Chemicals in Drinking Water

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CHEMICALS IN DRINKING WATER

Disinfection of drinking water is considered one of the greatest public health advances of the 20th Century. Water is disinfected to control microbial contamination that can lead to disease. Chlorination is the most common method of disinfection in Canada and this is the treatment method used by Toronto. Some chemicals found in drinking water are the result of the treatment process.

Chemicals enter drinking water supplies at many points before reaching the tap: from the source water, during the treatment process, and from the distribution pipes and the fixtures (Morris, 1995). Although pollution can result in the contamination of water supplies, most of the chemicals in the source water are naturally occurring minerals. Chemicals are also added to water during treatment. Some of these react with substances found in the water to form other chemicals, while some remain unchanged in the treated water. Chemicals that are found in the drinking water as a result of the disinfection process are called disinfection by-products (or DBPs). Lastly, as water passes through the pipes from the treatment plant to the point of use, it will dissolve some of the piping material, which then finds its way into the drinking water.

Concern that chlorinated drinking water could lead to cancer or to reproductive effects has resulted in research into ways to reduce levels of the main DBP – trihalomethanes (THMs) – found in chlorinated water and to consider ways other than chlorination to disinfect water. A factor that makes the assessment of the quality of drinking water difficult is that DBPs are complex mixtures that vary greatly in composition. This variation is the result of many interacting factors such as the characteristics of the source of the water, the daily and seasonal changes in the source water such as temperature, adjustments made in the treatment process, and the point within the distribution system. This report looks at the various technologies used to treat water and summarises the main concerns related to chemicals found in drinking water due to (1) substances in the source of drinking water, (2) the treatment process, and (3) the distribution system.

TORONTO'S WATER TREATMENT

All current modes of water disinfection result in by-products (Table 1). By-products of chlorination have been studied most extensively, whereas much less is known about the by-products from other methods of treatment. Many factors, including the hardness, acidity (pH) and temperature, will influence the levels of contaminants in the treated water. Given the complex chemistry, minimising unwanted by-products is a complex undertaking. Table 2 outlines some of the advantages and disadvantages of the major drinking water treatment options currently available. The choice of water treatment method is a delicate balance between risks and benefits as changes at one point in the treatment system have effects at another.

Toronto uses a combination of chlorination for primary disinfection followed by the use of chloramine for residual disinfection. Activated carbon filters are also used to help address the taste and odour problems that occur when warm summers lead to higher lake water temperatures. These carbon filters also help remove other pollutants such as pesticides.

The quality of drinking water in Toronto is regulated by the Ontario Drinking Water Protection Regulation. Among other requirements, this regulation sets out levels of chemicals that are allowed in drinking water. Health-related standards are based on the potential adverse effects to health. There are also aesthetic standards which are applicable to the taste, colour, and other non-health concerns of the treated water. In addition, operational guidelines indicate the optimum levels of specific parameters to ensure the effectiveness of the treatment process. The Water and Wastewater Services of Works and Emergency Services continuously monitors the quality of drinking water in Toronto. Monitoring data for 1999 were recently published in the "1999/2000 Review: Water - Toronto treats it with care".

CHEMICALS IN THE SOURCE WATER

Toronto gets its water from Lake Ontario. The intake pipes are located 1-3 km from shore and 15 metres below the surface. Toronto monitors over 300 different chemicals in its drinking water. Results of this monitoring show that many metals and most organic pollutants are below the detection limit. When they are found, they are well below provincial drinking water standards (Toronto, 2000).

Chemicals Related to Hardness:

Chemicals found in the source water can be both of natural origin and the result of pollution. Without chemicals in it, water would have no taste. Much of the taste of water is due to naturally occurring minerals. These minerals, salts of calcium, magnesium, strontium, iron, barium and manganese, are the principal contributors to hardness. Hardness due to carbonate and bicarbonate salts can be removed by boiling. Carbonate hardness results in scale deposits in hot water pipes and tea-kettles. Non-carbonate, or permanent hardness, the result of sulphates, chlorides and nitrates, cannot be removed by boiling.

Hardness is measured as calcium carbonate equivalent. Waters with levels less than 60 mg/L are considered soft, and above 180 mg/l as very hard. Waters with hardness of 200 mg/L are considered poor but are tolerated by most people. Hardness of over 500 mg/L is unacceptable for most domestic purposes. Hardness can be removed using lime or soda ash but this can result in high levels of sodium in the water. Therefore, to prevent excess consumption of sodium, when waters are softened, it is recommended that a separate unsoftened water supply is kept available for drinking purposes (Health Canada, 1979).

