Chapter 6 Drinking Water Treatment Technologies

Contents

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6.1 Introduction

Part 2 of this Inquiry focuses on safe water for Ontario's future, which largely involves managing water supply systems and the policy and regulatory apparatus that governs them. The safety of the water supply also raises issues about the science and technology of water treatment and delivery. A basic understanding of the main techniques and controversies in water treatment will help the reader to understand the reasons for many of the following recommendations.

The next several chapters provide an overview of issues that are often considered straightforwardly scientific and engineering in content but that also involve issues of values and public choice. They draw heavily on a voluminous technical literature,[1] including the Inquiry's own commissioned background papers. These chapters attempt also to reflect some of the current developments in technology because current and future developments are likely to have an impact on new regulatory initiatives in the coming years.

Water can become contaminated as part of natural processes. Many contaminants are benign. The less-benign contaminants fall into two general categories, solutes and particles, which require different approaches to treatment. Solutes are chemicals that dissolve completely. Particles may be inorganic, like clay fines (colloids), or organic. Among the organic particles are micro-organisms, which themselves come in several forms – algae, protozoa, bacteria, and viruses. Again, most of these are benign with respect to human health. Only specific organisms, referred to as human pathogens, cause human disease.

The principal purpose of water treatment is to reduce the risk from pathogens and solutes to acceptable levels. Its secondary purposes include ensuring that the water is of high aesthetic quality – that is, its taste, odour, clarity, or colour do not so offend consumers that they are tempted to turn to less safe sources –

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[1] In the chapters on treatment and distribution especially, I have relied extensively on the reference works of the American Water Works Association (AWWA), of which the Ontario Water Works Association (OWWA) is a chapter. The AWWA's *Journal* provides an excellent overview of current and emerging issues, and I also rely on its most recent volumes. The American Water Works Association bibliographic service is excellent on all technical and regulatory matters related to water supply: American Water Works Association, 2001, *Waternet,* CD-ROM (Denver: AWWA) (published by subscription every six months).

and ensuring that the water's chemical constituents do not result in operational problems in distribution systems.

This chapter provides an overview of the main treatment technologies in use and available in Ontario today.[2] It is principally descriptive and is intended as a background for the more policy-oriented chapters that follow, but I do make some recommendations here that deal more with the management of technology than with science or engineering as such.

A main point is that there are always trade-offs among objectives and that attaining all objectives is rarely possible. The problem for design engineers is optimization: how to safely meet or exceed all the regulatory standards at the lowest possible cost.

6.2 The Importance of Source

Recommendation 30: All raw water intended for drinking water should be subject to a characterization of each parameter that could indicate a public health risk. The results, regardless of the type of source, should be taken into account in designing and approving any treatment system.[3]

The choice of water treatment technologies is strongly affected by the qualities of the source water. The most basic distinction for treatment purposes is between surface and ground sources, a point that has generated a great deal of controversy over the years. Surface waters vary in quality and are always subject to some microbial contamination, therefore requiring more treatment. Groundwater not under influence from the surface may have a relatively high mineral content but generally is much less affected by contamination that is pathogenic or of

[2] There is a large literature on water treatment. This chapter relies on the Inquiry's own summary background paper (E. Doyle, 2002, "Production and distribution of drinking water," Walkerton Inquiry Commissioned Paper 8), as well as several of the standard works in the field, notably Canada, Department of National Health and Welfare, Health Protection Branch, 1993, *Water Treatment Principles and Applications: A Manual for the Production of Drinking Water* (Ottawa: Canadian Water Works Association); R.L. Droste, 1997, *Theory and Practice of Water and Wastewater Treatment* (New York: John Wiley & Sons); HDR Engineering Inc., 2001, *Handbook of Public Water Systems*, 2nd ed. (New York: John Wiley & Sons); American Water Works Association, 1999, *Design and Construction of Small Water Systems*, 2nd ed. (Denver: AWWA); Great Lakes–Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, 1997, "Recommended Standards for Water Works*,"* Bulletin 42.

[3] I include in the term "treatment system" those systems that are necessary to monitor the effectiveness of the treatment in real time, such as continuous chlorine residual and turbidity monitors.

human origin. In particular, groundwater not under the direct influence of surface events will, by definition, be free of pathogens.

Most Ontarians draw their drinking water from high-quality sources: "Almost three quarters (73%) of Ontario residents served by municipal water systems drink Great Lakes water. This water is typically low in turbidity, low in microbiological contamination and low in concentration of chemicals."[4] The variations in its quality tend to be slow and predictable. The smaller the water system, however, the more likely it is to use groundwater as a source. Thus, the water may have either high mineral content or high variability, depending on whether or not it is much affected by surface events.

Some may argue that modern engineering can overcome all the problems that source water might present. This may be so, but at a price: the worse the raw water quality, the more demanding is each step in the purification process and errors or accidents tend to have more severe consequences. Research in Canada and Australia has demonstrated that where the source water quality is impaired, even treated water that meets current standards may cause 20–30% of all gastrointestinal disease. By comparison, where source water is already of high quality, treated drinking water may be responsible for up to 15% of gastrointestinal disease.[5]

6.2.1 Groundwater under the Direct Influence of Surface Water

I have come to conclude that "groundwater under the direct influence of surface water" is not a useful concept for regulatory purposes and should be dropped in favour of Recommendation 30. In the Part 1 report of this Inquiry, I

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[4] Doyle, p. 2.

[5] P. Payment et al., 1991, "A randomized trial to evaluate the risk of gastrointestinal disease due to consumption of drinking water meeting current microbiological standards," *American Journal of Public Health*, vol. 81, pp. 703–708; P. Payment et al., 1995, "A prospective epidemiological study of gastrointestinal health effects due to the consumption of drinking water," *International Journal of Health Research*, vol. 7, pp. 5–31; M.E. Hellard et al., 2001, "A randomized, blinded, controlled trial investigating the gastrointestinal health effects of drinking water quality," *Environmental Health Perspectives,* vol. 109, pp. 773–778; P. Payment, 2001, "Tap water and public health: The risk factor," *Water*, vol. 21, p. 9.

The importance of good treatment standards, even when the watershed is well protected and the water chlorinated, is suggested by a recent epidemiological study of gastrointestinal illness in Vancouver, which does not filter its water: J. Aramini et al., 2000, *Drinking Water Quality and Health Care Utilization for Gastrointestinal Illness in Greater Vancouver* <http://www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/vancouver_dwq.htm> [accessed December 1, 2001].

recommended that the Ministry of the Environment (MOE) should develop criteria for identifying groundwater under the direct influence of surface water as a means for determining treatment and treatment-monitoring requirements and as a guide to inspections.[6] On reflection, I have concluded that the distinction is difficult to make, both in theory and in practice, and in any case the design of barriers between contaminants and consumers should take into account the specific set of challenges posed by a specific water source. I would thus broaden my recommendation in the Part 1 report to read as Recommendation 30 does.

Much more effort than in the end is useful has gone into defining groundwater under the direct influence of surface water.[7] This groundwater must be treated as if it were surface water, a generally more expensive proposition and thus one that some local authorities have attempted to circumvent over the years. An example of how complex the definition may become is the following, from the United States Environmental Protection Agency:

> Groundwater under the direct influence of surface water means any water beneath the surface of the ground with significant occurrence of insects or other macro organisms, algae, or large-diameter pathogens such as *Giardia lamblia* or [for … systems serving at least 10,000 people only] *Cryptosporidium*, or significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the State. The State determination of direct influence may be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation.[8]

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[6] Ontario, Ministry of the Attorney General, 2002, *Report of the Walkerton Inquiry, Part 1: The Events of May 2000 and Related Issues* (Toronto: Queen's Printer), p. 298.

[7] The American Water Works Association Research Foundation (AWWARF), for instance, found that none of the water quality parameters tested in a large-scale Florida study "appeared to be a good predictor of direct surface water influence on groundwater." Temperature was fairly good; colour, conductivity, turbidity successively were much poorer; and turbidity, pH, heterotrophic plate count, as well as total and fecal bacteriological data, showed no relationship between ground and surface water: J.C. Jacangelo et al., 2001, *Investigation of Criteria for GWUDI Determination* (Denver: AWWARF) <http://www.awwarf.com/exsums/2538.htm> [accessed April 16, 2002].

[8] United States Environmental Protection Agency, National Primary Drinking Water Regulations, 40 C.F.R., c. 1, § 141.2 (July 2000), p. 338. See <http://www.epa.gov/safewater/regs/cfr141.pdf> [accessed April 16, 2002].

This is a generous definition. It fails to mention any bacteria or viruses and leaves some room for individual states to exercise discretion. Interestingly, the protection against *Cryptosporidium* is less for communities under 10,000 people. The definition properly mentions rapid change in certain easily measured physical parameters but does not define “significant” or “relatively rapid.”

