Chapter 5
Preventative/Mitigative Measures

This chapter discusses various options which could be used to reduce THM levels in drinking water. These options fall in the following two categories:

1) Source Control Measures (SCM)
2) Point-of-Entry (POE) or Point-of-Use (POU) Control Measures

The source control measures (SCM) refer to THM control strategies at the source level which are generally in the form of joint initiatives of both municipal and provincial governments. On the other hand, the point-of-entry (POE) refers to control measures adopted by consumers at the main water line into the house, and point-of-use (POU) refers to options that can be utilized by consumers at individual water taps in the house.

In this report, emphasis will be placed on source control measures for public water supplies which could achieve the fundamental objective of providing safe drinking water to all consumers. The applicability and suitability of a particular measure or measures will be decided on a case-by-case basis through site-specific assessment and evaluation. Such decisions will be made in consultation with appropriate government agencies and municipalities.

5.1 *Control Measures by Municipal and Provincial Governments (SCM)*

The THM monitoring program has been successful thus far due to initiatives and mutual interest of both municipal and provincial governments. Both levels of government must continue to work together to improve the drinking water quality through the implementation of cost-effective and affordable THM control measures. There are a number of options which could be implemented to control THM levels. However, each water supply will differ with respect to the selection and effectiveness of control strategy in order to achieve the required level of THM reduction. Factors such as: precursor levels, actual seasonal THM levels or THM formation potential, the type of disinfectant in use, residual chlorine levels, pH, residence time, economic viability of proposed improvements/changes and the technical expertise/knowledge of the water system operator(s), must be taken into consideration in the selection of THM control option(s).

It is recommended that one of the following options or combination of options should be assessed on a case-by-case basis using a cautious, progressive and sequential approach:

1) Watershed Protection
2) Chlorine Demand Management
3) Removal of THM Precursors

4) Use of Alternative Disinfectants
5) Conventional Water Treatment
6) Assessment of Alternative Water Supply Sources

The first step in the selection and implementation of THM control strategies would be to select a group of public water supply systems from Table 4.3 as pilot projects, and assess the feasibility of various options. This is considered to be the most appropriate approach, as the majority of systems listed in Table 4.3 have adequate baseline information on seasonal and spatial trends, and those with THM levels above 100 µg/L would require the implementation of some form of preventative or mitigative techniques to reduce THM levels. A similar approach would be adopted for any new water supply systems which would exceed the THM guidelines.

THM reduction strategies will first be applied to water supply systems (Table 4.3) with the highest seasonal averages, followed by systems with medium seasonal averages and then systems with low seasonal values. The treatment technologies will be applied sequentially as listed above ranging from preventative to mitigative techniques. This will allow the implementation of cost-efficient and affordable THM reduction options. However, if these measures are not successful in achieving the required level of THM reduction, then the feasibility of other options would be considered.

The training and education of municipal operators to be initiated shortly by the Department of Environment and Labour will be highly beneficial in the implementation of source control measures by the municipal and provincial governments.

5.1.1 *Watershed Protection*

Watershed protection can play an important role in complementing the overall efforts of drinking water quality improvement. For this reason, it is essential for municipalities, in consultation with the provincial government, to adopt a pro-active approach to maintain the integrity of drinking water sources. It is a well-known fact that if raw water quality is improved, then the cost of other treatment options would be substantially reduced and their effectiveness increased.

It is recommended that municipalities assume stewardship of public water supply areas. Formation of Watershed Monitoring Committees and the development of Watershed Management Plans have proven to be useful tools to maintain the integrity of drinking water sources. The use of these tools should be assessed and pursued on a case-by-case basis.

5.1.2 *Chlorine Demand Management*

Chlorination is the most commonly used method of disinfection throughout the province. As stated in Section 2.1, chlorine is a very effective disinfectant, however, it has been found to react with organic matter present in the source water to form THMs. The chlorine demand management concept could be used to maintain the required level of residual chlorine throughout the distribution system while at the same time minimizing the formation of CDBPs, especially THMs. If successful, this could be one of the most cost-efficient and affordable solutions to reduce THM levels. The balancing of risks from microbial pathogens and chlorination disinfection by-products is one of the major challenges.

The literature indicates that the level of THMs formed in a water supply system, as measured at the consumption point, depends on a number of factors including the amount of organics in the source water supply, chlorine dosage, water pH, water temperature, season of the year, water demand, and residence time in the system. The relationship between the level of THMs and these factors is very complex. For example, water demand can affect residence time, which in turn can determine the amount of THMs formed, the level of which would depend on the amount of chlorine in the system. Of these factors, chlorine dosage is probably the only factor over which one can have some direct control. It is generally accepted that chlorine in water distribution systems will either decay due to reactions with compounds contained within the bulk water or due to reactions at the pipe wall. Hence, controlling the chlorine supply offers another THM control avenue.