Water that is too soft can corrode pipes, resulting in high levels of metals (copper, zinc, lead cadmium) in the drinking water. In areas where the water is very hard, household pipes can get clogged with scale. Some studies show a possible health benefit from drinking hard water due to a lower incidence of heart and other diseases. The significance of these findings is still uncertain (Health Canada, 1979).

Toronto's water is moderately hard, with average level of hardness of 123 mg/L in 1999 (Toronto, 2000). Although this is higher than the Ontario Drinking Water Standard for hardness of 80-100 mg/L, it is not of health concern. The Ontario standard is based on aesthetic and other non-health effects such as scaling and scum.

Pollutants:

Arsenic, asbestos, radon, nitrates, pesticides and industrial pollutants are some of the chemicals of concern that can be found in water (Morris, 1995). Nitrates have been of concern in areas where the drinking water is derived from ground water. Nitrate levels in Toronto's water are about 25 times lower than the provincial drinking water standards of 10 mg/L. In 1999, only one of 113 pesticides monitored was found in Toronto's drinking water. This was atrazine. The average level of atrazine was 50 times below the provincial drinking water standard of 0.005 mg/L. Over 150 other organic pollutants are monitored. Geosmin and 2-methylisoborneol, which are linked to undesirable taste, were found at low concentrations. Other organic pollutants detected at trace levels in 1999 were: di-n-butyl phthalate, ethylbenzene, bis (2-ethylhexyl) phthalate, n-nitrosodimethylamine, phenol, toluene, and xylenes (Toronto, 2000). These trace amounts are well below levels of health concern.

CHEMICALS DUE TO WATER TREATMENT

Chlorination, the treatment method employed by Toronto, is still the most widely used method of disinfection. Several alternatives to chlorination have been advanced, of which ozonation is the most widespread. However, alternatives in some cases are not as effective as the use of chlorine to control microbiological disease organisms found in water and they also result in the creation of other by-products. The toxicity of many of these by-products has not been fully evaluated. As well, these alternatives do not eliminate the need for chlorine, which is still used in many water systems to provide residual disinfection in the distribution pipes. By-products of chlorination and the most common alternatives are listed in Table 1.

By-products of Chlorination:

Animal and epidemiological studies have suggested that some by-products of disinfection in chlorinated drinking water may cause bladder, rectal, and colon cancer. There are also some data that suggest that chlorinated drinking water could cause birth defects or reproductive effects (Health Canada, 1993). It has been estimated that 14-16% (160-165 cases) of bladder cancers in Ontario could be attributed to long-term exposure to drinking waters with high levels (over 100 μg/L) of chlorination by-products (Wigle, 1998). An Expert Working Group convened to advise Health Canada concluded that it was possible that chlorination by-products pose a significant risk to the development of cancer, particularly bladder cancer, and that this was of moderate public health concern. It also concluded that more research is needed before conclusions could be drawn on adverse reproductive effects. However, if these effects are confirmed, this could pose an important health problem as even a small excess risk could contribute to a large number of adverse outcomes (Mills, et al. 1998).

The most important group of compounds created during chlorination of drinking water are trihalomethanes (THM), in particular: chloroform, bromodichloromethane, chlorodibromomethane and bromoform. Of these, chloroform is usually found at the highest concentrations. These four compounds have been classed as possible carcinogens in humans. The available data link the drinking of chlorinated drinking water to bladder and colon cancer in humans (Health

Canada, 1993). Results from experiments in animals have not shown chloroform to cause birth defects, but there is limited data to indicate that other THMs such as bromoform and bromodichloromethane may be teratogenic.

The Canadian Drinking Water Guidelines for trihalomethanes are based on the toxicity of chloroform. This is the THM with the most available data and which is present at the highest level in drinking water. The other THMs are usually found at concentrations 10 to 100 times lower than that of chloroform. The interim Maximum Acceptable Concentration for THM is 100 µg/L. At this concentration the risk of cancer due to exposure to chloroform is estimated to be 3.64×10^{-6}. Levels of THMs have been decreasing in Toronto's water. The average THM concentration in Toronto's drinking water over the last ten years has been below 20 µg/L. In 1999 it was 11.5 µg/L (Toronto, 2000). This represents a cancer risk of less than 1 in 1 million, which is considered by many agencies as "de minimis risk".