Ontario does not formally define groundwater under the direct influence of surface water, although the concept is referred to in Schedule 2 of Ontario Regulation 459/00. I remarked in the Part 1 report of this Inquiry that the MOE’s failure to apply a 1994 policy requiring continuous monitors for groundwater sources under the direct influence of surface water to Walkerton was a contributing factor in that tragedy.[9] Although the terms of reference for a current survey of potential groundwater under the direct influence of surface water contains a highly detailed statement of what such groundwater constitutes,[10] the MOE’s thrust is generally to require a detailed characterization of the source water, regardless of whether it comes from a well, a lake, or a river, and to design the treatment accordingly. To be useful for specifying treatment, a definition for such groundwater would have to be quite strict, including at least the following concepts:

- no known hydrogeological connection to the surface that would allow percolation into the aquifer in less than a specified number of years;
- the complete absence, over many tests, of any positive results from a broad-spectrum bacterial test such as heterotrophic plate counts, as well as absence in tests for specific protozoa and viruses; or satisfactory results from microbial particulate analyses;
- the absence of solutes, such as nitrates, known to derive from fertilizers, sewage, or manure; and
- the absence of rapid shifts in turbidity, temperature, pH, or conductivity, as the U.S. Environmental Protection Agency suggests.

Under the circumstances, dropping this intermediate definition in favour of a focus on the more direct parameters makes sense.

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[9] Ontario, Ministry of the Attorney General, p. 293.

[10] Ontario, Ministry of the Environment, 2001, *Terms of Reference: Hydrogeological Study to Examine Groundwater Sources Potentially under Direct Influence of Surface Water* <www.ene.gov.on.ca/envision/techdocs/4167e.pdf>.

6.3 Water Treatment Processes

A water treatment plant must be able to treat source water to meet the maximum volume demand at the poorest raw water quality levels without compromising the quality of the final product. A wide variety of processes are available, depending on the problems posed by the source water (see Table 6.1). Usually the plant selects a combination of several processes that work together to meet the required quality standard. In Ontario, a typical process is chemically assisted filtration followed by disinfection. I summarize the standard set of methods below.

Table 6.1 Water Treatment Processes

Parameter Group	Conventional Processes	Advanced Processes
Microorganisms	Chlorination Chloramination Chlorine dioxide	Membrane filtration Ultraviolet Ozone
Turbidity	Chemically assisted filtration	Flotation Granular activated carbon (GAC) Biological processes Oxidation Membrane filtration Ion exchange (humics)
Total organic carbon	Coagulation, flocculation, sedimentation	Powdered activated carbon (PAC) Flotation
Trihalomethanes	Reduced chlorine dose Elimination of pre-chlorination Improved coagulation (precursor removal) Change in disinfectant	PAC GAC Air stripping Biological precursor removal
Specific organics (other than THMs)	Air stripping GAC Oxidation	PAC Membrane filtration Biological processes
Ammonia	Breakpoint chlorination	Ion exchange Biological processes Air stripping Ferrate
Gasoline		GAC Air stripping
Nitriloacetic acid	None	Biological processes Ozonation
Pesticides	PAC	GAC Biological processes
Inorganics (heavy metals)	Chemically assisted filtration	Ion exchange Precipitation Sequestering

Table 6.1 Water Treatment Processes (continued)

Parameter Group	Conventional Processes	Advanced Processes
Mercury	None	Ferric sulphate Coagulation (inorganic Hg) Ion exchange (organic Hg)
Asbestos	Chemically assisted filtration	
Fluoride	None	Alum coagulation Lime softening Activated alumina Reverse osmosis Electrodialysis
Cyanide	Oxidation	
Iron and Manganese	Oxidation Sand filtration Greensand	Biological processes (Mn)
Hydrogen sulphide	Aeration	
Nitrite	Chlorination	Biological processes
Nitrate	Ion exchange	Biological processes
Total dissolved solids		Ion exchange Membrane filtration Electrodialysis
Hardness (Ca and Mg)	Lime-soda softening	Ion exchange
Algae	Chemically assisted filtration Application of algicides to raw water Oxidation	Coagulation Flotation
Colour	Coagulation Oxidation	Flotation
Taste and odour	Aeration Oxidation (O_3) PAC Change of oxidant/disinfectant	GAC Biological processes Membrane filtration
pH	Acid or base addition	
Radioactivity		Greensand Ion exchange (Ra, U) Air stripping (Ra)

Source: Adapted from Canada, Department of National Health and Welfare, Health Protection Branch, 1993, pp. 168–169.

6.3.1 Conventional Processes

Screening: An inexpensive process, screening puts relatively coarse screens at the intake point of the raw water and places finer screens at the water treatment plant.[11] The finer screens usually require frequent cleaning.

[11] Finer screens may recommend themselves in some instances. In Tasmania, migrating eels expiring in the water system recently caused foul water: D. Rose, 2001, "Dead eels in water supply," *Mercury* (Tasmania), November 2. Here, as elsewhere, the Inquiry is indebted to pioneering Australian work.

Coagulation: The next several steps "clarify water, reduce the organic load, and greatly decrease the microbial count so that subsequent disinfection will be more effective."[12] Coagulation has the further benefit of reducing the chemical disinfectant dose and thus lowering the levels of disinfection by-products.

Micro-organisms and clay colloids in water are negatively charged, a feature that stabilizes their dispersion in water. Adding positively charged (cationic) metals, such as soluble aluminum or iron salts, or cationic organic polyelectrolytes, neutralizes their charges. This destabilizes the colloidal suspensions and results in agglomeration into small flakes, or microflocs. Aluminum and iron salts hydrolyze to form a gelatinous polymer that further entraps and adsorbs clay particles and micro-organisms. Chemical reactions between the salts and free organic acids or proteins can also result in precipitation.[13] The processes are temperature and pH dependent and are less efficient in cold water, thus requiring careful attention to mixing times and pH.[14] Design mistakes may lead to this process's poor performance in winter.

Aluminum and iron salts have been used to remove colour and enhance particle removal. Their use is preferred because of their efficiency, cost, and ability to control aluminum and iron residuals for a given water quality. Synthetic coagulants (polymers or polyelectrolytes) or activated silica can also be used. They are usually more expensive, but smaller doses may be required. Polymers form gelatinous masses that entrap smaller flocs and particles more efficiently than do the metal hydroxides formed by the hydrolysis of metallic salts.

Flocculation: The process of slowly agitating the coagulated mix is known as flocculation. It allows microflocs to agglomerate, which increases the size of the floc and thereby enhances the gravity sedimentation of the larger flocs while allowing the capture of floc-adhering particles that are otherwise too tiny to be trapped in the relatively coarse filters that follow. Flocculators can be mechanical, pneumatic, or hydraulic, but the mixing action is relatively slow. Baffled channels can be effective flocculators if the velocities are maintained between 0.1 and 0.4 metres per second and the detention time is about 15–20 minutes. In a tapered flocculation process, water flows through a series of cells at decreasing speed. This allows for rapid floc formation in the early stages

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[12] S.S. Block, 1991, *Disinfection, Sterilization and Preservation*, 4th ed. (Philadelphia: Lee and Febiger), p. 719.
[13] Ibid., pp. 719–720.
[14] HDR Engineering Inc., c. 10.

while preventing floc break-up and encouraging sedimentation in the later stages.

Sedimentation: Sedimentation is the separation of suspended material by gravity. Sedimentation basin design depends on the settling velocity of the lightest particles to be removed from suspension. This provides a nice example of the need to optimize the trade-offs among processes considered together: if flocculation is highly efficient (particles are large and heavy), sedimentation may be rapid and the tank small – but at the cost of higher dosage or the selection of a more expensive chemical coagulant.

Flotation: An alternative to sedimentation is flotation, in which solids are transported to the surface through their attachment to bubbles and are then skimmed off. This method can remove smaller particles than can sedimentation, at some cost in capital and power requirements, and is particularly suitable for waters that have a high algal content, low natural turbidity, or high colouration. Flotation is not as efficient as sedimentation for the removal of particles and turbidity and is sensitive to temperature; it performs poorly in very cold water.

Flotation is provided electrolytically or through dissolved or dispersed air.[15] In the first case, the electrolysis of water generates bubbles of hydrogen and oxygen. Dispersed air is a froth in which bubble formation and dispersion is achieved through violent agitation, or a foam in which tiny bubbles are formed when air passes through a porous medium or sparger. Dissolved air flotation is the most popular method. Small-diameter air bubbles are generated by reducing a high-pressure (345–552 kPa) saturated stream to atmospheric pressure in the bottom of the tank.[16] In all cases, bubbles attach themselves to floc or are trapped inside it, and the floc rises to the top, where it is skimmed off.

The choice of separation technique – sedimentation or flotation – depends on factors such as source water quality (presence of algae and lime or silt), objectives in turbidity and particulate removal, rapid start-up, sludge removal and disposal constraints, cost, and the skill level of the operating personnel. The design trade-off at the level of coagulation/flocculation/clarification is the choice between a high level of particle removal versus optimal conditions for the reduction of the natural organic matter, which leads to the formation of disinfection by-products. The former approach removes more micro-organisms;

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[15] Ibid, p. 337.
[16] Canada, Department of National Health and Welfare, p. 53.

the latter limits the secondary impact of disinfecting the remaining micro-organisms with chlorine.

