash waste and often wastewater can be discharged into a river or lake following settlement of solids subject to approval from the appropriate government authorities.

Filtration and backwash cycles can be manually or automatically controlled. Automatically controlled systems typically use programmable logic controllers and require almost no operator supervision; however, the operator is required to check the process airflow periodically and carry out laboratory analyses on the raw and treatment water.

Recovery of the filters after normal operational shutdowns of 1 to 12 hours or after a backwashing is rapid, generally requiring less than 10 minutes. It is recommended that a filter-to-waste cycle be employed on each start-up of the filter system following short-term shutdowns and backwashing to ripen the filter. For process shutdowns of several days, weeks, or even months, the restart time is significantly longer; however, it is

usually faster than the initial reactor seeding. If the medium is kept wet during a filter shutdown, it will recover more rapidly than if the filters are drained and allowed to dry out.

Biological filtration as pretreatment for reverse osmosis results in the removal of organics, promoting a stable operation of the membrane and a reduction of toxic organics, which in turn are not concentrated in the brine. Moreover, just as membrane filtration does not require chemical addition that can cause disinfection by-products, biofiltration works without chemicals that could cause membrane fouling. That makes membranes and biofiltration a sustainable combination of processes. One of the most beneficial effects of biofiltration as pretreatment for membranes is that reduced fouling enables a significant increase in the volume of water that can be treated before the membranes require cleaning. Where typically membranes require cleaning every two to three months, at some of the installations in Saskatchewan, membrane production has far exceeded a period of one year without cleaning. This should also significantly increase the lifespan of the membranes.

By removing ammonia, organics, and other reducing compounds, the finished water has a low disinfectant demand and a low disinfection by-product formation potential. This would allow free chlorine to be used for primary and secondary disinfection but at a much lower dose than what is currently being applied.

SIBROM water is now extremely pure and needs to be run through a mineral contactor, which adds some calcium and magnesium back into the water making it both healthy and non-corrosive. This water is still soft. Without the addition of calcium and magnesium to RO processed water, the water will be aggressive leaching out copper and lead out of plumbing. Another method is to add corrosion control inhibitor chemicals. This method adds both cost and makes the water less desirable to drink. It is interesting that some of these chemicals that are still freely used to treat drinking water in North America, are banned in Europe. Sapphire suggests the use of a pH contactor and stilling tank as part of a SIBROM system.

OVERVIEW

Finished Water Quality

The biological filters produce high quality water, with no nutrients or energy sources for bacteria or biofilms in the distribution system. With no nutrient or energy sources for bacteria in the water, the treated water reservoirs and distribution system will not become overburdened with biofilm forming bacteria. Reverse osmosis membranes are capable of rejecting practically all particles, bacteria, and organics, and are highly effective in removing total dissolved solids, sulphate, hardness, and heavy metals such as lead. By not using oxidants and by adding a disinfectant to a very high purity water, no disinfection byproducts are formed.

Ability to Meet Future Regulations

Biological filtration followed by reverse osmosis membranes limits the formation of disinfection by-products by removing most, if not all of the disinfection by-product precursors. Membranes also offer an absolute barrier to pathogens and particulate matter larger than the size-exclusion characteristics of the membrane. In some parts of the United States, this has resulted in membranes being awarded a greater number of disinfection credits, which corresponds to an even lower reliance on chemical disinfection. With the discovery of more disinfection by-products and continued stringency in regulations for both disinfection by-products and disinfectant residuals, this makes membranes very advantageous.

Biological filtration also reduces regulatory issues regarding the quality of process wastewater disposal as contaminants are consumed rather than concentrated.

Sustainability

Very low wastewater volumes make biological filtration an extremely efficient process which reduces pumping costs, and places less loading on the sanitary system. Increased production rates between backwashing also make it an excellent process in areas with limited water resources. This is somewhat offset by the recovery rate of membranes which the vendor consulted conservatively estimated to be 75%. However, biological filtration reduces the chemical demand to only low dosages of membrane antiscalant and chlorine and significantly prolongs the period between membrane cleaning, which should significantly prolong the life of the membranes.

Ease of Operations

Little to no chemicals significantly reduces operation and maintenance cost and creates a less hazardous environment for operators. Because the processes produce water with no nutrients or energy sources for bacterial growth in the distribution system, periods between distribution flushing can be prolonged.