A chlorine demand management strategy would generally consist of the following two approaches, either each on its own or both in conjunction:

(1) management of chlorine dosage at the water supply source, and
(2) use of satellite treatment, such as re-chlorination at storage tanks or multiple chlorine injection points along the water distribution system.

Management of chlorine dosage at the water supply source would include a set of guidelines on the ranges of chlorine dosages that could be adopted for various ranges of factors implicated in the formation of THMs such as water demand and season. By controlling the dosage at the source on the basis of THM causative factors, under- or over-supply of chlorine can be avoided. It is important that with this approach, the required level of chlorine residual, which is critical for preventing waterborne diseases and destroying pathogenic organisms, is maintained.

The use of satellite treatment or multiple chlorine injection points provides for lower chlorine dosage at multiple points. The objective in this approach is to distribute the chlorine dosage over the extent of the water supply system so that (a) the availability of chlorine for reaction with organics is optimized and (b) the “contact time” between chlorine and organics in the water is also optimized. Again, it is critical that in this approach the required chlorine residual is maintained.

These two approaches outlined above would be particularly applicable in existing water supply systems where significant infrastructure modifications or changes to other disinfectants are not feasible. The chlorine demand management strategy is, however, dependent on comprehensive modelling and analysis of the water supply system supplemented by adequate sampling for model calibration processes. EPANET is a computer program developed by the U.S. Environmental Protection Agency (EPA) for simulation of hydraulic and water quality behaviour (chlorine residual in particular) within drinking water distribution systems. EPANET can also be used to model the growth of chlorination disinfection by-products such as THMs, where the ultimate formation of THMs is limited by the amount of reactable precursor present. The modelling process however requires the determination of parameters such as the chlorine decay and THM growth constants. These parameters can only be determined from calibration using water sampling results.

The effectiveness of the model to simulate multiple chlorine injection points can be determined using data collected on the Placentia and Upper Island Cove water distributions systems. The two systems have booster chlorination points within the system. The Community of Comfort Cove has a fish plant. When the fish plant is in operation, the amount of chlorine injected at the water supply source is increased almost ten-fold. Data from this system can be used to assess the effectiveness of the model to simulate chlorine residual and THM growth due to changes in chlorine dosage. Based on the results of the sampling and model simulations, the effectiveness of using EPANET in chlorine demand management can be assessed.

An important side benefit of modelling and analysis of water distribution systems is that it can also be useful for the design of a water sampling program. The level of THMs formed has been shown to be spatially variable. Monitoring of THM levels and development of control strategies depend on judicious choices of sampling sites.

The selected systems for modeling purposes will represent various types of water systems covering distribution system characteristics, population serviced, geographic region and general characteristics of the raw water such as DOC, colour and pH. The modelling results could be used to develop guidelines for chlorine dose during different seasons of the year for different types of water sources.

5.1.3 *Removal of THM Precursors*

After assessing the effectiveness of watershed protection and chlorine demand management to reduce THM levels, it may be necessary to implement a non-conventional water treatment technology for a few water supplies. The main objective of this approach would be to remove THM precursors from the raw water. It has been reported in the literature that the removal of natural organic matter or precursors would result in substantial reduction of THM levels.

Infiltration gallery is considered a reasonable low cost, non-conventional option to reduce turbidity, suspended organic loading and possibly dissolved organic carbon. Typical construction of an infiltration gallery involves building a dam across a stream to form a natural pool and installation of perforated pipes in a bed of graded gravel and some form of multi-media filter such as activated carbon.

Anthracite has a highly porous surface with a large sorption capacity for many water impurities, including THM precursors such as DOC and colour. As the water passes through the gravel beds and multi-media filter, it becomes depleted in DOC and colour. Infiltration galleries that do not utilize a multi-media filter may possibly achieve a reduction in turbidity, however, they may not achieve a significant decrease in THM precursors.

As shown in Table 3.4, infiltration galleries have been implemented in a number of water supply systems across the province. Two of these galleries (Northern Arm and Twillingate) are of special interest as these have been provided with anthracite as one of the filter medias. The effectiveness of these galleries for precursor removal and consequent reduction in THM formation is under assessment. The results of these assessments will play an important role in the selection of infiltration gallery as one of the potential THM control options.

In some cases, THM precursors could also be reduced through some infrastructure modifications such as: changes in intake depth and installation of smaller sized screens.

5.1.4 *Use of Alternative Disinfectants*

The use of alternative disinfectants is another option that could possibly reduce THM levels in surface water supplies. It is important to note that the selection of the most appropriate disinfection technique is a site-specific decision unique to each water supply system. Such decisions must be made in consultation with government agencies and municipalities, and must take into consideration operator's skill and knowledge.