Sand Filtration: Clarified water then passes through a filter, conventionally a thick layer of sand and anthracite, which is occasionally overlain by granular activated carbon. Since the pore spaces in these filters are much larger than the few microns of a typical protozoan or bacterium, the coagulation and flocculation steps are critical to effective filtration.[17] The particles remaining in the clarified water fed to the filter are small, but they are still much larger than the pathogens they may contain.

Filter beds must be taken out of service periodically for backwashing when the accumulation of solids causes excessive pressure drop or particle breakthrough. The accumulated solids are evacuated by a combination of up-flow wash, with or without air scouring, and surface wash. The need for backwashing usually requires water treatment plants to have several filters arranged in parallel, so that one or two filters can be offline without reducing the rated capacity of the plant.

The effective backwashing of filters is critical to their proper performance. Air scouring, in particular, is critical to the adequate cleansing of the media of mud balls, filter cracks, and the accumulation of large macro-organisms (worms). But backwashing is also the most frequent source of filter failure.[18]

After the backwash period, commonly 5 to 60 minutes, filtered water often does not meet turbidity and particle removal goals. The efficiency of particle removal decreases following a backwash, when the filter is clean and the pores are at their maximum size.

Good practice (and regulation in the United States) now dictates that water produced during that period of "filter ripening" is sent to drain. Since the

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[17] Following optimal coagulation, conventional filtration can result in as much as a 4- to 5-log removal of *Cryptosporidium*, but performance apparently depends on close process control: N.R. Dugan, K.R. Fox, and R.J. Miltner, 2001, "Controlling *Cryptosporidium* oöcysts using conventional treatment," *Journal of the American Water Works Association,* vol. 93, no. 12, pp. 64–76. Filter performance data from normal operations show much lower removals and a great sensitivity to chemical conditioning.
[18] R.D. Letterman, ed., 1999, *Water Quality and Treatment: A Handbook of Community Water Supplies*, 5th ed. (New York: McGraw-Hill/American Water Works Association), c. 8.

amount of water wasted during filter ripening may be 5% of overall production, it is often recycled to the head of the plant, but this may simply increase the load of micro-organisms to the plant, risking microbial breakthrough. Thus, recycling is no longer recognized as a good practice. Providing filter-to-waste facilities is an important step in lessening the overall risk of pathogen passage into finished water. Many plants in Ontario, especially the smaller ones, are not equipped with filter-to-waste piping.

The trade-off in filtration is the efficiency of particle removal versus filter productivity. It would be possible to construct particle filters with a much finer pore structure: diatomaceous earth is a good example of such a filter.[19] But the filtration rate would be unacceptably slow under gravity alone, making pressurization (an added expense) necessary. The most common trade-off facing designers is between the area and the depth of the media, that is, between the length of the filtration cycle and the initial period of particle breakthrough.

The combination of steps described so far is referred to in engineering shorthand as "chemically assisted filtration."

Disinfection: Because it removes or inactivates pathogens, disinfection is the vital step in preventing the transmission of water-borne disease. By far the most common disinfectant is chlorine, which has been in wide use for more than a century. Chlorine is effective against bacteria and viruses but not against encysted protozoa.

The effectiveness of disinfection is generally calculated for different types of disinfectants, using a complex equation based on the concentration of the disinfectant (C) and the contact time (T), which is often referred to as the CT.

The usual shorthand in the water business is to say that a particular treatment provides, for example, "3-log inactivation or removal for *E. coli*," which means that 99.9% of the *E. coli* bacteria in the raw water have been killed (or in the case of filtration, removed). Thus, 4-log means that 99.99% of the *E. coli* have been inactivated, and so on. Different standards apply for different organisms. For example, *Giardia* inactivation should have 3-log efficiency, while the usual minimum for viruses is 4-log. To quote again from the Inquiry's commissioned paper:

[19] Diatomaceous earth under lab conditions yields approximately 6.3-log *Cryptosporidium* removal: J.E. Ongerth and P.E. Hutton, 2001, "Testing of diatomaceous earth filtration for removal of *Cryptosporidium* oöcysts," *Journal of the American Water Works Association,* vol. 93, no. 12, pp. 54–63.

> Depending on the treatment process, a substantial portion of these requirements could be achieved through filtration, often leaving a remaining disinfection requirement of 0.5-log *Giardia* inactivation and 2-log virus inactivation. Systems would then determine the *CT* required to achieve these inactivation targets, using tables provided in the regulatory literature that correlate *CT* values to different levels of *Giardia* and virus inactivation. The new Ontario standard uses this approach …
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> An extremely important consideration with the *CT* approach is the determination of *C* and *T*. When a disinfectant is applied to the water, it reacts with the various impurities and decays. Thus, *C* is continuously changing. Furthermore, not every element of water passes through the treatment system in the same amount of time. Some elements pass quickly while others move through eddies or stagnant regions and take longer. Thus there is no single contact time *T* that can be used to describe the entire flow of water. [20]

The most commonly used oxidants in drinking water disinfection are chlorine, ozone, and chlorine dioxide. Of these, by far the most common are chlorine gas and hypochlorite, which have been in widespread use for a century. However, concerns about the formation of potentially harmful halogenated by-products have led many water systems to adopt alternative oxidants for disinfection.

Chlorine is the oldest and most widely used disinfectant. It is effective against bacteria and viruses, though not against encysted protozoa. *Giardia* is very resistant to chlorine, whereas *Cryptosporidium* cannot be inactivated by chlorine doses that are compatible with drinking water treatment.

The most commonly used and lowest-cost form of chlorine is chlorine gas, a highly toxic chemical that must be transported (unless it is produced on-site), handled, and accounted for with great care and only by trained and certified people. Chlorine in storage or transport may pose unacceptable security risks. It can, however, be produced on-site from the electrolysis of a brine solution, avoiding the hazards associated with the transport and handling of gaseous chlorine. This is now almost the only form of chlorine used in urban European plants, and it is gaining ground rapidly in the United States.

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[20] E. Doyle, 2002.

Sodium hypochlorite is another form of chlorine that is safer to use than chlorine gas. This option is typically provided in a water solution ranging from 5–15% available chlorine.[21] High-strength solutions degrade fairly rapidly, so low-strength solutions are preferred if the storage period is likely to last weeks or months. Calcium hypochlorite is provided as a dry solid; in commercial products it may contain between 65% and 70% available chlorine. The reaction with water occurs in a similar manner to that of sodium hypochlorite.

Whatever the source, chlorine in solution takes the form of hypochlorous acid, which partly dissociates into hypochlorite ions. Both of these forms are referred to as free chlorine. Hypochlorous acid is the most effective form of chlorine-based disinfectant. At higher pH (>7.5), the less effective hypochlorite ion will dominate, so pH control during disinfection is important. Free chlorine reacts with organic and inorganic material that is dissolved or suspended in water, as well as specifically with micro-organisms. Simply adding more chlorine to satisfy the demand caused by this non-toxic material results in higher concentrations of harmful disinfection by-products (DBPs), which in turn means that it is important to minimize total organics before the chlorination step.

Production of Chloramines: The reaction of aqueous chlorine with ammonia produces chloramines. This may be done purposely by adding ammonia to chlorinated water to convert the free chlorine residual into chloramines.[22] Monochloramine is a form of combined chlorine that, although it is less effective than free chlorine, is much more stable, which makes it particularly useful for maintaining a chlorine residual in the distribution system.

Use of Chlorine Dioxide: A strong oxidant used mainly for taste and odour control, chlorine dioxide is also used to oxidize iron and manganese. Since it is highly unstable, it cannot be transported or stored and must be produced on-site on a continuous basis. It is effective against *Giardia* and *Cryptosporidium,* and its application is mainly restricted by the limitations on its undesirable inorganic by-products, chlorate and chlorite.

Maintaining a Residual: The topic of maintaining a chlorine residual received a good deal of attention in Part 1 of the Inquiry. It is normal practice to have a chlorine residual (either free chlorine or chloramines) in the water as it leaves the treatment plant. This residual is meant to prevent the regrowth of microbes

[21] American Water Works Association, 1973, *Manual of Water Supply Practices: Water Chlorination Principles and Practices*, M20 (Denver: AWWA), p. 10.
[22] Letterman, pp. 12–14.

in the water until it reaches the consumer's tap. The current Ontario requirement is a free chlorine residual throughout the distribution system in concentrations of between 0.2 and 4.0 mg/L.[23]

In the 1990s, concern about the formation of chlorine disinfection by-products during distribution caused a major shift toward using chloramines in distribution systems. Chloramines are less potent but more persistent disinfectants,[24] with applied dosages ranging between 1.0 and 3.0 mg/L. Chloramines have been shown to be more efficient in controlling biofilm and in reducing the coliform-positive events in corroded distribution systems. However, they have also been linked to increased heterotrophic plate counts, at least during the transition from chlorine to chloramines.[25]

Ozonation: The main chemical alternative to chlorine, ozone is used in several of the larger treatment plants in Ontario, notably in those of Windsor and Kitchener-Waterloo. Widely used in Europe, the United States (more than 400 plants), and Quebec (more than 20 plants), ozone is used to oxidize organic matter (including trihalomethane precursors); to reduce objectionable taste, odour, and colour; and to inactivate pathogens. Ozone is effective against bacteria, viruses, and protozoa. It is one of the few disinfectants capable of inactivating *Cryptosporidium*.

