

BMPs for the Control of Disinfection By-Products

Issue:

Long-term exposure to disinfection by-products in drinking water (and possibly short term exposures in pregnancies) may pose a health risk to the population of Newfoundland and Labrador. Mitigative measures can be taken to help reduce disinfection by-products to below guideline levels for new, upgrading and existing water distribution systems.

Background:

Provincial guidelines require that water supplies be disinfected and maintain a disinfectant residual in the water distribution system in order to ensure the destruction of potentially harmful pathogens. Chlorine is the most commonly used form of disinfectant in the province. Disinfection by-products (DBP) are chemical compounds formed by the reaction of a water disinfectant with a precursor in a water supply system. DBPs are undesirable in drinking water as there is some evidence that long-term exposure may cause health risks. While minimizing disinfection by-products is important, the risks of not disinfecting water far outweigh the risks created by disinfection by-products. There is a wide array of mitigative options available to deal with DBP issues, and any action taken to reduce one type of DBP is likely to help reduce other forms as well. The main DBPs of concern in Newfoundland and Labrador are trihalomethanes (THMs), bromodichloromethane (BDCMs), and haloacetic acids (HAAs).

THMs and HAAs have been identified as the two largest classes of DBPs detected on a weight basis in chlorinated finished water. THM and HAA levels tend to peak in the fall for most water distribution systems in the province. DOC is the most significant available predictor of THM and HAA formation potential in drinking water in the province followed by chlorine dosage. Reaction kinetics in the formation of DBPs are higher at warmer temperatures. The rate of formation of THMs is fastest in the initial hours after chlorine has been added and then slows down. THM formation can proceed for several days in a distribution system as long as there is free chlorine residual. BDCMs are more likely to occur in surface water sources with high bromide levels in exposed coastal areas. The majority of drinking water systems in the province that display high HAAs also display pH levels below the minimum guideline level of 6.5.

Best Management Practices:

BMPs for the reduction of DBPs in new, upgrading and existing drinking water systems may apply only selectively. The following are BMPs for the control of disinfection by-products in drinking water systems in Newfoundland and Labrador:

Policy Measures

- It should remain the mandate of any community with a centralized water distribution system to provide adequate quality drinking water to users; the onus for providing potable water meeting GCDWQ should not be placed on the water consumer.
- In very small and small communities with DBP levels significantly above the guideline value, a policy of point of use household treatment devices can be

implemented as a temporary or emergency measure. A temporary measure should be considered as lasting three months or less.

- More diversity in water disinfection methods should be promoted in the province.

Source Based Control Measures

- All existing, new and potential surface and groundwater supplies should be designation as Protected Public Water Supply Areas.
- Water source options and recommendations are conditional on water availability.
- Waters sources and source water intakes should be located as far as possible from the coastline and prevailing coastal winds. Water sources should be sited in locations sheltered (by trees, differences in elevations, berms, fences, etc.) from ocean salt-water spray, and prevailing westerly and coastal winds.
- The lower the level of DOC in surface water sources, the lower the formation potential for DBPs. Any source water with DOC greater than 2 mg/L can produce unacceptably high levels of DBPs with the addition of chlorine for disinfection. As a guideline, surface waters with a DOC less than 4.2 mg/L should be used as new source water supplies to minimize DBP formation potential. DOC levels between 0 and 4.2 mg/L represent the 1st quartile of the range of DOC levels in surface water sources across the province.
- Reservoirs filled by small streams/springs and groundwater sources are the preferable source water type when trying to maintain DBPs within guideline levels.
- Groundwater and surface waters should not be mixed in the same distribution system if the only source of treatment is disinfection through chlorination as this significantly contributes to the formation of THM species (BDCMs). Mixing should only be allowed if there is either significant removal of natural organic material, bromide or both.
- Where a land area is to be flooded to create a surface water reservoir, vegetation must be removed from the area prior to inundation as per permit requirements. Where a vegetated area has already been flooded to create a source water reservoir, water levels should be lowered and vegetation removed if DBP levels warrant. Alternatively, methods to remove vegetation without lowering water levels can be investigated.
- Shallow ponds with long fetch lengths in the direction of prevailing winds should be avoided as water sources.
- The optimal type of surface water intake is one that permits varying the depth of water withdrawal to alternate with seasonal changes.
- The intake should be located off the bottom of the waterbody to ensure conduit openings are not clogged by bed-load deposits (silt, sand, gravel, debris), and deep enough below the water surface to ensure submersion during extreme low water events.
- The optimal depth for an intake structure is below the summer thermocline, typically in deeper water, but not at the lowest level in the waterbody.
- Horizontal intake filtration berms have a negligible effect on reducing DBP precursors.