Biological filtration is slow to react to rapid changes in the flow rate; therefore, biological treatment systems are designed so that water flows through the filters at a predetermined, relatively constant flow rate. High and low flows will need to be attenuated using potable water storage.

Biological filtration is also slow to react to changes in raw water quality, and close monitoring is required when water quality variances are expected to ensure the proper environment for each species of micro-organism is maintained; however, this is typically not a concern when dealing with groundwater. Membranes are also considered to be low maintenance.

The above discussion supports our recommendation that a Sapphire Integrated Biological and Reverse Osmosis (SIBROM) is the best available technology for water treatment.

Some general constituents of concern are:

TOTAL DISSOLVED SOLIDS (TDS)

Total dissolved solids (TDS) usually refers to the amount of minerals such as sodium, calcium, magnesium bicarbonate, sulphate, chloride, potassium, nitrate, and carbonate present in a water; however, it can also include dissolved organic matter. As a whole, total dissolved solids do not pose a direct health risk; however, individual ions may pose a health risk if present at sufficient levels.

Total dissolved solids in Saulteaux's raw and treated water exceed 800, the provincial aesthetic objective of 1500 mg/L; however, the Health Canada aesthetic objective and the United States Environmental Protection Agency secondary standard for total dissolved solids is only 500 mg/L. At levels above the aesthetic objective set by Health Canada, total dissolved solids in drinking water may lead to excessive hardness, mineral deposition and corrosion. Even at low levels, total dissolved solids affect the way water tastes.

Health Canada and the United States Environmental Protection Agency's more stringent guideline for total dissolved solids is an indicator that the Saskatchewan Environment's standard may also become more stringent during the design life of the facility.

NITROGEN AMMONIA

Free chlorine disinfection is favoured, particularly by small systems. However, if free chlorine is to be used for disinfection in water where ammonia is present, breakpoint chlorination must be achieved by adding enough chlorine to consume all the ammonia and produce a free chlorine residual. While iron, manganese, and dissolved organic carbon create a chlorine demand, ammonia creates a much larger chlorine demand.

Reactions between chlorine and contaminants in the water, including ammonia, occur over extended periods of time. In addition, the presence of chloramines interferes with free chlorine DPD testing methods often providing false positive test results for free chlorine. In order to ensure that all the ammonia has been consumed and a stable free chlorine residual exists, a large percentage of the chlorine residual at the end of the distribution system should consist of free chlorine.

In some cases, when water contains high levels of natural ammonia, chloramines may be favourable to free chlorine due to the high dose of chlorine required in order to create free chlorine. Chlorine readily reacts with ammonia to form monochloramine, dichloramine, and nitrogen trichloride. Chloramines have relatively weak disinfecting properties for inactivation of viruses and protozoa pathogens, and need to be used in conjunction with another disinfectant such as ozone, UV, or chlorine dioxide. Out of these, only chlorine dioxide is capable of providing a prolonged residual; however, chloramines are more stable than either free chlorine or chlorine dioxide in the distribution system and

consequently are more effective for controlling bacterial regrowth. Additionally, the chlorine dose required to create monochloramine, the chloramine of choice for disinfection, is less than half of that required to create a free chlorine residual, which should significantly reduce the amount of trihalomethanes and haloacetic acids formed.

The downside to using chloramines for disinfection when high levels of natural ammonia are present is that residual ammonia entering the distribution system can promote the growth and provide a source of food for nitrifying bacteria. Nitrifying bacteria convert ammonia into nitrite, then nitrite to nitrate. Nitrates will convert back into nitrites in conditions of low oxygen. Once ingested, natural body processes readily convert nitrate to nitrite. High levels of nitrite in the body can cause methemoglobinemia, an illness in which nitrite interferes with the transport of oxygen in blood in the body. Infants up to six months in age are particularly susceptible to the health risks associated with nitrite levels in drinking water. Raw water tests show 1.6 mg/L of nitrate in the distribution system. The variance of nitrate levels could be an indication that nitrification is occurring in the distribution system. Measures to control nitrification include minimizing the amount of ammonia entering the distribution system, increasing the disinfectant dose, removing organic compounds at the water treatment plant, and implementing a regular distribution flushing program.