Ozone's limitations include its sensitivity to temperature (all chemical disinfectants work less well at low temperatures) and the fact that ozonation increases the amount of biodegradable organic matter reaching the distribution system, which may, under favourable conditions, increase bacterial regrowth.[26] However, it is the only chemical disinfectant that will work at low water

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[23] The requirement is not in the regulation, which simply requires disinfection, but is mentioned in the new chlorination bulletin, Procedure B13-3, which is appended to the new Ontario Drinking Water Standards (ODWS).

[24] Letterman, pp. 12–45.

[25] A shift has occurred in European practice regarding the maintenance of chlorine residuals in distribution systems. Until the events of September 11, 2001, European practice was to lower or avoid altogether the presence of chlorine in distribution systems, mainly in response to the high sensitivity of customers to taste and odour generated by chlorine. This practice has now ceased: M. Prévost, 2002, personal communication, February 4.

[26] I.C. Escobar and A.A. Randall, 2001, "Case study: Ozonation and distribution system biostability," *Journal of the American Water Works Association,* vol. 93, no. 10, pp. 77–89. Regrowth in this study of Orlando, Florida, occurred under a combination of conditions including the presence of food (biodegradable organic matter produced by ozone); temperature (>15°C); oxidant depletion (absence of residual); and material (proper housing for bacteria). Vancouver, however, chose ozonation, together with proper residual maintenance, and experienced a decline in regrowth.

temperatures (albeit with higher doses) without causing unacceptable levels of disinfection by-products. It is good at controlling taste and odour problems and is unexcelled for the control of algal toxins.

6.3.2 Disinfection By-products

Recommendation 31: The Advisory Council on Standards should review Ontario's standards for disinfection by-products to take account of the risks that may be posed by the by-products of all chemical and radiation-based disinfectants.

Disinfection by-products (DBPs) are the unintended result of drinking water disinfection and oxidation. The compounds of most concern contain chlorine and bromine atoms and may be either organic or inorganic. Precursors of DBPs include natural organic matter such as humic and fulvic acids, total organic carbon, and bromides.

Chlorine is not alone in forming DBPs, but chlorine-derived DBPs were the first to be recognized and have been the source of some controversy.[27] Chemical disinfectants in general produce DBPs by oxidation and halogen substitution in some precursor in the raw or semi-processed water. Halogenated organic DBPs include chloroform and other trihalomethanes (THMs), haloacetic acids, and haloacetonitriles. Total THM concentrations in drinking water are limited to 0.1 mg/L in Ontario. Typically, waters with high natural organic matter concentrations are at greater risk of exceeding chlorine-related DBP limits. The tea-coloured lakes and streams of northern Ontario get their characteristic colour from high concentrations of natural organic matter.

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[27] These matters are reviewed in P.C. Singer, ed., 1999, *Formation and Control of Disinfection By-products in Drinking Water* (Denver: American Water Works Association); see also the references in note 1. Chloroform was first recognized as a by-product of water treatment in Holland: J.J. Rook, 1971, "Headspace analysis in water," (translated) *H2O,* vol. 4, no. 17, pp. 385–387; and 1974, "Formation of halogens during the chlorination of natural water," *Water Treatment and Examination*, vol. 23, pp. 234–243, cited in J.M. Symons, "Disinfection by-products: A historical perspective," c. 1, in Singer, ibid. Health Canada has a Chlorinated Disinfection By-products Task Group, whose publications are available through the Health Canada Web site. For an up-to-date summary, see S.E. Hrudey, 2001, "Drinking water disinfection by-products: When, what and why?" proceedings at the Disinfection Byproducts and Health Effects Seminar, Cooperative Research Center for Water Quality and Treatment, Melbourne, Australia, October 29.

Chlorine dioxide undergoes a wide variety of oxidation reactions with organic matter to form oxidized organics and chlorite. All three forms of oxidized chlorine species – chlorine dioxide, chlorate, and chlorite – are considered to have adverse health effects. There is no current regulation of chlorine dioxide and its by-products, chlorite and chlorate, in Ontario. The ozonation by-product of major concern is bromate, formed by the oxidation of bromide. Bromate is not regulated in Ontario but the European Union, the United States Environmental Protection Agency, the World Health Organization, Australia, and Quebec do set maximum contaminant levels for bromate.

The use of chemical disinfectants requires a balance between ensuring proper disinfection and minimizing unintended and undesirable by-product formation. In all cases and for all chemical disinfectants used, the uncertain long-term risk from DBPs must be weighed against the acute and more certain risk of inadequate disinfection. The failure to put disinfection first can have immediate and catastrophic effects, as occurred in Peru in 1991[28] and in Nigeria in 2001.[29]

Three general approaches are available to control DBPs:

- **Minimizing Natural Organic Matter before Disinfection:** Natural organic matter can be reduced through coagulation, adsorption, oxidation, or nano-filtration. This is common practice in Ontario. Chlorination DBPs can also be minimized by moving chlorine application downstream, to a later point in treatment, after some of the natural organic matter has been removed by coagulation.

- **Changing Oxidants:** The most common modifications are to use chlorine dioxide or ozone for primary disinfection, or chloramine for the residual.[30]

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[28] A misunderstanding about relative risk led to the cessation of chlorination, with the result that at least 3,000 people died and 320,000 were made ill with cholera: C. Anderson, 1991, "Cholera epidemic traced to risk miscalculation," *Nature*, vol. 354, November 28, and Pan American Health Organization, 2002, "Cholera: Number of Cases and Deaths in the Americas (1991–2001) <www.paho.org/English/HCP/HCT/EER/cholera-cases-deaths-91-01.htm> [accessed May 1, 2002]. It is fundamental that "management actions to reduce the potential risk posed by DBPs must not compromise the microbiological quality of the drinking water": Singer, p. 113.

[29] A. Aboubakar, 2001, "Hellish scenes in Nigeria's cholera city," *Agence France Presse* (Kano), November 26; see also <http://www.theage.com.au/breaking/2001/11/27/FFXE97A4HUC.html>, [accessed May 1, 2002].

[30] "After the THM rule became effective in 1979, some water utilities had to make changes in their practices to come into compliance. [Enactment resulted, on average] in a 40 to 50 percent lessening in TTHM [total trihalomethane] concentrations for the larger utilities surveyed. … Although the median concentration [38 µ/L] was not influenced much, utilities with high TTHM levels were

- **Optimizing Disinfection:** This can be achieved by using just enough oxidant to achieve the necessary disinfection and applying it under conditions that minimize DBP formation. One example is pH adjustment for bromate control. Lowering the pH before ozonation can almost entirely prevent bromate formation. Both overdosing and underdosing pose threats; thus, a careful assessment of *CT* based on the particular design of a facility, combined with an equally careful approach to overall risk management and a routine audit of the number of surviving micro-organisms, must be employed.[31]

All chemical disinfectants produce undesirable by-products that can and must be minimized to lower long-term risk while providing immediate disinfection and other water quality benefits. However, the current regulations in Ontario limit only the levels of chlorination DBPs, which creates a regulatory void that may cause inappropriate shifts from one oxidant to another. A balanced view is required. The proposed Advisory Committee on Standards should examine this issue.

6.3.3 Innovative Disinfection Technologies

The recent focus on chlorine-resistant micro-organisms such as *Cryptosporidium* results directly from recent outbreaks such as those in Milwaukee, the United Kingdom, and North Battleford, Saskatchewan, as well as a suspected outbreak that may never have occurred in Sydney, Australia. These outbreaks have shown the inability of conventional separation processes coupled with chlorination to ensure the reliable removal of these pathogens. In each of these cases, the treatment processes in place were theoretically capable of preventing the passage of these micro-organisms. Since *Cryptosporidium* is highly resistant to chlorine, chemically assisted filtration done in an optimal mode is the main barrier available in a conventional plant. However, an inadequate operation of treatment processes may result in the massive contamination of drinking water, with

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able to lessen their TTHM concentrations substantially. … Of those systems that implemented THM control measures, the majority did one or more of the following: (1) modified their point(s) of chlorine application [to follow filtration], (2) changed their chlorine dosages, and (3) adopted the use of chloramines": Symons in Singer, pp. 16–17.

[31] The U.S. Environmental Protection Agency proposed in 1978 a THM limit that would apply only to utilities serving more than 10,000 people because of a concern that "if the smaller utilities tried to alter their disinfection practice to lessen TTHM concentrations, because of a lack of technical expertise, an increased risk of microbial contamination in the finished water might result": Symons in Singer, p. 12.

dramatic consequences for the local consumers. As a result, it is now accepted practice to recommend the provision of an additional barrier to ensure the removal or inactivation of these pathogens. This provision is not yet required by regulation in Canada or the United States, although it will become a requirement in the United States with the promulgation of the Stage II Microbial/Disinfection By-product Rule in 2003. This is a clear case of practice preceding regulation to provide safer drinking water.

It is in this context that alternative technologies such as ultraviolet radiation (UV) disinfection and membrane filtration have recently been recognized as efficient technologies to remove or inactivate these chlorine-resistant pathogens in drinking water. The great interest in these technologies lies in the fact that there is no known production of DBPs as a result of using these technologies.[32] However, neither technology is a complete barrier to bacteria and viruses, and neither carries a disinfectant residual. Because of these limitations, they must be applied together with a chlorine or chloramine residual.