- Where a high quality drinking water source is available either as a primary, secondary, or emergency supply, use of this source should be made to lessen the formation potential of DBPs, especially during periods of maximum DBP formation potential, typically summer and fall.
- Any potential new water source that is to be disinfected with chlorine should have a chlorine decay rate test and THM formation potential test performed at an accredited laboratory prior to final selection, development and commissioning of the new source. If THM formation potential under reasonable worst case scenario conditions (temperature, pH, DOC, time, chlorine) based on known system conditions is greater than 150 µg/L, consideration should be given to abandoning the source if a more viable source is available, or treatment options or alternative disinfectants made a requirement for that drinking water system.

Chlorine Demand Management

- The maximum residual disinfectant level in any drinking water system should not exceed 4.0 mg/L. Chlorine residuals above this level can cause known or expected health risks such as eye nose irritation and stomach discomfort.
- A detectable free chlorine residual should be considered anything greater than or equal to 0.05 mg/L unless accompanied and confirmed by a total residual chlorine test. A free chlorine residual of 0.02 mg/L may be acceptable if total chlorine residual confirms presence and removes the possibility of tester error.
- A contact time or CT factor value for inactivation of *giardia* should only be used when the distribution system has experienced a previous *giardia* contamination event and relies on chlorine disinfection as its only form of treatment.
- The chlorine dosage should be kept as low as possible while still maintaining required primary and secondary disinfection objectives. If chlorine residuals at all points (particularly end points) in the distribution system are typically over 0.1 mg/L, there is potential to reduce the chlorine dosage to achieve “detectable” levels. Typical chlorine dosages for drinking water disinfection in the province range between 2-15 mg/L. High chlorine demand results in a high chlorine dose.
- The application point of the chlorine dose should be as close to the first user as possible while still achieving primary and secondary disinfection objectives.
- A buffer above the minimum contact time and CT value should be incorporated into the required primary disinfection objectives for chlorine to take into account future developments either down-pipe or up-pipe of the design *First User*. The buffer should not exceed 2-10 times the minimum contact time or CT value.
- Chlorination systems should be located down-pipe of water storage tanks in systems where a sufficient contact time or CT value is available. This may increase system maintenance requirements. The placement down-pipe of the tank depends on system hydraulics and the location of the tank.
- Once an optimal point of chlorination has been identified based on an established *First User* location, future residential, commercial, institutional or industrial development up-pipe of this *First User* site should be restricted, or provision for the relocation of the chlorination system made.

- Calculation of CT factor values and contact time is important for system design purposes and should be reviewed regularly with each season and with any new developments on a distribution system.
- For calculation of the CT factor value, worst-case scenario conditions should be evaluated: the contact time at peak daily flow should be used, and the minimum observed chlorine residual (within the normal observed range) at the first point of use for the period of interest.
- THMs in the province tend to peak during the fall and are relatively high during the spring and summer in response to peaks in THM precursors. THMs are at their lowest during the winter. Chlorine demand is at its highest during the spring and at its lowest during the winter. Adjusting chlorine dosage, or targeting the use of other specific corrective measures (flushing, bleeding system, not mixing groundwater with surface water, use of deeper intakes, reducing tank storage capacity, use of POE/POU devices, etc.) during periods of highest THM formation potential or highest chlorine demand may help reduce DBP formation.
- Where removal of DBP precursors is not possible, practical or affordable, lowering the chlorine dosage (while still maintaining required primary and secondary disinfection objectives) can be used as a first response to high DBP levels.
- Chlorine boosters have limited application for reducing DBPs, and should only be used for this purpose where the initial chlorine dose is high or when the free chlorine residual reading at the first point of use is over 4.0 mg/L. The only potential a chlorine booster has for reducing DBPs is if the total combined chlorine dose from primary and booster chlorination systems is less than the chlorine dose from a single primary chlorination system.
- Water distribution systems with existing booster chlorination systems need to optimize their chlorine dosages so as to minimize overall chlorine use.
- On long distribution systems, chlorine boosters should be located relatively close to more densely populated areas.
- All communities using chlorine for disinfection should be equipped with at least two field chlorine test meter. Manual chlorine residual readings should be collected from multiple points on the distribution system on a daily basis as per Permit to Operate requirements. Values should be recorded and archived.
- All water distribution systems should be equipped with a flow meter. Communities should take regular flow meter readings (at least once a week), with values recorded and archived. Flow meters should be properly sized, sited, installed, maintained and calibrated.
- As a minimum, all communities disinfecting with chlorine should use flow meter readings and manual chlorine residual readings in order to make decisions concerning chlorine dosage control.
- Combined automated flow and residual analyzer control of chlorine dosage should only be considered for large communities or communities with dedicated and well-trained water system operators and well-maintained distribution systems.
- Chlorine residual feedback controls have limited application for reducing DBPs.