Halogenated acetic acids (HAAs) are another family of organic chemicals that occur frequently in drinking water. Health Canada has yet to establish drinking water guidelines for haloacetic acids in drinking water. The US Environmental Protection Agency (EPA) has established drinking water levels for trichloroacetic acid based on its developmental toxicity and limited evidence of carcinogenicity in animals (63FR69389, 1998). The US EPA has classified dichloroacetic acid as a probable carcinogen based on liver tumours in mice and rats (63FR69389, 1998). A recent study also found that dichloroacetic acid (DCA) caused testicular toxicity (Boorman, 1999). In 1999, levels of HAAs in Toronto's water were 10 µg/L, below the US EPA maximum acceptable level of 60 µg/L (Toronto, 2000).

Other chemicals produced during chlorination include halogenated acetonitriles, chlorinated ketones, halogenated phenols, cyanogen halides and chloral hydrate and these are sometimes detected in drinking water. These chemicals generally occur at very low concentrations (less than 5 µg/l). There is little toxicity information available for these compounds, although halogenated acetonitriles have caused mutations in various assays (Boorman, 1999). Trace levels of some of these compounds have been detected in Toronto's water (Toronto, 2000). The health significance of these levels is not known since no health criteria have been set.

Chlorinated furanones have received attention because one member of this family, 3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone (MX), accounts for most of the mutagenicity found in chlorinated drinking water. Recent Finnish studies have shown that this chemical can cause cancer in several organs in rats. This chemical has not been evaluated in mice. MX occurs at low levels in some chlorinated drinking water but is more potent than other DBPs (Boorman, 1999). It is not possible to assess the significance of MX, or the need to monitor it at this time, as there is insufficient information to set a health guideline for exposure to this compound.

By-products from Chloramination:

Chloramine is a by-product of chlorination and, as in Toronto, may also be added to maintain residual disinfection in the distribution system. The use of chloramine results in lower concentrations of THMs than chlorine, but is not as strong a disinfectant as chlorine (Health Canada, 1996a).

Reported toxic effects of chloramine include possible effects on the immune system and damage to red blood cells of patients on dialysis. Monochloramine is classified as a possible cancer-causing agent in humans due to leukaemia observed in animals. Part of the eye irritation felt by swimmers in swimming pools may be due to chloramine. Health Canada has established a Maximum Acceptable Level for total chloramine in drinking water of 3 mg/L (Health Canada, 1996). While Toronto does not specifically measure chloramine in finished water, it does monitor total residual chlorine, which is known to be composed mainly of monochloramine. Average levels of total residual chlorine in 1999 were 0.92 mg/L.

Although chloramination reduces the levels of THMs it produces other by-products such as aldehydes, chlorophenols, chloropicrin, cyanogen chloride, haloacetic acids, haloecetonitrile, and haloketones. Chloramine results in higher levels of cyanogen chloride than does chlorination. The conversion of cyanogen chloride to cyanide and thiocyanate could be responsible for some chronic toxicity of drinking water disinfected using chloramine (Health Canada, 1996a). Cyanide has not been detected in Toronto's drinking water.

By-products from Alternative Treatment Technology:

Ozonation

The most commonly used alternative to chlorination is ozonation. Ozone is an excellent disinfectant and does not form chlorinated by-products (Health Canada, 1993). However it provides no residual disinfection to maintain water quality as it passes through the distribution system. It is therefore necessary to supplement ozonation with chlorination or chloramination. This results in many of the same by-products as in chlorination (Boorman, 1999).

A 1995 Health & Welfare Canada survey of Canadian drinking water found that systems using ozone had lower levels of THMs during the winter than chlorine-chloramine systems (as is used in Toronto). However, chlorine-chloramine systems had lower levels of THMs during the summer (See Table 3). When these levels are averaged over the whole year, water treatment using chlorine for primary disinfection followed by chloramine for residual disinfection had lower overall levels of THMs.

The main disinfection by-products from the use of ozone are bromates. These are also of potential health concern. Bromate is formed in the presence of naturally occurring bromine. At high levels it cause irreversible renal failure, deafness and death. In experimental animals, it caused kidney cancer. The interim Maximum Acceptable Concentration for bromate is 10 μg/L (Health Canada, 1999). Monitoring of 12 drinking water systems that use ozone in Québec found an average level of 1.71 μg/L (0.55-4.42) bromate (Health Canada, 1997a). Using Health Canada's (1997a) risk assessment, this is equivalent to a lifetime cancer risk of about 1 in 1 million, greater than the estimated risk from trihalomethanes (THMs) at levels found in Toronto's drinking water.