The need to remove or inactivate chlorine-resistant pathogens has resulted in major changes in regulations around the world and has spurred tremendous interest in the development of alternative technologies to reach that goal. As a first response to this threat, other oxidants, such as ozone and chlorine dioxide, appeared to be viable alternatives that could be used with success. However, their application may be limited by their production of undesirable DBPs.

Ultraviolet Radiation: UV technology is not new, and its application for disinfection is well established. It has been applied with success for decades to disinfect wastewater effluents. Today, the UV disinfection of drinking water is widely used in Europe, where more than 2,000 UV installations exist, and it is also common in the United States, where there are more than 1,000 installations, the majority of which are in small systems, with about 40% applied to surface water.[33]

UV is most effective when the water is already clear – when there are no particles in or behind which micro-organisms may shelter from the killing light. Hence, it is usually placed toward the end of the treatment processes.

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[32] In the case of UV, however, this may be due in part to a lack of relevant research.

[33] United States Environmental Protection Agency, 2001, *Draft UV Guidelines,* CD-ROM (Washington, DC).

Disinfection by UV light is fundamentally different from disinfection by chemical disinfectants such as chlorine, chlorine dioxide, and ozone. UV inactivates micro-organisms by damaging their nucleic acids and preventing the micro-organisms from replicating. A micro-organism that cannot replicate may not be dead, but it cannot infect. The UV adsorption for DNA peaks at 265 nm, well within the UV range.

UV radiation is extremely effective against chlorine-resistant pathogens such as *Cryptosporidium* and *Giardia* and requires small dosages for bacterial inactivation, whereas the inactivation of certain viruses requires significantly higher dosages.

The U.S. Environmental Protection Agency's Federal Advisory Committee of 21 stakeholders has been studying the efficacy, current use, performance, reliability, and cost of UV since 1999.[34] Its economic analyses show that using UV to treat water for *Cryptosporidium* costs significantly less than using other technologies, such as membrane filtration.[35]

Concurrent with its publication of the proposed rules (LT2ESWTR and Stage II Microbial/Disinfection By-product Rule), the United States Environmental Protection Agency intends to publish the following in the summer of 2002:

- tables specifying UV doses (product of irradiance (I) and exposure time (T)) needed to achieve up to 3-log inactivation of *Giardia lamblia*, up to 3-log inactivation of *Cryptosporidium*, and up to 4-log inactivation of viruses;[36]

- minimum standards to determine whether UV systems are acceptable for compliance with drinking water disinfection requirements; and

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[34] D.C. Schmelling, 2001, "Disinfection goals: Crypto? Viruses? Both?" proceedings at the American Water Works Association Annual Conference, Washington, DC, June 17–21.

[35] C.A. Cotton et al., 2001, "The development, application and cost implications of the UV dose tables for LT2ESWTR compliance," presentation at the Water Quality Technology Conference, Nashville, Tennessee, November; C.A. Cotton et al., 2001 "UV disinfection costs for inactivating *Cryptosporidium*," *Journal of the American Water Works Association*, vol. 93, no. 6, pp. 82–94.

[36] C.A. Cotton et al., 2001, "The development of the UV dose tables for LT2ESWTR implementation," presentation at the First International Congress on UV Technologies, International UV Association, Washington, DC, June.

- a final *UV Guidance Manual*, the purpose of which is to facilitate the design and planning of UV installations by familiarizing regulators and utilities with important design and operational issues, including redundancy, reliability and hydraulic constraints in UV system design, and design considerations with respect to plant and pipe size, water quality (e.g., UV absorbance, turbidity), lamp fouling and aging, appropriate operations, and maintenance protocols to ensure the performance of UV lamps (e.g., sleeve cleaning systems).[37]

Germany has already developed a standard[38] and has accredited eight manufacturers. The National Water Research Institute (NWRI) and the American Water Works Association Research Foundation (AWWARF) have similar guidelines, but the expected U.S. Environmental Protection Agency guidelines will set the accreditation framework in the United States. The UV guidance manual is likely to require full-scale validation testing based on German DVGW guidelines.

UV disinfection has many advantages. First, it is much less demanding on the operator than are any of the chemical disinfectants. Although the minimum dose must be met, modest overdosing is not known to create hazards. Continuous optimization is not required. A second advantage is the apparent lack of DBPs, although it must be understood that little research has been done to date, especially on the question of whether any problematic non-halogenated DBPs may be produced. The area of current concern is the production of nitrite, which can be formed from nitrate, but keeping the lamp output above 240 nm can avoid this reaction. A third advantage of UV is its excellent capacity, much better than all available oxidants, to inactivate protozoan pathogens, most notably *Cryptosporidium*. Lastly, the technology is easily scalable: it can work economically all the way from the point-of-use or point-of-entry level to that of a full-scale water plant. Perhaps the most obvious attraction of UV is its low cost. It is increasingly thought of as inexpensive insurance, and several utilities are installing UV without being compelled to do so by regulatory obligation.

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[37] See also National Water Research Institute and American Water Works Association Research Foundation, 2000, "Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse," NWRI-00-03.

[38] Deutsche Vereinigung des Gas-und Wasserfaches eV., 1997, Arbeitsblatt W-294.

A good deal of work is being done in the United States to fine-tune and standardize the use of UV in large systems.[39] As mentioned above, the U.S. Environmental Protection Agency's Federal Advisory Committee has been studying the issue since 1999.[40] At the time of writing, the agency was circulating a draft of its forthcoming *UV Guidance Manual.* In Canada, UV has been gaining ground. The Edmonton utility Epcor ordered a UV system in December 2001. Also in 2001, Quebec reviewed its drinking water regulations, and a minimum 2-log *Cryptosporidium* removal requirement was introduced. As a result, more than 100 projects are now under review for approval by Quebec's ministry of the environment.

Membrane Filtration: If micro-organisms are not killed with chemical disinfectants or radiation, they can simply be excluded physically from the finished water. Membrane processes currently in use for drinking water production include reverse osmosis, nano-filtration, ultra-filtration (UF), and micro-filtration (MF). Nano-filtration, the most recently developed membrane process, is used to soften water, to remove DBP precursors, and more recently (in Europe) to trace contaminants such as pesticides. Ultra-filtration and micro-filtration are used to remove turbidity, pathogens, and particles from surface waters. Coagulants or powdered activated carbon (PAC) must be used in MF or UF to remove significant amounts of dissolved components such as natural organic matter, DBP precursors, taste and odour compounds, and trace contaminants such as pesticides, herbicides, and arsenic. Depending on water quality, MF and UF can be used as stand-alone separation processes in which coagulant and PAC is added, or in combination with other separation technologies such as high-rate clarification or filtration.

Membranes can be classified by such properties as geometry, molecular weight cut-off, operating pressures, and membrane chemistry, but the most common classification is by their pore size, as shown in Table 6.2. Size is critical. Protozoa are typically larger than 4 µm and bacteria larger than 0.5 µm. *E. coli* is a rod-shaped bacterium 0.5 to 2.0 µm long; *Campylobacter* is a spiral-shaped or curved bacterium from 0.2 to 0.5 µm wide and from 0.5 to 5.0 µm long.[41] Viruses

[39] See two papers from the June 2001 AWWA meetings in Washington, DC: R.H. Sakaji, R. Haberman, and R. Hultquist, "UV disinfection: A state perspective"; and V.J. Roquebert et al., "Design of UV disinfection systems for drinking water treatment: Issues and alternatives," proceedings at the American Water Works Association Annual Conference, Washington, DC, June 17–21.

[40] Schmelling.

[41] American Water Works Association, 1999, *Manual of Water Supply Practices: Waterborne Pathogens,* M48 (Denver: AWWA).

and viral particles can be much smaller – as small as 0.02 µm. Only recently have filters been developed that are both fine enough to exclude micro-organisms and capable of providing a high enough throughput capacity to be practical. Membrane filters are now commercially available at all suitable scales.

Table 6.2 Membrane Filter Terminology

Term	Pore size lower limit	Pressure
Micro-filtration	0.1 µm	4–10 psi
Ultra-filtration	0.01 µm	10–30 psi
Nano-filtration	0.001 µm	80–120 psi
Reverse osmosis	0.0001 µm	125–200 psi

A membrane filter looks like a large number of thin drinking straws suspended in a frame. These hollow fibres have holes in them of the desired size, so that applying positive pressure to the feed water or negative pressure to the header – sucking on the straw – pushes or draws water through the filter, leaving the impurities on the outside.

Membrane filtration is used in a number of medium-sized communities in Ontario, notably Owen Sound and Thunder Bay; Walkerton now has such a system, operated under contract by the Ontario Clean Water Agency.