- Chlorine control using a fixed location residual analyzer can only optimize chlorine levels at a specific point, with mixed results (greater variation in chlorine residuals) elsewhere on the system.
- Automated flow and/or residual analyzer controls should not be installed with the expectation that they can replace water distribution system operators, or negate the need for manual chlorine residual readings.

Retention Time Management

- Water storage tanks contribute significantly to DBP levels in a distribution system due to dead zones, low water turnover rates, and poor circulation. These effects can generally be reduced by proper design and operation of storage facilities, such as appropriate tank sizing, inlet/outlet configuration, mixing, and operational schedule.
- Storage tank volumes should be minimized to avoid unnecessary storage. Stored water volumes should be optimized to meet requirements for storage, pressure and volume for fire fighting.
- Where the main purpose of a water storage tank is to provide pressure to the water distribution system, elevated storage tanks should be used as opposed to standpipe tanks.
- Tanks located at the beginning of the distribution system tend to reduce overall water age in the tank and distribution network, and reduce variability in chlorine residuals.
- The balance between supply from the pumps and network demand should be optimized in order to reduce the volume of storage required.
- Variation in water level in the tank should be maximized to force turnover of water in the tank.
- Systems with variable speed pumps or multi-pump installations can be configured to increase the pumping rate for a short period each emptying/filling cycle so as to increase the velocity at the tank inlet and improve mixing.
- When there are no issues involved (with supply, pressure or CT value), absolute storage capacity on a distribution system can be reduced by taking storage tanks off line or reducing the maximum water level in a tank.
- Tank design must incorporate the need for greater mixing through replacing a common inlet/outlet with separate pipes, installing baffles, moving the location or orientation of the inlet, increasing the distance between the inlet and outlet, reducing the diameter of the inlet, installing a duckbill valve to increase the velocity of the inlet jet, or installing a paddle or impellor devices to improve mixing within the tank.
- Water temperature stratification is an issue with above ground standpipe tanks.
- Water retention times in storage tanks should be minimized.
- Communities with slower DBP growth rates should be preferentially targeted for retention time management corrective measures.
- For water storage tanks with long residence times, aeration systems can be used to strip volatile DBP compounds from the water. With the installation of a water

storage tank aeration system, consideration must be given to the resulting loss of chlorine residuals.

Water Demand Management

- Effort should be made to locate new water connections, and manual and automated flushing sites on areas of the distribution network with high retention times so that demand is increased in these areas.
- Manual or automatic flushing for the control of DBPs must occur so that the period between flushing is less than the maximum retention time in the distribution system. A manual flushing program with a flushing frequency of more than once a day is not practical. System flushing is most appropriate on distribution systems with excess capacity.
- A distribution system can be bled continuously in order to lower retention times under certain conditions. Continuous bleeds are most appropriate on linear systems or systems with excess capacity.
- Flushing or bleeding the system is not practical where the distribution network has a contact time at peak flow close to 20 minutes.

Water Distribution system Operational and Infrastructural Measures

- Distribution system flushing can be used as a first response measure to water quality failures, including high levels of DBPs. One time flushing, however, can only be considered a short term response.
- Minimizing the number of shut valves required to produce a hydraulic boundary, and locating valves in areas with relatively high demand on either side of the shut valve can reduce retention times. Shut valves can be used in a network to re-route flows through parts of a system with low demand and high retention times. This may only be appropriate for larger water distribution systems.
- Continual system flushing (manual, automated or through a continuous bleed) and reducing overall system capacity (abandoning mains, downsizing mains) offers positive potential for reducing DBP levels, but must be weighed against water conservation needs, and contact time or CT factor requirements.
- Pumping water from one zone in a distribution system to another in order to re-circulate water can be used to reduce overall peak retention times.
- Decay of chlorine at the pipe wall is the leading contributor to overall chlorine decay in the distribution system. Pipe wall decay of chlorine can be reduced by regular system flushing, chemical flushing, swabbing, pigging or relining pipe. Chemically assisted flushing programs should be targeted to communities that are unable to achieve flushing velocities of 0.75 m/s without encountering negative pressures in the distribution system.
- Pipes greater than 25 years old, particularly unlined cast iron pipes, should either be replaced or relined if known to be contributing to water quality problems. Unlined and cast iron pipe should only be used if there is no reasonable alternative.
- New development in communities should be controlled so as to promote optimal water distribution system layout. Networks should be designed to avoid