There are three key driving forces that must be balanced when selecting an appropriate alternative disinfection strategy for water treatment. These are as follows:

1) Providing water free of pathogen

> It is essential that an alternative disinfectant achieves the same level of disinfection (i.e. inactivate pathogens) as chlorination. The inactivation of pathogenic organisms must not be compromised.

2) Avoiding the production of DBPs

> As stated in Section 2.2, there are numerous other DBPs, in addition to THMs, that are formed during the use of disinfectants and their formation must be minimized.

3) Requiring residual disinfection to maintain the bacteriological quality in the water by controlling regrowth

> It is important that an alternative disinfectant can maintain a required residual level throughout the distribution system to control microbial regrowth.

In addition to these fundamental requirements, it is necessary to take into account other specific issues such as the economical and technical feasibility of switching to an alternative disinfectant. It is important to note that the use of an alternative disinfectant should only be considered if the previously stated THM control options (i.e. watershed protection; chlorine demand management; removal of precursors) are neither feasible nor effective.

As stated in section 2.1, there are numerous other disinfection techniques in use worldwide. The Environmental Protection Agency of the United States has prepared a guidance manual of alternative disinfectants and oxidants that provides in-depth technical and engineering information on numerous disinfectants. The main advantages and disadvantages of selected disinfectants are highlighted below. It is important to note that because of the wide variation of system size, water quality and dosages applied, some of these advantages and disadvantages may not apply to all systems.

Ozone

The use of ozone as a water treatment practice originated in Europe in the late 1800's. After many years of use throughout Europe, it was eventually introduced into North America. As of April 1998, it is reported that 264 operating plants in the United States use ozone. In Canada, the number of water supplies being treated with ozone is growing slowly. At present, there are two water treatment facilities in Newfoundland that utilizes ozone as a primary disinfectant. Ozone is a powerful oxidant with high disinfectant capacity.

Advantages:

- Ozone is more effective than chlorine, chloramines and chlorine dioxide for inactivation of viruses, *Cryptosporidium* and *Giardia*.
- Ozone oxidizes iron, manganese and sulphides.
- Ozone can sometimes enhance the clarification process and turbidity removal.
- Ozone controls colour, taste and odours.
- It is one of the most efficient chemical disinfectants because it requires a very short contact time.
- In the absence of bromide, halogen-substitutes DBPs are not formed.
- Upon decomposition, the only residual is dissolved oxygen.
- Biocidal activity is not influenced by pH.

Disadvantages:

- DBPs are formed, particularly by bromate and bromine-substituted DBPs, in the presence of bromide, aldehydes, ketones, etc.
- The initial cost of ozonation equipment is high.
- The generation of ozone requires high energy and should be generated on-site.
- Ozone is highly corrosive and toxic.
- Biologically activated filters are needed for removing assimilable organic carbon and biodegradable DBPs.
- Ozone decays rapidly at high pH and warm temperatures.
- Ozone provides no residual and chlorination will be required to maintain required residuals.
- Ozone requires a high level of maintenance skill.

Chlorine Dioxide

During the 1950's, chlorine dioxide was introduced as a drinking water disinfectant and is presently in use worldwide. Chlorine dioxide is a powerful oxidant, however, it may be more difficult to handle than other forms of chlorine and, therefore, trained staff are required to manage its use. Also, chlorine dioxide is very reactive and thus consumed so rapidly that it may not provide a residual disinfectant in the distribution system. Photochemical decomposition of ClO_2 in reservoirs may increase chlorate concentrations. The generation process used and water pH may also affect chlorate and chlorite levels.

Advantages:

- Chlorine dioxide is more effective than chlorine and chloramines for inactivation of viruses, *Cryptosporidium* and *Giardia*.
- Chlorine dioxide oxidizes iron, manganese and sulphides.
- Chlorine dioxide may enhance the clarification process.
- Taste and odours resulting from algae and decaying vegetation, as well as phenolic compounds, are controlled by chlorine dioxide.
- Under proper generation conditions (i.e. no excess chlorine), halogen-substituted DBPs are not formed.
- Biocidal properties are not influenced by pH.

Disadvantages:

- The process used with chlorine dioxide forms the specific by-products, chlorite and chlorate.
- Generator efficiency and optimization difficulty can cause excess chlorine to be fed at the application point, which can potentially form halogen-substituted DBPs.

- Costs associated with training, sampling and laboratory testing for chlorite and chlorate are high.
- Equipment is typically rented and the cost of sodium chlorite is high.
- Measuring chlorine dioxide gas is explosive, so it must be generated on-site.
- Chlorine dioxide decomposes in sunlight.
- Chlorine dioxide can lead to the production of noxious odours in some systems.