N-nitrosodimethylamine (NDMA) is an emerging disinfection by-product of interest that has been connected to the use of chloramines (and in some cases, ozone). Studies have investigated the formation of N-nitrosodimethylamine via a reaction between chlorine, ammonia, inorganic nitrogen (nitrates, nitrites), and organic nitrogen (amines and amino acids). N-nitrosodimethylamine has been classified as “probably carcinogenic to humans” by the International Agency for Research on Cancer and is perceived to have an even greater impact on public health than trihalomethanes as a result of its carcinogenicity and toxicity. Some health effects connected N-nitrosodimethylamine include headache, fever, nausea, jaundice, vomiting, dizziness, damage to the liver and kidneys, and internal bleeding.

Environment Canada concluded that N-nitrosodimethylamine is considered to be entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health. Based on this conclusion, N-nitrosodimethylamine was added to the List of Toxic Substances of Canadian Environmental Protection Act 1999 on May 15, 2003. Nitrosamines are currently included in the recently announced Health Canada’s Drinking Tap Water Survey and are listed as a priority pollutant in the United States Environmental Protection Agency’s Unregulated Contaminant Monitoring Rule 2. These two studies require public water systems to gather occurrence data of N-nitrosodimethylamine levels in the finished water and distribution systems. This data will be used to support in regulatory assessment and decisions.

While neither Health Canada nor the United States Environmental Protection Agency has yet to set a federal standard, the absence of federal standards for N-nitrosodimethylamine has prompted provinces and jurisdictions to set their own action limits. First detected in

municipal drinking water in Ontario in 1989, the province of Ontario has set an interim maximum acceptable concentration of 9 ng/L (0.009 ug/L or 0.000009 mg/L) for N-nitrosodimethylamine for drinking water and an interim Provincial Water Quality Objective for the protection of surface water of 15 ug/L. The province of Quebec set a surface water quality criterion of 0.69 ng/L (0.00069 ug/L or 0.00000069 mg/L) for the prevention of contamination of water and aquatic organisms. The Regional Municipality of Waterloo and the City of Ottawa have both implemented maximum discharge limits of N-nitrosodimethylamine in their respective sanitary system by-laws.

California's Department of Health Services set a notification limit of 10 ng/L (0.010 ug/L or 0.000010 mg/L) and a public health goal of 3 ng/L (0.003 ug/L or 0.000003 mg/L) for N-nitrosodimethylamine in drinking water, and a 10 ng/L (0.010 ug/L) notification level for two other nitrosamines, N-nitrosodiethylamine (NDEA) and N-nitroso-n-propylamine (NDPA). Delaware, District of Columbia, Maryland, Pennsylvania, West Virginia, Virginia, Arkansas, Louisiana, New Mexico, Oklahoma, and Texas have set a non-enforceable limit for N-nitrosodimethylamine in tap water of 0.42 ng/L.

Several studies have and continue to be conducted to better understand how N-nitrosodimethylamine is formed and how it can be treated. Once formed, N-nitrosodimethylamine is highly soluble and cannot effectively be removed by activated carbon, adsorption, ozone, or biofiltration. At this time, UV is currently considered the best available technology, as treatment can decompose N-nitrosodimethylamine back to its precursors. However, at doses in the order of 1,000 mJ/cm² which is approximately 25 times greater than that required for equivalent *Cryptosporidium* inactivation, UV treatment is expensive. Suspended solids, organics, iron, alkalinity, and hardness, all of which are prevalent in Saskatchewan groundwater, will also affect overall UV effectiveness. As UV simply decomposes N-nitrosodimethylamine back into its precursors, it is possible for the N-nitrosodimethylamines to regenerate within distribution systems. One study of interest tested 20 Alberta municipal drinking-water distribution systems for the presence of N-nitrosodimethylamine and seven other N-nitrosamine species. Analytical results revealed the occurrence of N-nitrosodimethylamine (up to 100 ng/L) as well as two other N-nitrosamines (N-nitrosopyrrolidine and N-nitrosomorpholine) within select Alberta drinking water supplies.