- branching, to minimize the number of dead ends, and to maximize looping of the system.
- Looping of the distribution system is optimal on networks that do not display overcapacity or excessive water age.
 - The design of water distribution systems needs to reflect current long term declining population trends in the province when estimating future water demand.
 - Pipe size should be optimized to meet required hydraulic conditions.
 - Consideration should be given to a design guideline requiring the achievement of a daily peak water velocity for all pipes in a distribution system in the range of 0.2-0.4 m/s.
 - Centralized or regional drinking water systems are most appropriate in high population, high population density areas that are relatively flat with a deep soil profile for the laying of extensive pipeline.
 - Centralized or regional drinking water systems should include a water treatment plant if the population being serviced is medium to very large in size.
 - Centralized or regional drinking water systems require support from the communities involved and should have well trained, full time operators.
 - Only NSF approved chemicals and materials should be used in water disinfection and treatment.

Alternative Disinfectants

- Alternative disinfectants such as ozone, chloramines, UV and MIOX can significantly reduce the production of chlorinated DBPs.
- In order to provide a disinfectant residual in the distribution system, ozone and UV must be paired with a disinfectant that does leave a residual, such as chlorine.
- All disinfection methods, except for UV, will produce some form and level of DBPs.

Source Water Treatment

- Source water treatment for the targeted removal of DBP precursors provides the best assurance that DBPs will not form.
- Natural organic material can be removed to varying degrees using conventional, standard, and advanced treatment processes. Bromide removal requires advanced treatment processes.
- A water treatment plant (WTP) on a distribution system will not necessarily reduce THM levels if the WTP has not been designed specifically to remove DBP precursors or if the treatment system has not been adequately designed. WTPs in communities with DPB issues must be designed for the removal of DBP precursors.
- The practice of continuous pre-chlorination prior to any other form of treatment in the WTP should be discontinued. Depending on the treatment train, chlorine may be added before filtration, but never before coagulation and sedimentation. Pre-chlorination in conventional treatment plants may be necessary on a periodic cycling basis to deal with in-plant vectors such as algae growth and odour conditions.

- The most successful forms of treatment to reduce THM formation are chemical treatment (coagulation and flocculation, GAC), multi-media filtration, membrane (micro to nano) filtration, and reverse osmosis.
- Stand-alone pre-filtration systems (of pore size $>10 \mu\text{m}$) have no significant effect on reducing DBPs.
- To be effective in reducing DBPs, filtration systems (granular) must be in combination with chemical treatment, they must be appropriately sized and maintained (all types), or they must be of sufficiently small pore size (ultra-filtration, nano-filtration).
- pH adjustment has a limited effect on reducing DBPs. pH adjustment should be optimized for each individual system and should occur post chlorination.
- Iron and manganese removal (preferably through the use of permanganate) offers positive potential for the reduction of DBPs through reducing chlorine demand and required chlorine dosage, and the oxidation of DBP precursors. Primary disinfection requirements must still be met with any reduction in chlorine dosage.
- Large scale advanced water treatment processes are not appropriate for very small and small sized water distribution systems in the province.

Point of Use/Point of Entry Measures

- Advanced water treatment technology may be appropriate in very small and small sized communities on a small scale in the form of Potable Water Dispensing Units (PWDUs).
- Collection of drinking water in containers from a centralized location (roadside springs, stores) is common practice in many communities of the province. Roadside springs are not reliable sources of safe drinking water and their use should be discouraged.
- PWDUs should not replace regular water distribution systems and should not replace regular water disinfection or treatment systems.
- There should be demonstrated community support for the installation of a PWDU.
- Household Point of Use and Point of Entry (POU/POE) treatment systems must be used and maintained properly by the consumer including cleaning, replacement of parts, and proper storage of treated water.
- POU/POE control measures may be applicable for very small communities that cannot afford any water treatment, as an interim solution to water quality problems while a more permanent solution is being sought, for situations where DBPs may be high for certain periods of the year, for houses located on parts of the distribution system that have extremely high residence times and known DBP issues. POU/POE devices are only effective if properly maintained.

Water System Design Measures

- The design of water distribution systems and water treatment plants is not static. New concerns, scientific knowledge, methods and innovations occur over time and those who design drinking water distribution and treatment systems must be flexible and knowledgeable enough to incorporate such changes.

- The NL *Guidelines for the Design, Construction and Operation of Water and Sewerage Systems* should be updated at least every 10 years.
- Distribution system modeling and water treatment plant modeling should be used as a tool in the design of water distribution and water treatment systems.

Operator Education and Training

- Operator education and training is an essential component of any DBP control methodology.
- Communities should require that their water system operators be certified.