Potassium Permanganate

Potassium permanganate ($KMnO_4$) is a strong oxidizing agent used in many bleaching applications. It will oxidize most organic compounds and is often used to oxidize iron from the ferrous to the ferric form for ferric precipitation and filtration. Potassium permanganate is only available in dry forms for transportability. On-site, a concentrated $KMnO_4$ solution is generated for disinfection. Residuals of $KMnO_4$ are not desirable because of its tendency to give water a pink colour.

Advantages:

- Potassium permanganate oxidizes iron and manganese.
- It oxidizes odour and taste-causing compounds.
- It is easy to transport, store and apply.
- Potassium permanganate is useful in controlling the formation of THMs and other DBPs.
- Potassium permanganate controls nuisance organisms.
- The use of potassium permanganate has little impact on other treatment processes at the water treatment facility.
- Potassium permanganate has been proven effective against certain viruses.

Disadvantages:

- Long contact time is required.
- Potassium permanganate has a tendency to give water a pink colour.
- Potassium permanganate is toxic and irritating to skin and mucous membranes.
- No by-products are generated when preparing the feed solution, however, the dark purple/black crystalline solid can cause serious eye injury, is a skin and inhalation irritant and can be fatal if swallowed. Over-dosing is dangerous and may cause health problems such as chemical jaundice and drop in blood pressure.

Chloramines

The disinfectant potential of chlorine-ammonia compounds or chloramines was identified in the early 1900's. Chloramines were used regularly during the 1930s and 1940s for disinfection. However, due to a shortage of ammonia during World War II, the popularity of chloramination declined. Interest in chloramination as an alternative disinfectant has once again increased due to recent concern over chlorinated organics in water treatment and distribution systems, and the fact that chloramines form very few DBPs.

Despite the fact that chloramines possess certain advantages over other disinfectants (i.e. long residual effect; low production of DBPs), they are not widely used. Compared to chlorine and ozone, chloramines possess less potency as a germicidal agent and therefore requires longer contact times. Also, careful monitoring of the ratio of added chlorine to ammonia is essential. Failure to do so can result in odour and taste problems or biological stability of water in the distribution system. Excess ammonia (i.e. low chlorine to ammonia ratio) can promote growth of nitrifying bacteria, which convert ammonia to nitrates and nitrites. Ammonia dose must be tempered by any natural ammonia occurring in the raw water.

Advantages:

- Chloramines are not as reactive with organics as free chlorine in forming DBPs. The monochloramine residual is more stable and longer lasting than free chlorine or chlorine dioxide, thereby providing better protection against bacterial regrowth in systems with large storage tanks and dead end water mains. However, excess ammonia in the network may cause biofilming.
- Because chloramines do not tend to react with organic compounds, many systems will experience less incidence of taste and odour complaints when using chloramines.
- Chloramines are inexpensive.
- Chloramines are easy to make.

Disadvantages:

- The disinfecting properties of chloramines are not as strong as other disinfectants, such as chlorine, ozone and chlorine dioxide.
- Chloramines cannot oxidize iron, manganese and sulphides.
- When using chloramines as the secondary disinfectant, it may be necessary to periodically convert to free chlorine for biofilm control in the water distribution system.
- Excess ammonia in the distribution system may lead to nitrification problems, especially in dead ends and other locations with low disinfectant residual.
- Monochloramines are less effective as disinfectants at high pH than at low pH.
- Dichloramines have treatment and operational problems.
- Chloramines must be made on-site.

Peroxone (Ozone/Hydrogen Peroxide)

Peroxone is a new process of adding hydrogen peroxide to ozonated water. This increases ozone decomposition and produces high concentrations of hydroxyl radicals leading to efficient disinfection.

Advantages:

- Oxidation is more reactive and much faster in the peroxone process compared to the ozone molecular process.
- Peroxone is effective in oxidizing difficult-to-treat organics, such as taste and odour compounds.
- Peroxone processes have been shown to be effective in oxidizing halogenated compounds.
- The tendency to transform organic carbon compounds to a more biodegradable form may be increased with the addition of peroxide.
- Pumps used to house peroxide are not very large, so space requirements are not significant.

Disadvantages:

- Peroxide is a strong oxidant and contact with personnel is extremely dangerous.
- Peroxide can be stored on-site, but deteriorates gradually even when stored correctly.
- Peroxone as a disinfection process does not provide a measurable disinfectant residual. It is therefore not possible to calculate contact time (CT) similar to the use of other disinfectants.
- The ability of peroxone to oxidize iron and manganese is less effective than that of ozone.

Ultraviolet Radiation

Ultraviolet (UV) radiation inactivates organisms by absorption of the light which causes a photochemical reaction that alters molecular components essential to cell function. As UV rays penetrate the cell wall of the microorganism, the energy reacts with the nucleic acids and other vital cell components, resulting in injury or death of the exposed cells.