Advanced oxidation with UV and hydrogen peroxide can prevent formation and re-formation of N-nitrosodimethylamine by destroying precursors, and can also destroy N-nitrosodimethylamine once it is formed, though the use of hydrogen peroxide may interfere with maintaining disinfectant residuals in drinking water systems. Reverse osmosis has been shown to remove approximately 50% of N-nitrosodimethylamine. However, as with other disinfection by-products, it is best to remove the precursors to avoid N-nitrosodimethylamine formation altogether. In order to avoid excessive chlorine demands which can lead to trihalomethanes and haloacetic acids in the presence of organics, and the issues surrounding the use of chloramines to provide prolonged

disinfection residuals in the distribution system, it is recommended that levels of ammonia in the raw water supply be reduced. Methods of reducing ammonia include air stripping with pH adjustment, ion exchange, biological filtration, and reverse osmosis.

ORGANIC CARBON AND DISINFECTION BY-PRODUCTS

Generally, the current water treatment processes are unable to reduce dissolved organic carbon. Organic carbon is not regulated by any of the water authorities; however, high levels of organic carbon can sometimes cause color, affect chemical oxidation, and can hinder the filtration process. More significantly, naturally occurring organic material can react with selected disinfectants to form disinfection by-products. Currently, trihalomethanes and haloacetic acids are the two major groups of chlorinated disinfection by-products monitored in drinking water supplies. Generally found at the highest levels, together, these two groups can be used as indicators for the presence of all chlorinated disinfection by-products in drinking water supplies, and their control is expected to reduce the levels of all chlorinated disinfection by-products and the corresponding risks to health.

The four most common trihalomethanes typically found in water are chloroform, bromoform, bromodichloromethane and dibromochloromethane. Although the trihalomethanes guideline applies to the total concentration of all four, the guideline is based on health effects of chloroform which has the highest solubility in water of the four and is usually present in the highest concentration in drinking water. Increases in temperature, pH, and chlorine dose all contribute to an increased likelihood for trihalomethane formation. Prolonged consumption of drinking water containing high levels of trihalomethanes has been linked with diseases of the liver, kidneys, bladder, or central nervous system, and may result in an increased likelihood of cancer. A small risk exists for trihalomethane exposure via inhalation while showering, bathing or washing clothes and dishes. Health Canada and Saskatchewan Environment have established a maximum acceptable concentration for total trihalomethanes in drinking water of 0.1 mg/L (100 ug/L) based on an annual average. This is higher than the current United States Environmental Protection Agency regulation of 0.08 mg/L.

The presence of bromide in a water supply can influence the type of trihalomethane formed. Health Canada has created a separate guideline for bromodichloromethane in drinking water of 0.016 mg/L (16 ug/L). Bromodichloromethane can be used as an indicator of the presence of other brominated trihalomethanes in drinking water. Animal data has consistently shown significantly higher levels of toxicity for brominated disinfection by-products than chlorinated disinfection byproducts.

The haloacetic acids most commonly found in drinking water are monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. When consumed in drinking water, haloacetic acids are easily absorbed into the bloodstream. Links have been made between exposure to concentrations above the regulatory limits and injury to the liver, kidney, eyes, nerves and the reproductive system. Health Canada's maximum acceptable concentration of haloacetic acids in drinking water

is 0.08 mg/L. This is higher than the United States Environmental Protection Agency regulation of 0.060 mg/L. Saskatchewan Environment is expected to adopt Health Canada's limit in the next year.

The most common method of disinfection by-product control is removing the organic matter from the water before chlorine is added, by optimizing the disinfection process, by using alternative disinfection methods, or by using a different water source. Methods of removing organic precursors include coagulation, sedimentation, and filtration; adsorption; ion exchange; membrane filtration; and biological degradation. Depending on other quality characteristics of the source water, alternative disinfectants can sometimes limit disinfection by-product formation. These include chloramines, chlorine dioxide, ozone, and ultraviolet irradiation, better known as UV. In some cases, trihalomethanes can be removed after they have formed via aeration and activated carbon filtration; however, the efficiency of these processes is generally limited. Regulatory authorities recommend that every effort be made not only to meet the guideline, but to maintain concentrations of as low as reasonably achievable without compromising the effectiveness of water disinfection.

Biological pre-treatment allows the use of RO membranes without damaging the membranes. Longevity of the RO membranes in the SIBROM process is expected to be longer than 10 years.