There are other by-products formed during ozonation, such as aldehydes, glyoxals bromoform, dibromoacetic acid, cyanogen bromide, formaldehyde (Boorman, 1999). These have not been fully evaluated (Health Canada, 1993).

Chlorine Dioxide

Chlorine dioxide is an effective drinking water disinfectant. Chlorine dioxide will produce lower levels of THMs than chlorine but will produce similar organic by-products as ozone (e.g., aldehydes, ketones). Significant by-products from the use of chlorine dioxide are chlorite and chlorate. These compounds can cause anaemia and effects on reproduction (Boorman, 1999; US EPA, 1999). The US EPA has established a maximum contaminant level goal of 80 µg/L for chlorite based on effects on the nervous system during pregnancy (63FR69389, 1998).

Ultraviolet Light

The use of ultraviolet light (UV) is effective against many bacteria and viruses and does not seem to form DBPs directly or affect the levels of DBPs that are formed when chlorine or chloramine is used for residual disinfection. However, small quantities of formaldehyde have been measured in waters treated with UV and some researchers have suggested that UV could result in similar by-products to those of ozonation or other oxidation processes (US EPA, 1999).

Aluminum in Drinking Water:

One of the best ways to control the levels of by-products in drinking water is to remove the precursors. Coagulation is the most common method used to remove organic matter and other dissolved solids from the water. Alum or aluminum sulphate is used to help remove organic and other matter that are found in natural waters, including disease-causing micro-organisms. Levels of aluminum in drinking water are therefore often higher in the final drinking than in the source water.

The removal of colour and organic materials makes disinfection more effective and reduces the amount of by-products from chlorination. Alternative coagulants such as iron chloride and polyaluminum sulphate will result in lower aluminum residues in the water, but they are not always effective (Health Canada, 1998). In 1999, levels of aluminum in Toronto's drinking water ranged from 0.019 to 0.29 with an average of 0.063 mg/L (Toronto, 2000). The Ontario Drinking Water Standard for aluminum is 0.1 mg/L.

Aluminum is the most abundant metal on Earth. Surface waters can contain up to 2.25 mg/L of aluminum. Aluminum has no known beneficial effects in humans. At high doses it is neurotoxic in animals. The role of aluminum in human diseases such as amyotrophic lateral sclerosis, Parkinson's dementia and Alzheimer's Disease is not clear. Food is the major source of aluminum in the human diet, with water contributing about 3 percent of the total. What is not known is whether the form of aluminum in drinking water is more readily absorbed than the form in food. Health Canada (1998) concluded that there was insufficient information to support setting a health-based guideline for aluminum in water as there is no indication that aluminum in levels found in drinking water contributes significantly to the total aluminum burden. However, it cautions that, due to the uncertainty, efforts should be made to keep levels of aluminum in treated water as low as possible.

Other Methods of Precursor Removal:

Other ways to remove THM precursors include enhanced coagulation, granulated activated carbon (GAC) filters, or membrane filtration. The effectiveness of precursor removal varies with different source waters and treatment techniques and does not necessarily replace the use of aluminum compounds (US EPA, 1999). Strong oxidants may play a role in disinfection and by-product control strategies. Several strong oxidants, including potassium permanganate and ozone, may be used to control precursors. For example, potassium permanganate can be used to oxidise organic precursors at the beginning of the treatment process, thus minimising the formation of by-products at the later disinfection step of the plant (US EPA, 1999).

Granulated Activated Carbon

GAC adsorption can be used following filtration to remove additional organic matter. There are several limitations. The need for frequent regeneration of the filters and long contact times make the use of GAC expensive. When pre-chlorination is used, the chlorine rapidly degrades the filters. Under some conditions, there is also the possibility that previously adsorbed compounds leach from the filters into the treated water (US EPA, 1999).

Membrane Filtration

Membrane filtration has been shown effective in removing precursors in some instances. Significant limitations in the use of membranes include disposal of the waste brine generated, fouling of membranes, cost of membrane replacement, and increased energy cost (US EPA, 1999).