UV radiation has been found to be an effective disinfectant in treatment of relatively clean source waters. Historically, UV radiation has been adapted to disinfect reclaimed water, treated sewage, industrial process water and small groundwater supplies. Simplicity of installation, ease of operation and maintenance and low costs relative to chemical disinfection, make UV a useful small systems disinfection technology option.

UV radiation as a germicidal agent is effectively applied at a wavelength of 253.7 nanometres (or a range of 250-270 nanometres) through application of low-pressure mercury lamps. UV dose is expressed in units of milliwatt-sec per square centimetre (mW-sec/cm^2), the product of the intensity (I) of the UV lamp (mW/cm^2) and time (T) of exposure (sec).

Research has confirmed that UV effectiveness is relatively insensitive to temperature and pH differences, and that application of UV as a primary disinfectant (followed by chlorination or chloramination) does not contribute to DBP formation. In addition, UV application was found not to convert nitrate to nitrite or bromide to bromines or bromates.

However, it has long been observed that turbidity, natural organics, iron, calcium hardness suspended solids and other factors can reduce UV transmission and cause lamp fouling, thus lowering disinfection effectiveness.

In addition to pretreatment and/or automatic cleaning systems to remove above-cited dissolved and/or suspended materials, which can impede UV performance, a secondary disinfectant is necessary to provide a residual protection of water in distribution systems. Continuous dose measurement, remote alarms, automatic cleaning of UV components and annual UV sensor maintenance may also be important design components to prevent deposition or scaling and to minimize on-site operator attention.

Presently, there are two emerging UV technologies (Pulsed UV and UV Oxidation) that may become more popular in the years ahead.

Combined Disinfectants

The sequential or simultaneous use of two or more disinfectants have been used with increasing frequency in recent years. *Interactive disinfection* is considered an emerging technology. Combinations of different disinfectants are mostly categorized into primary and secondary stages. Primary disinfection refers to the inactivation of microorganisms to meet the regulatory bacteriological requirements and secondary disinfection refers to application of a disinfectant to meet regulatory requirements for distribution system bacteriological quality. By separating the inactivation function and residual disinfection function in water treatment, each can be optimized independently. Different combinations include: chlorine/chlorine; chlorine/chloramine; chlorine dioxide/chlorine dioxide; chlorine dioxide/chloramine; ozone/chlorine; ozone/chloramine; UV/chlorine; and UV/chloramine. Table 5.1 briefly comments on the above potential combinations of primary and secondary disinfectants.

In a study entitled "Complying with Trihalomethane Reduction Requirements in Water Treatment Facilities", eight utilities in five states (Florida, Indiana, Virginia, and North and South Carolina) were switched to alternative disinfectants to determine (a) the extent to which water treatment plants that had recently adopted the use of chlorine dioxide, ozone, potassium permanganate or chloramines to partially or fully offset the use of free chlorine have been able to

Table 5.1: Combined Disinfectants and Their Applications

Primary/Secondary Disinfectants	Typical Application	Comments
Chlorine/Chlorine	low THMFP raw water; low TOC; conventional treatment with optimal coagulation	most commonly used disinfection scheme effective system
Chlorine/Chloramine	moderate THM production situation; typically with conventional treatment	chlorine to provide disinfection and monochloramine to limit DBP formation
Chlorine Dioxide/Chlorine Dioxide	high DBP production; require filteration to remove *Cryptosporidium*; low chlorine dioxide demand in treated water	primary and secondary usage requires a limit on chlorine dioxide dose to reduce residual chlorate/chlorite.
Chlorine Dioxide/Chloramine	high DBP production; require filtration to remove *Cryptosporidium*;	primary chlorine dioxide dose limited to residual chlorate/chlorite stable, low reactive secondary disinfectant
Ozone/ Chlorine	moderate DBP formation; direct or no filtration; low THMFP	highly effective disinfection to achieve high log inactivation low THMFP to accept free chlorine
Ozone/ Chloramine	moderate DBP formation; direct or no filtration; low THMFP	highly effective disinfection to achieve high log inactivation low THMFP to require combine chlorine residual
UV/Chlorine	requires membrane treatment to provide effective *Giardia* and *Cryptosporidium* removal; UV only for virus inactivation; ground water disinfection; low THMFP	rare application but feasible in special circumstances little *Giardia* and no *Cryptosporidium* inactivation
UV/Chloramine	requires membrane treatment to provide effective *Giardia* and *Cryptosporidium* removal; UV only for virus inactivation; ground water disinfection; moderate THMFP	rare application but feasible in special circumstances no *Giardia* and *Cryptosporidium* inactivation

comply with the THM regulation; (b) the impact these modifications have had on other water quality parameters and other treatment objectives, such as disinfection, iron and manganese removal, and total organic halide (TOX) formation; and (c) the costs of these modifications and their impact on overall treatment costs.