One commentator observed that, from a safety point of view, membrane filtration and UV have interesting characteristics: "They have virtually eliminated the risk of chemical by-products and all of their health concerns, which mean the operator skill level and the attendants needed to adjust the processes are significantly reduced."[42] Their costs have been coming down rapidly. UV systems are already available at the scale of individual households, and a household-scale membrane system is just becoming available in Ontario at the time of writing. Maintaining home UV systems is not difficult, especially when the unit has a monitor showing that the lamp has not burned out. Membrane systems need periodic maintenance, but this may be done under contract by the same utility that rents the system to the homeowner. Household-scale UV systems now cost $400 to $1,500. Membrane systems are entering the market at about $4,000 but deal with a wider range of contaminants. The

[42] K. Mains, Walkerton Inquiry Submission (Public Hearing, September 12, 2001), transcript pp. 94–95.

importance of economical point-of-entry technologies for disinfection is substantial if Ontario is to reach the goal of having safe water for all its citizens. The prices may be seen as putting a notional cap on the amount that rural groundwater users need to spend.

Heat: The principle behind pasteurization, heat, is also a good killer of micro-organisms. It is applied in desalination schemes in the Middle East and other dry areas of the world. The typical flash distillation process heats the water sufficiently and for a long enough time to inactivate micro-organisms. Such expensive schemes are irrelevant in Canada.

Comparison of New Disinfection Techniques: A recently reported Wisconsin study evaluated ozone, membranes, and four kinds of UV treatment.[43] The latter's performance strongly depended on the clarity of the water. Lamps aged in predictable fashion and were readily cleaned; indeed, they performed better than the flux measurement devices did. Low-pressure, high-output (LPHO) lamps at 40 mJ/cm^2 used 43% of the power used by medium-pressure lamps (12.5 kWh/ML[44] versus 28.75 kWh/ML), but they did little for taste, odour, and colour problems, which were better dealt with by the broader energy spectrum. Ozone (O_3) required 167 to 325 kWh/ML, and performance depended on temperature and pH. UV worked superbly on *Cryptosporidium*. The first demonstration run of LPHO lamps at 45 mJ/cm^2 gave >4.7-log inactivation, the limit of measurement.

The huge Metropolitan Water District of Southern California has likewise been evaluating UV and O_3.[45] It found that a mere 3 mJ/cm^2 produced 1-log reduction, though with high variance. It saw both techniques as having a place in a multi-barrier system, noting that beyond treating bacteria, UV was a *Cryptosporidium* specialist and O_3 was good at pre-oxidation for particulate control, micro-pollutant oxidation, taste, odour, and colour reduction. Bromate, a probable carcinogen that occurs when there is substantial bromide in the raw

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[43] E.D. Mackey, R.S. Cushing, and G.F. Crozes, 2001, "Evaluation of advanced UV disinfection systems for the inactivation of *Cryptosporidium*," proceedings at the American Water Works Association Annual Conference, Washington, DC, June 17–21.

[44] ML: megaliter, or 1,000,000 L.

[45] B.M. Coffey et al., 2001, "Comparing UV and ozone disinfection of *Cryptosporidium parvum*: Implications for multi-barrier treatment," proceedings at the American Water Works Association Annual Conference, Washington, DC, June 17–21. An interesting side point was that *Bacillus subtilis* may be a useful surrogate for *C. parvum* (r^2 = 0.93 for UV and r^2 = 0.96 for O_3).

water and that may be an ozone disinfection by-product,[46] was judged to be a treatable concern.

This work by the U.S. Environmental Protection Agency showed that, for typical installations, the ratio of cost was around 10 for micro- or ultra-filtration to 2 or 3 for ozone to 1 for UV, though the ratios are said to be narrowing even as the absolute cost numbers decline. One senior Canadian engineer thinks that ozone will eventually be replaced by high-performance membranes and UV disinfection, especially in cold climates, unless there are specific geosmin[47] and related summer taste problems, with which ozone deals well; even so, ozone can in some circumstances impart a phenolic-like taste.[48] A comparison of costs by another practising engineer showed that none of these advanced treatment costs was large, in the context of the delivered cost of potable water.[49]

6.3.4 Meeting Other Treatment Objectives

Total Organic Carbon Removal: Total organic carbon (TOC), which consists of dissolved and particulate matter, can be removed from water through coagulation or by magnetic ion exchange. It has generally not been possible to remove TOC economically, so raw waters that are high in TOC tend to be avoided if possible. As an indicator of organic DBP precursors, TOC serves as the basis for coagulation requirements in the U.S. EPA regulations.

pH Correction: The pH level may have to be corrected during the treatment process for a variety of reasons. Some chemicals are more effective at certain pH levels, so pH adjustments may be necessary to optimize disinfection. Further, some treatment processes alter pH.

Corrosion Control: In the plant and distribution system, corrosion control must include the control of environmental parameters, the addition of chemical inhibitors, electrochemical measures, and system design considerations. Corrosion control and inhibitor chemicals include polyphosphates, zinc

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[46] Federal–Provincial Subcommittee on Drinking Water, 1999, "Bromate," establishes an IMAC of 0.01 mg/L. See <http://www.hc-sc.gc.ca/ehp/ehd/catalogue/bch_pubs/summary.pdf>.

[47] Geosmin is "the common name for *trans*-1,10-dimethyl-*trans*-9-decalol, an earthy-smelling chemical produced by certain blue-green algae and *Actinomycetes*. This odorous compound can be perceived at low nanogram-per-litre concentrations": Symons in Singer, p. 183.

[48] K. Mains, 2001, personal communication, June 18.

[49] W.B. Dowbiggin, 2001, "Advanced water treatment without advanced cost," proceedings at the American Water Works Association Annual Conference, Washington, DC, June 17–21.

orthophosphates, and silicates.[50] Electrochemical methods convert the infrastructure to a cathode (a receiver of electrons) to prevent chemical reactions from occurring or, more precisely, to confine them to the sacrificial anode.

Taste and Odour Control: Offensive taste and odour, often seasonal problems, arise most commonly as a result of generally very small amounts (ng/L) of secretions from blue-green algae and *Actinomycetes.* There are also a wide number of sources that have a human origin. No single treatment can be specified without an exhaustive characterization of the water, but in general, oxidation followed by filtration reduces the problem to manageable levels.[51]

6.3.5 Choosing an Optimal Treatment Strategy

The choice of an efficient strategy must reflect the fundamental objective of disinfection, which is to ensure the reliable removal or inactivation of pathogenic micro-organisms, thus dealing with the largest and most acute health risk. But the benefits and appropriateness of available technologies must also be evaluated in the context of the whole water system, from source water to tap. The strength and reliability of the technical barriers must reflect the risks associated with the level of contaminants in the source water. As for treatment, disinfection is the first but not the sole objective: the removal of hardness, particles, DBP precursors, natural organic matter, colour, iron, manganese, taste and odour, trace contaminants, and so on must also be taken into account when selecting the best treatment solutions.

The order in which individual treatment steps are arranged can affect both their effectiveness and the overall efficiency of the treatment processes. Some steps are affected by other processes or by water properties or constituents. Some result in by-products that must be removed. For example, the effectiveness of disinfection in general and UV irradiation in particular are maximized when turbidity is low, so these processes are usually performed after chemically assisted filtration. Treatment for iron and manganese must be followed by filtration to remove the resulting sludge. Some disinfectants form nuisance residuals that need to be removed. Moving the point of chlorine addition to the point of minimum dissolved organic carbon can reduce DBP formation. However, since disinfection is improved by maximizing contact time, a strategy favouring the reduction of DBPs may make disinfection less efficient.

[50] Canada, National Health and Welfare, p. 188.
[51] HDR Engineering Inc., pp. 538–554.

Beyond simply performing the steps in the right order, the quantities of chemical additives may have to be continuously adjusted as a result of slight changes in such raw water parameters as temperature and turbidity. Chemical disinfection is particularly delicate because the desired dose range is typically narrow to inactivate microbial pathogens and minimize DBP formation.

6.4 Water Recycling

All water is recycled through nature's hydrological cycle. The term "direct recycling" means treating wastewater so that it can be reused immediately for drinking purposes. This extreme of treatment is clearly required in some places, such as in space or in deserts, where a grave shortage of water exists alongside a relatively unconstrained demand. However, Ontario does not require such extreme measures and should not permit the increased risks that come from direct recycling. That said, it is inevitable, even in Ontario, that wastewater after treatment will be discharged into the environment to enter the source water of drinking water systems. Both California and Florida indirectly recycle water to some degree, through groundwater recharge, irrigation projects, and the like, but not without controversy.[52] However, it will not be long before an amount equal to half of Ontario's reliably available annual water supply is used, in some form, at least once. In inland areas of intense use, such as in the Grand River basin, water is now being used much more intensively than is the Ontario average. Under these circumstances, and with the example of such non-arid but industrialized regions as Europe's Rhine River valley, Ontario should at least keep up-to-date with recycling research in developed countries.

Water recycling can reduce the amount of water needing to be treated through the use of a dual water supply system. This relatively expensive technique is particularly suited to regions where raw water is costly or scarce, as in parts of the United States, the Middle East, and even northern Canada. These systems separate grey water (bath, dish, and wash water) from black water (household sewage). Black water is sent to a sewage treatment plant, as it is in traditional systems. Grey water is recycled and brought back into residences via a second local distribution system. This water is then used for non-potable purposes, such as toilet flushing and garden irrigation. Grey-water recycling systems can

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[52] For example, see M. Zapler, 2001, "Recycled water draws scrutiny," *Mercury News* (San Jose), October 21, p. B1.

be adopted at the individual or communal level; in Australia it is used in communities ranging from 1,200 to 12,000 households.[53]

Grey water is a lesser source of pathogenic micro-organisms and parasites than sewage is, and its organic content decomposes much faster. It is not, however, an acceptable source of drinking water at present. Laundry and kitchen wastes can be heavily loaded with pathogens as well as more generalized biochemical oxygen demand.