Ozonation

Research has also been done on the use of ozone to reduce the levels of precursors. Results have been very variable, and under some conditions ozone could actually increase the levels of precursors. Variables that seem to determine the effectiveness of ozone include dose, pH, alkalinity, and the nature of the organic material (US EPA, 1999). In combination with additional biological filtration, the use of ozone might improve drinking water quality but this would make the treating water process more complex and expensive.

Fluoride:

Some waters are naturally high in fluoride, and in other cases fluoride is added to help prevent dental caries. Since high exposure to fluoride can result in a condition called fluorosis, some people have expressed concern over the practice of adding fluoride to drinking water. A person who is exposed to too much fluoride can get dental fluorosis. In its mild form, this is a discolouring of the teeth and is considered an aesthetic effect. Higher exposures can result in a weakening of the tooth enamel. Skeletal fluorosis, which weakens the bones, will occur at even higher levels of exposure. A recent review of fluoride in drinking water concluded that fluoride in drinking water could reduce the number of caries. The only negative effect of fluoridation was the potential for an increase in dental fluorosis (McDonagh, 2000). Another recent study found no adverse effects on bones or fractures in the elderly (Phipps, 2000).

There are animal studies that indicate a potential for adverse effects on reproduction due to exposure to fluoride. However, data in humans have not found such adverse effects. For example, a study in the US found a lower number of birth defects among women who took fluoride supplements. A US National Toxicology Program cancer study found an increase in bone cancer due to exposure to fluoride. Health Canada (1997b) concluded that the existing studies do not support an association between fluoridation and cancer. The CEPA review of fluoride concluded that the available data on carcinogenicity were inconclusive. It established a tolerable daily intake (TDI) of 122 µg /kg per day based on prevention of dental fluorosis in children.

In addition to water, Canadians are exposed to fluoride in toothpaste, food supplements, fluoride mouth rinses, and fluoride gels used by dentists. Using the TDI established under CEPA, Health Canada (1997b) concluded that drinking water containing 0.8 to 1.0 mg/L of fluoride combined with average daily fluoride intake from other sources should convey the beneficial dental effects of fluoride. At the same time, this level should provide protection from the adverse effects that can occur at higher levels of exposure. Fluoride is now added to Toronto's drinking water to achieve a level of 0.8 mg/L. This level was set in consultation with the Medical Officer of Health.

CHEMICALS FROM THE DISTRIBUTION SYSTEM

The materials from pipes, joints and fixtures can leach into the water as it passes through the distribution system. Examples of these are: asbestos (from concrete-asbestos pipes); iron, copper and lead (from metal pipes and fixtures); polyvinyl chloride (PVC) and, polyethylene (from plastic pipes) (Morris, 1995). The leaching of metals from pipes and fixtures into the drinking water is more of a concern in soft than hard water. The fact that Toronto's water is relatively hard helps minimise the amount of iron, copper and lead that finds its way into the drinking water.

Both copper and iron are considered essential elements but can be toxic at high concentrations. Levels in drinking water for these metals are limited in order to prevent problems with taste and soiling, rather than on health considerations.

The primary sources of lead exposure are food, soil and dust. At very low levels, lead in children causes IQ deficiencies, reading and learning disabilities, impaired hearing, reduced attention spans, hyperactivity, anti-social behaviour and other problems. Prolonged exposure to even a small amount of lead may have some impact on intellectual and neurological development of the foetus, infant and young children as well as reproductive effects in adults (Health Canada, 1996b).

Levels of lead in tap water increase with the length of time the water is left standing in the pipes. Unless they have been replaced, homes built before 1950 can still have leaded pipes. In some cases, this can result in high levels of lead in the drinking water. Solders used to connect the pipes can also leach lead into the water. Under the Ontario Building Code, it is no longer permitted to use lead solder in pipes. Under the City’s Water Service Repair Program, homeowners, schools and city-owned facilities can apply for the replacement of lead or galvanised pipes that service their properties. It is also possible to reduce lead exposure from drinking water by flushing standing water from the plumbing system (i.e. running the taps until the water gets cold) and avoiding the use of hot water for drinking or cooking.

CONCLUSIONS

The drinking water treatment process being used by the City of Toronto is providing good quality water to the city. There has been a steady improvement in the quality of drinking water over the past ten years in Toronto. Although the levels of chemicals in Toronto’s drinking water may still present a small risk to health, these risks must be balanced with the risks that would occur from untreated or inadequately treated water. Water and Wastewater Services of Works and Emergency Services learns from the on-going research efforts on water treatment technology and strives to continually improve the quality of Toronto’s drinking water.