The study of these facilities incorporated the historical record of THM compliance monitoring, the results of the research team's field sampling visits and the impact of the alternative disinfectant treatment modifications on finished water quality, treatment plant operations and performance, and cost.

Overall, of the eight facilities examined only two were able to successfully reduce the extent of THM formation to unequivocally demonstrate compliance with THM regulations, while the other six were able to reduce THM formation significantly but either were unable to clearly demonstrate that they consistently met the requirements of the THM regulations as a result of the modifications or encountered other difficulties in treatment plant operations in producing an acceptable finished water.

It is evident from this study that the use of alternative disinfectants to reduce THM levels is site-specific.

5.1.5 *Conventional Water Treatment*

In some circumstances, depending largely on the source water quality, it may be necessary to implement a conventional water treatment option in order to reduce THM levels significantly. Conventional water treatment options are known to be the most costly method of improving water quality, however, in most cases, these treatment options are very effective.

Specific water treatment methods vary from system to system, but they generally fall into one or a combination of the following general treatment methods.

1) **Chemical Storage and Feeding** - Chlorine (or an alternative disinfectant) is added to the incoming water to inactivate pathogenic microorganisms. Alum and lime may also be added. Alum concentrates suspended particles such as silt to aid their removal. Lime changes the pH level when required. The chemicals are mechanically mixed into the water before moving onto the flocculating basin.

2) **Flocculating Basin** - The flocculating basin stirs the water to concentrate suspended particles. The clumps of particulate which form are known as "floc".

3) **Settling Basin** - Heavy flocs drop out of the water in the settling tank and collect along the bottom. The settled floc is removed by scrapers which move along the bottom. The cleanest water

is left at the surface to be drawn off through spillways which lead to filtering basins.

4) **Rapid Sand Filters** - The water is already quite clear when it reaches the stacked layers of fine sand, activated carbon, gravel and rocks which form the rapid sand filters. The layer of sand removes fine bits of floc, algae and silt. The layer of activated carbon removes taste and odour producing chemicals from the water.

5) **Pure Water Basin** - The purified water goes into holding basins prior to distribution. Safe levels of chlorine are added to check the growth of algae and microorganisms. Lime may be added to control the pH level of the water. This protects the metal components of the distribution system from corrosion.

There are numerous conventional water treatment options available. The National Drinking Water Clearinghouse produced a technical brochure entitled “Treatment Technologies for Small Drinking Water Systems” that classifies the treatment technologies into the following categories:

1) Disinfection
2) Coagulation/Filtration
3) Ion Exchange and Demineralization
4) Organic Removal
5) Lime Softening/Corrosion Control

Each of these treatment technologies will be described briefly. More detailed information on all treatment technologies can be found in a book entitled “ Safe Water From Every Tap” produced by the National Research Council.

5.1.5.1 *Disinfection*

It is absolutely essential to disinfect surface water supplies in order to inactivate pathogenic microorganisms. Thus, disinfection is considered a conventional water treatment option. As was stated in Section 5.1.4, there are numerous forms of disinfectants, each with definite advantages and disadvantages.

5.1.5.2 *Coagulation/Filtration*

Conventional filtration includes chemical coagulation, rapid mixing and flocculation followed by floc removal by sedimentation or flotation. The clarified water is then filtered. Common filter media designs include sand, dual-media and tri-media. It is important to note that conventional filtration does not work properly if the coagulation chemistry is incorrect.

Slow Sand Filtration - The filter consists of a bed of fine sand approximately three to four feet deep supported by a one-foot layer of gravel and an underdrain system. It is a low-cost, simple to operate, reliable technology and it is able to achieve greater than 99.9% *Giardia* cyst removal. Slow sand filtration is not suitable for water with high turbidity. The filter surface requires maintenance. Extensive land is required due to low-flow operation. Biological processes and chemical/physical processes common to various types of filters occur on the surface of the filter bed.

Diatomaceous Earth Filtration - DE filtration, also known as precoat or diatomite filtration, relies on a layer of diatomaceous earth approximately 1/8th-inch thick placed on a septum or filter element. Septums may be placed in pressure vessels or operated under a vacuum in open vessels. The filters are simple to operate and effective in removing cysts, algae and asbestos. They have been chosen for projects with limited initial capital, and for emergency or standby capacity to service large seasonal increases in demand. This filter is most suitable for water with low bacterial counts and low turbidity.

Direct Filtration - All direct filtration systems include a chemical coagulation step followed by rapid mixing, and all exclude the use of a sedimentation or clarification step prior to filtration. Direct filtration is often used with steel pressure vessels to maintain the pressure in a water line to avoid repumping after filtration. Direct filtration is only applicable for systems with high quality and seasonally consistent influent supplies. Direct filtration requires advanced operator skill and has frequent monitoring requirements.