Rainwater reclamation is similar in principle to grey-water recycling, but the reclaimed rainwater is potentially much cleaner, depending on how it is collected and stored. The water is used, untreated, for purposes not requiring water of a quality as high as that of drinking water. Although not as reliable, rainwater reclamation is a cheaper and healthier alternative to grey-water recycling. In regions where the wells produce hard water, rain barrels are common because rainwater is much softer. Its attractiveness for bathing and hair washing can lead, as in Walkerton, to breaches in system integrity through mismanaged cross-connections. There seems to be no compelling reason to prohibit rainwater use by individual households so long as there is no potential for contaminating a communal supply. The information provided to the public about individual household supplies should include advice about good practice.

There is no need for the direct recycling of grey or black water for potable uses to be permitted under Ontario Regulation 459/00.

6.5 Wastewater Treatment

Because sewage treatment plant standards and operations go beyond the mandate of this Inquiry, I make only the following recommendation, recognizing that it should be seen in the context of a larger program of reform and upgrading:

Recommendation 32: The provincial government should support major wastewater plant operators in collaborative studies aimed at identifying practical methods of reducing or removing heavy metals and priority

[53] N. Booker, 2000, "Economic Scale of Greywater Reuse Systems" in *Built Environmental Innovation & Construction Technology*, Number 16 (Canberra: CSIRO); see <http://www.dbce.csiro.au/inno-web/1200/economic-scale.htm> [accessed May 2, 2002].

organics (such as endocrine disruptors) that are not removed by conventional treatment.

Sewage treatment plant discharges should be brought within the cumulative loadings established under the watershed management plans recommended in Chapter 4.

A brief discussion of wastewater treatment technology is appropriate here. Technically, wastewater treatment shares many features with drinking water treatment. An impure influent must be cleaned, but not to the same standards as those required for drinking. Rather, the standards are constructed (somewhat loosely) around the notion of no harm being done to receiving waters or their fauna. It is not just technical similarity that makes the topic worthy of concern, however. Protecting source waters by introducing sewage treatment is one of the most important public health measures ever devised.[54] Treatment techniques are grouped into imperfectly defined baskets labelled as primary, secondary, and tertiary (see Table 6.3).[55]

Primary treatment involves little more than screening raw sewage, separating the grit particularly associated with infiltration and with combined storm and sanitary sewers, and sedimentation. "It is unlikely that a certificate of approval would be issued by MOE today for a new primary plant. Although several primary plants exist throughout the province, most of them face regulatory pressure to … move toward secondary treatment."[56]

Secondary treatment adds a biological reactor – active or passive, aerobic or anaerobic – in which bacteria absorb dissolved and colloidal organic matter so that they can be separated from the aqueous phase. The biological sludge that is typically separated by sedimentation can be further stabilized by digestion, in which the microorganisms metabolize the available organic matter until it is all consumed, effectively starving to death. Anaerobic digestion, the normal process in a septic tank, produces methane gas and a relatively inert sludge.

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[54] J. Benidickson, 2002, "Water supply and sewage infrastructure in Ontario, 1880–1990s: Legal and institutional aspects of public health and environmental history," Walkerton Inquiry Commissioned Paper 1. S. Gwyn (1984) has given a wonderful account of miasmic Ottawa in the 1870s in her history of the city: *The Private Capital* (Toronto: McClelland and Stewart).
[55] E. Doyle et al., 2002, "Wastewater collection and treatment," Walkerton Inquiry Commissioned Paper 9, contains a fuller description, covering not only technology and standards, but also the current state of the art in Ontario and comparisons with a number of other jurisdictions.
[56] Doyle et al., 2002, Paper 9, p. 100.

Table 6.3 Typical Effluent Quality for Different Levels of Treatment (mg/L)

Parameter	Level of Treatment				
	Influent	Primary	Secondary	Tertiary	Objective[57]
Total suspended solids (TSS)	200	110	15	5	25
5-day biochemical oxygen demand[58] (BOD_5)	170	70	~15	~6	25
Total Kjeldahl nitrogen (TKN)	30	25	20	5	–
Total phosphorus (TP)	7	5	3.5	0.3	0.3

Note: In addition, typical influent carries 10^4–10^5 fecal coliforms and 10–100 enteric viruses per mL. Feces may contain 10^9 bacteria per gram.

Source: E. Doyle et al., 2002, "Wastewater collection and treatment," Walkerton Inquiry Commissioned Paper 9, Tables 4.1 and 4.2, pp. 98–99.

The most common form of secondary treatment in Ontario, the century-old activated sludge process, adds air to a mechanically stirred mix, which allows aerobic micro-organisms (the active component of the activated sludge) to flourish. These organisms then consume dissolved and colloidal carbonaceous matter so that, upon separation, the clarified effluent has a much-reduced biochemical oxygen demand. Effective exploitation of activated sludge occurred only after treatment specialists realized that the settled concentrated sludge should be recycled and mixed with incoming sewage to build up a high concentration of micro-organisms that would remove the organic matter on contact. Secondary treatment may also include phosphorus removal.

Tertiary treatment is generally required when the volume of receiving water is low or zero. "A dry or perennial stream is defined by the 7Q20 rule (referring to the minimum flow recorded or predicted over a 7-day period in the past 20 years)." [59] Tertiary treatment is usually required when streams run dry or when less than 10:1 dilution is available under the "7Q20 rule." The requirement is specified in terms of more stringent limits on effluent biochemical oxygen demand, total suspended solids, total phosphorus, and ammonia nitrogen than

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[57] This is a basic set of effluent quality standards; more stringent standards are required for more sensitive receiving waters.

[58] BOD is a generic measure of the biodegradable organic matter present in water, as exhibited by the dissolved oxygen consumed by bacteria as they decompose organic compounds. When receiving waters are overloaded with BOD, the limited supply of dissolved oxygen can be totally consumed, creating anaerobic conditions and killing all higher forms of life.

[59] Doyle et al., 2002, Paper 9, p. 111.

can be achieved through secondary treatment. Filtration, often chemically assisted, through beds of ground anthracite and fine sand, is the norm. The chemicals used for coagulation, the familiar alum or ferric chloride from drinking water treatment, assist in capturing phosphorus.

Disinfection can be added to any of these processes, although the standards required are quite different than they are for drinking water. (Ontario tolerates 100 *E. coli* colonies per 100 mL in water used for recreation.) Chlorine is the most common disinfectant, but it has all the disadvantages that were noted earlier for drinking water – handling problems, need for precise dosage, DBPs – as well as one other: the final effluent must be dechlorinated before release because even the small quantities associated with a chlorine residual in drinking water distribution systems can be harmful to aquatic fauna. Fish, crustaceans, and other aquatic organisms breathe dissolved oxygen, with the result that they will be exposed to dissolved chlorine through their respiratory apparatus as well as through their gastrointestinal tract. Across all species, the gastrointestinal tract is far less susceptible to chemical insult than are the respiratory organs, which likely explains why fish and other aquatic organisms are so much less tolerant of dissolved chlorine than are humans.

UV radiation has gained widespread acceptance for sewage disinfection in the past decade in Ontario and has been the technique of choice for treating drinking water for a longer period in Europe. According to Doyle,

> UV systems consume much more power than chlorination, but they have many advantages, including
>
> - very short retention times of one minute or less, compared to 30 minutes for chlorine (hence compact size),
> - non-toxic effluent,
> - no residual by-products such as trihalomethanes,
> - no need to transport, store and handle hazardous chemicals,
> - no need for emergency ventilation and scrubbing systems as necessary for chlorine,

- simple and accurate process control, and
- low and simple maintenance.[60]

Membrane technology is emerging as a strong competitor to UV disinfection; indeed, its first large-scale use was for the purification of wastewater in Europe. Their considerable advantages can overcome an initial cost disadvantage (which is declining). Again, Doyle states:

- They eliminate secondary clarifiers, which invariably are the limiting process in terms of plant rating and performance.
- They eliminate tertiary filtration.
- Aeration tanks can operate at a mixed-liquor suspended solids (MLSS) concentration of approximately 15,000 mg/L, compared to 2,000–5,000 mg/L for conventional plants. Simplistically, this reduces the aeration tank footprint and volume by a factor of 3 or 4, which is a dramatic difference made even more so when the elimination of clarifiers and filters is taken into account.
- Rather than reduce the size of the aeration tank, the high MLSS concentration can be used to increase solids retention time, promote nitrification, and reduce the volume of solids or sludge …
- Membrane pore sizes are small enough to strain out bacteria physically, effectively eliminating the need for disinfection.
- Effluent suspended solids are consistently maintained at <5 mg/L to non-detectable, regardless of the quality of the flocculated mixed-liquor solids, a factor crucial to the operation of conventional secondary clarifiers.[61]

For all water treatment processes, there remains the problem of getting rid of the (semi-)solid sludge left at the end of these processes. The biosolids can be

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[60] Ibid., p. 117.
[61] Ibid., pp. 120–121.

incinerated, thus contributing to Ontario's air pollution, or they can be partially dewatered and applied to agricultural land, as discussed in Chapter 4. When biosolids are completely dried and pelletized, they may be used as an organic fertilizer. In all the recycling methods, however, the control of contamination by heavy metals and key endocrine-disrupting substances is perhaps the most intractable problem. The wide variety of endocrine-disrupting substances, the fact that many are not sequestered or degraded by conventional treatment and are apparently ubiquitous in rivers downstream from cities or intensive livestock agricultural areas,[62] is a matter for concern and will require research in many jurisdictions, both in Canada and abroad.