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Table 1: By-products of Disinfection

By-products formed by chlorination	

THMs
  Chloroform
  Bromodichloromethane
  Chlorodibromomethane
  Bromoform
HAAs
  Dichloroacetic acid
  Trichloroacetic acid
  Bromochloroacetic acid
  Monochloroacetic acid
  Dibromoacetic acid
  Monobromoacetic acid
  Tribromoacetic acid
  Bromodichloroacetic acid
  Chlorodibromoacetic acid
	HANs
	  Dichloroacetonitrile
	  Bromoacetonitrile
	  Bromochloroacetonitrile
	  Dibromoacetonitrile
	  Trichloroacetonitrile
	  Tribromoacetonitrile
	Haloketones
	  1,1,1-Trichloropropanone
	  1,1-Dichloropropanone
	  1,3-Dichloropropanone
	Others
	  Chlorate
	  Chloral hydrate
	  Chloropicrin
	  MX
	  Cynogen Chloride
	  Cynogen bromide
	  Halonitriles

By-products formed by use of ozonation	

Aldehydes
Formaldehyde
Acetaldehyde
Glyoxal
Dimethyl glyoxal
Methyl glyoxal
Benzaldehyde
	Brominated by-products (due to bromine found in the source of drinking water)
	  Bromate
	  Bromoform
	  Brominated acetic acids
	  Bromopicrin

By-products formed by use of chlorine dioxide	
Chlorite Chlorate Plus similar oxidation by-products as ozonation	
By-products formed by chloramination	

Similar to chlorination, but
  Lower THMs,
  Lower cyanogen bromide
  Enhanced levels of cyanogen chloride
  Enhanced levels of larger hydrophilic organic halides not further defined	

Abbreviations: HAAs = haloacetic acids; HANs = haloacetonitriles; MX = 3-chloro-4(dicloromethyl)-5-hydroxy-2(5H)-furanone

Source: Boorman, 1999

Table 2: Advantages and Disadvantages of Different Treatment Methods

Advantages	Disadvantages
Use of Chlorine: • Oxidises soluble iron, manganese and sulphides • Enhances colour removal • Enhances control of taste and odour • May enhance coagulation and filtration of particles • Is an effective biocide	• May reduce effectiveness of coagulation and filtration of organic substances • Forms halomethanes • Depending on the level of chlorine residual in the system, can present a taste and odour problem
Use of Ozone: • An efficient disinfectant, and it is more effective in the inactivation of viruses, *Cryptosporidium* and *Giardia* • Oxidises iron, manganese and sulphides • Can enhance removal of turbidity • Controls for taste, colour and odour	• In the presence of bromine, it will result in bromate and other by-products • High initial cost and high energy requirement • Needs the use of biologically activated filters • Does not have any residual activity • Plant operation is more difficult
Use of Chlorine Dioxide: • It is more effective than chlorine or chloramine for the inactivation of viruses, *Cryptosporidium* and *Giardia* • Oxidises iron, manganese and sulphides • Can enhance removal of turbidity • Controls for taste, colour and odour • Provides a residual	• Will form chlorite and chlorate as by-products • More difficult to ensure correct level of chlorine dioxide use • High cost of sampling for chlorite and chlorate • Chorine dioxide must be generated on site • Concerns about taste and odour have limited its use as a residual disinfectant
Use of Chloramine: • Produces fewer halomethane by-products than free chlorine • Fewer taste and odour complaints • Provides better residual action	• It is not a strong disinfectant • Cannot oxidise iron, manganese and sulphides • Excess ammonia in the distribution system can result in unwanted growth of bacteria in the system • Chloramine must be generated on site
Use of Ultraviolet: • Effective against bacteria and viruses at low dosage • Produces few by-products	• • Very high UV dosage is necessary for control of *Cryptosporidium* and *Giardia* • Not effective in water with high degree of turbidity, colour or dissolved solids • Difficult to use in systems with large water flow • High energy use

Source: US EPA, 1999

Table 3: Comparison of Average THM levels

Treatment Type	Average Levels of THMs (µg/L) Winter 1993	Summer 1993
Chlorine-Chloramine systems	13.7	32.8[a]
Ozone with residual disinfection[b]	9.9	66.7

[a] Toronto uses a chlorine-chloramine system. Average levels of THMs in 1999 were 11.5 µg/L.

[b] Residual disinfection effected by use of either chlorine or chloramine

Source: Health Canada, 1995