Membrane Filtration

- *Nanofiltration (NF)*: This membrane process employs pressures between 75 to 150 pounds per square inch (psi) for operation. While it provides removal of ions contributing to hardness (i.e. calcium and magnesium), the technology is also very effective for removing colour and disinfection by-product precursors.

- *Ultrafiltration (UF)*: Operational pressures range from 10 to 100 psi, depending upon the application. UF may be employed for removal of some organic materials from freshwater, and may be used for liquid/solid separation.

- *Microfiltration (MF)*: The major difference between UF and MF is membrane pore size. The primary applications for this membrane process are particulate and microbial removal.

Bag Filtration - Bag filtration systems are based on physical screening processes. If the pore size of the bag filter is small enough, parasite removal will occur. Unless the quality of the raw water precludes the need for pre-treatment, EPA recommends pre-treatment of the raw water using sand or multi-media filters, followed by preliminary bag or cartridge filtration, and the use of micron filters as final filters to increase particulate removal efficiencies and to extend the life of the filter.

Cartridge Filtration - Cartridge filters are an emerging technology suitable for removing microbes and turbidity. These filters are easy to operate and maintain, making them suitable for treating low-turbidity influent. They can become fouled relatively quickly and must be replaced with new units. Although these filter systems are operationally simple, they are not automated and can require relatively large operating budgets. A disinfectant is recommended to prevent surface-fouling microbial growth on the cartridge filters and to reduce microbial pass-through.

Backwashable Depth Filtration - Backwashable depth filters operate in part like cartridge filters. This method filters uncoagulated water and is designed to be backwashed when terminal head loss is attained or turbidity breakthrough occurs.

5.1.5.3 *Ion Exchange and Demineralization*

Ion exchange and membrane processes are becoming used extensively in water treatment. Ion exchange is primarily used to remove hardness ions such as magnesium and calcium, and for water demineralization.

Ion Exchange - IO units can be used to remove any charged (ionic) substance from water, but are usually used to remove hardness and nitrate from groundwater. Ion exchange effectively removes more than 90% of barium, cadmium, chromium, silver, radium, nitrites, selenium, arsenic and nitrate. Ion exchange is usually the best choice for removing radionuclides.

Reverse Osmosis - RO systems are compact, simple to operate, and require minimal labour, making them suitable for small systems where there is a high degree of seasonal fluctuation in water demand. RO can effectively remove nearly all inorganic contaminants from water. Properly operated units will attain 96 % removal rates. RO can also effectively remove radium, natural organic substances, pesticides and microbiological contaminants. RO is particularly effective when used in series. Water passing through multiple units can achieve near zero effluent contaminant concentrations.

Electrodialysis - Electrodialysis is very effective in removing fluoride and nitrate and can also remove barium, cadmium and selenium.

Some of the advantages are:

- all contaminant ions and most dissolved non-ions are removed
- it is relatively insensitive to flow and total dissolved solids (TDS) level, and
- it may have low effluent concentration.

Some of the limitations are:

- high capital and operating costs,
- high level of pre-treatment required,
- reject stream is 20 to 90 % of feed flow, and

- electrodes require replacement.

Activated Alumina - AA is a physical and chemical process in which ions in the feed water are sorbed to an oxidized AA surface. AA is used in packed beds to remove contaminants such as fluoride, arsenic, selenium, silica and natural organic matter.

5.1.5.4 *Organic Removal*

The technologies most suitable for organic contaminant removal in drinking water systems are granular activated carbon (GAC) and aeration.

Granular Activated Carbon - GAC has been designated as the best available technology (BAT) for synthetic organic chemical removal. Several maintenance and operational factors affect the performance of GAC. Contaminants in the water can occupy GAC adsorption sites, whether they are targeted for removal or not. Also, adsorbed contaminants can be replaced by other contaminants with which GAC has a greater affinity. Therefore, the presence of other contaminants might interfere with the removal of the contaminants of concern. Also, after a period of months or years, depending on the concentration of contaminants, the surface of the pores in the GAC can no longer adsorb contaminants and must be replaced.

Aeration - Aeration, also known as air stripping, mixes air with water to volatilize contaminants (turn them to vapor), which are either released directly to the atmosphere or treated and released. Aeration is used to remove volatile organic chemicals (VOC) and can also remove radon. A small system might be able to use a simple aerator constructed from relatively common materials instead of a specially designed aerator system. Aerators include:
- a system that cascades the water or passes it through a slotted container,
- a system that runs water over a corrugated surface, or
- an airlift pump that introduces oxygen as water is drawn from a well.

There are numerous aeration types available including Packed Column Aeration, Diffused Aeration, Multiple Tray Aeration, Shallow Tray Aeration, Spray Aeration and Mechanical Aeration.

5.1.5.5 *Lime Softening/Corrosion Control*

Various chemicals such as lime, lime-soda ash or caustic soda, may also be added during conventional water treatment as part of the lime softening process. This process raises the pH of the water sufficiently to precipitate calcium carbonate and, if necessary, magnesium hydroxide. Both calcium and magnesium ions in water cause hardness; hard water is undesirable for consumers because it can cause scaling problems in water heaters and soap lathers poorly in hard water.

Corrosion control is an essential consideration for water treatment. Operators can adjust the pH level of the water so that the least amount of corrosion takes place in the distribution system. It is important to note that operators must understand lime softening chemistry and pH measurements. Failure to maintain the proper pH in softened water prior to filtration at a lime softening plant could result in precipitation of excess lime in the filter beds and formation of calcium carbonate deposits within the filters.

5.1.6 *Assessment of Alternative Water Supply Sources*

Another THM control option is to consider the possibility of utilizing an alternative suitable public water supply (either surface water or groundwater). It is essential that the alternative supply has good source water quality with reasonable background levels of DOC and colour. Also, it is important to ensure that the environment surrounding the water supply has a minimum amount of competing land-use activities. Overall, a water supply with a low THM formation potential is needed.

5.2 *Control Measures by Consumers (POE or POU)*

Due to the increasing awareness of THMs in drinking water, consumers are actively seeking methods to improve the quality of drinking water. Consumers can choose to install a POE device that improves water quality at the main water line into the house, however, these devices are more expensive and require large filters. On the other hand, consumers can install a POU device that improves water quality at individual water taps in the house. POU devices mainly produce water that can be used for drinking and cooking. There are numerous makes and models of water filters available in the market today, however, **not all water filters can successfully reduce the amount of THMs in drinking water**. Filters which utilized activated carbon or reverse osmosis are considered to be the most effective filters in removing THMs.

Activated carbon filters utilize the process of adsorption to remove impurities from water. In general, adsorption is defined as the attraction and accumulation of a substance on a surface of another. In the case of activated carbon filters, the adsorption occurs between a liquid-solid interface. When water is subjected to an activated carbon filter, everything including the water is adsorbed, however, only certain molecules bind tightly to the activated carbon, while the binding of other molecules tend to be weak and reversible. For example, large organic molecules (e.g. volatile organic compounds) and non-polar substances (e.g. some inorganic chemicals) bind very tightly, while the molecules that comprise water bind weakly or not at all and simply flow through.

Reverse osmosis filters can also successfully remove THMs from drinking water. To understand the process of reverse osmosis, it is first necessary to know about osmosis. In general, osmosis is a process whereby a fluid diffuses through a semipermeable membrane to achieve an equal concentration of ions in the fluid on each side of the membrane. The force that moves fluid through a membrane is called osmotic pressure. In the case of reverse osmosis filters, a pressure greater than the osmotic pressure of the water entering the device forces a portion of the water through the membrane in the reverse direction and, therefore, improving its quality.

It is important when choosing a filtration unit to weigh the advantages and disadvantages associated with each type of filter. A reverse osmosis system may be effective in removing a wide range of contaminants, however, there are limitations. Primarily, if the incoming water is not very pure to begin with, the filter will clog quickly. Also, this process is very inefficient leading to the waste of significant amounts of water. An activated carbon filter is also effective in reducing contaminants from drinking water, but it also has limitations. Primarily, the activated carbon filter is not effective against microorganisms. The unit must be disinfected and maintained regularly to protect against the growth of microorganisms. With respect to both filters, it is also necessary to take into account the initial installation cost and subsequent maintenance cost as well. Most importantly, when the type of filtration unit has been decided upon, it is essential to purchase a filtration unit that is NSF certified for standard 53. NSF International is a third party tester. Some standard 53 certified units have the ability to remove THMs, however, some do not. Therefore, it is essential to determine that a unit has both standard 53 certification **and** the ability to remove THMs.

Consumers wishing to reduce their exposure to chlorination disinfection by-products can use a filter containing activated carbon certified to the NSF Standard 53 for THM removal. If a filter device is used it should be properly maintained because such devices can become sources of bacterial contamination in water. Although blending and boiling water will remove volatile (meaning easily evaporated) CDBPs such as THMs, they do not eliminate or necessarily reduce the health risks of other CDBPs that may not evaporate easily. As such, blending and boiling of water are not recommended by Health Canada as methods for reducing chlorination disinfection by-products. **It should be noted that no one method will eliminate all disinfection by-products in drinking water.**

Health Canada laboratories are currently testing a range of carbon filters and other treatment methods to see if they are able to remove most CDBPs. The results will be made public within a year. In the meantime, consumers can purchase water filters that reduce THM levels from local suppliers. Prices for properly certified filters range from $250 to $500 but consumers should compare prices and performance of units before making their decision.