6.6 Emerging Water Treatment Technologies

The treatment for protozoan pathogens has been a major topic of professional debate in the past few years. The debate will likely continue, although recent developments in membranes and UV radiation technology mean that attention is shifting to application rather than technological development as such. Although most water-borne viruses seem susceptible to known disinfection and filtration techniques (occasionally at higher dose or *CT* rates), more discussion is needed about these viruses. As a group they are poorly understood. Research is required to determine not only the risks they pose to people, but also to gather basic information about their sources and persistence in raw and finished waters.

The report on contaminants commissioned for the Inquiry,[63] as well as the expert meeting on contaminants, proposed that the main chemical contaminants of concern for drinking water in Ontario were lead, DBPs, nitrate/nitrite, fluorides and water treatment chemicals, and, potentially, pharmaceuticals and other endocrine disruptors. Better monitoring was recommended for pesticides and herbicides. Of these substances, the knowledge base concerning soluble antibiotics, other pharmaceuticals, and endocrine disruptors appears weakest.

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[62] K.K. Barnes et al., 2002, *Water Quality Data for Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999–2000,* Open File Report 02-94 (Iowa City, IA: United States Geological Survey).

[63] L. Ritter et al., 2002, "Sources, pathways, and relative risks of contaminants in water," Walkerton Inquiry Commissioned Paper 10. Environment Canada has published a broad review of 15 classes of hazard, summarizing current knowledge and suggesting areas for further research: Environment Canada, 2001, "Threats to sources of drinking water and aquatic ecosystem health in Canada," *NWRI Scientific Assessment Report Series 1* (Burlington, ON: National Water Research Institute) <http://www.cciw.ca/nwri/threats/threats-e.pdf>.

Because their concentrations in source waters are so low, the detection of these contaminants is difficult and expensive, and epidemiological studies are exceptionally difficult.

All of these chemicals are usually present, if at all, in very small concentrations, a situation that poses difficult engineering questions for treatment design. Ion exchange methods and enhanced membrane treatment are the focal points of much current work. The United States Environmental Protection Agency, as noted in Chapter 5, has a formal process in which larger water systems screen for the presence of any of a long list of suspect chemicals.[64] Whenever possible, the best option is to choose source waters already low in the contaminants that are difficult or expensive to sequester through conventional water treatment.

New technologies may be particularly helpful for very small systems, ranging from one to several dozen households. Sometimes, point-of-use devices may be more efficient for certain contaminants than large central facilities.[65]

Continuous improvement in water quality in response to emerging threats will require new and refined treatment techniques. A delicate balance must be achieved between innovation and reliability. A promising new treatment, if implemented without careful testing and evaluation, may have unhappy side effects or may be temperamental and require constant attention from highly skilled people to make it work as intended.

Society is properly risk-averse when it comes to public health. But an approach that unnecessarily slows the adoption of proven new techniques may have high social costs, too. The assessment, evaluation, and improvement of novel water treatment technologies prior to licensing their routine use should be done by the MOE's Drinking Water Branch.

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[64] United States Environmental Protection Agency, 2001, "Reference Guide for the Unregulated Contaminant Monitoring Regulation," EPA 815-R-01-023 (Washington, DC) <http://www.epa.gov/safewater/standard/ucmr/ref_guide.pdf>.

[65] P.L. Gurian and M.J. Small, 2002, "Point-of-use treatment and the revised arsenic MCL," *Journal of the American Water Works Association*, vol. 94, no. 3, pp. 101–108.

6.6.1 The Role of the Ministry of the Environment in Technology Development and Evaluation

Recommendation 33: The Ministry of the Environment should be adequately resourced to support a water sciences and standards function in relation to drinking water.

At present, the MOE's Environmental Sciences and Standards Division provides scientific support in relation to drinking water, as well as other aspects of the environment. In this division, there are four relevant branches: the Standards Development Branch, the Monitoring and Reporting Branch, the Laboratory Services Branch, and the Environmental Partnerships Branch. As it relates to drinking water, the science and standards function carried out by the Standards Development Branch and the Monitoring and Reporting Branch should be transferred to the new Drinking Water Branch that I recommend in Chapter 13. I discuss the future role of the Laboratory Services Branch in Chapter 9.

In this section, I discuss the important sciences and standards function to be carried out in the new Drinking Water Branch. As I indicate in Chapter 13, this function must be adequately resourced in terms of staffing, equipment, and other resources. At a minimum, the MOE's role in this regard includes

- evaluating research that has been done elsewhere to determine whether it is applicable in Ontario;
- supporting standards-setting processes;
- ensuring that research specifically relevant to Ontario is done;
- providing specialist expertise on a regular basis to support the new Drinking Water and Watershed Management branches of the ministry in the approvals and inspection activities (Chapter 12);
- coordinating, and partly funding, collaborative research involving universities and the water industry; and
- coordinating with Environment Canada and other agencies.

Ontario once had a world-leading reputation in research on water and wastewater treatment. The Ontario Water Resources Commission (OWRC), in its research activities, had the reputation for leading all organizations in Canada and was consulted by governments around the world. In 1972, the OWRC became part of the broader MOE. The change of focus, accompanied by budgetary pressures, meant a gradual reduction in the provincial government's capacity to stay abreast of technological developments in the water field. Although the capacity for building and managing waterworks remained, the capacity for innovation waned. The best practices manuals that the OWRC and its successor once published regularly became less frequent.[66] The last of these manuals were published in 1982 and 1984.

The private sector and, somewhat later, university researchers continued the work begun by the OWRC. Through the 1970s and 1980s, large engineering firms provided the new infrastructure demanded by a growing and increasingly environmentally conscious population. Since about 1990, Ontario universities have begun to pay new attention to water treatment. The University of Waterloo, through its pioneering engineering faculty, has been a consistent leader. In recent years, the federal government has supported this regrowth with a number of endowed chairs and a new Network of Centres of Excellence, which is centred at that university. The many other university research centres include the University of Guelph Centre for Land and Water Stewardship, the Trent University Water Quality Centre, and the University of Waterloo Centre for Groundwater Research and chair in groundwater remediation.

The rise of university research contrasts strongly with the increasing financial pressure that has curtailed the MOE's research capacity. The question is whether this imbalance should continue. I start with the premise that, one way or another, the MOE will be the ministry that is required to license the application of water treatment technology in Ontario. To what degree can it rely on work done elsewhere in coming to its regulatory decisions?

A number of resources are available to the MOE. The Canadian Construction Materials Centre, part of National Research Council (NRC) Institute for Research in Construction, was established as a solution to this problem in the construction industry. It evaluates innovative materials, products, systems, and services with respect to their intended uses and applicable standards.[67] The Canadian Commission on Construction Materials Evaluation, which includes

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[66] Ontario, Ministry of the Environment, 1982, "Guidelines for the Design of Water Treatment Works," and 1984, "Guidelines for the Design of Sewage Treatment Plants."
[67] See the Canadian Construction Materials Centre Web site <http://www.nrc.ca/ccmc/home_e.shtml> [accessed May 5, 2002].

members of the general public as well as representatives from industry and government bodies, provides policy and technical advice.

The NRC's Canadian Infrastructure Technology Assessment Centre (CITAC) offers similar services for infrastructure products. Its main focus is wastewater management technologies for residential purposes. On a fee-for-service basis, CITAC establishes testing methodologies and performance criteria. Testing is outsourced to an accredited facility for product assessment. Subsequently, CITAC evaluates the results of the assessment and provides a technical opinion on the product's suitability for use.[68]

The Environment Technology Verification (ETV) program is similar in that it "provides validation and independent verification of environmental technology performance claims."[69] ETV was once a federal concern, but it is now a private company owned by the Ontario Centre for Environmental Technology Advancement (OCETA) and operating under a licence agreement with Environment Canada. Products can be assessed within the ETV program if they are an environmental technology, provide environmental benefits, address environmental problems, or are an equipment-based environmental service.[70] These include water and wastewater treatment technologies. A recent success of the program is a novel process to remove arsenic from drinking water.

The American Water Works Association Research Foundation (AWWARF) is a principal source of research on new technology, methods, and evaluation. A strength of its large and active research program is the manner in which it uses its spending power to bring operators, university researchers, and the engineering profession together. A number of Ontario utilities are members of the AWWARF and participate in its projects, which benefit water consumers everywhere, and this cooperation should be encouraged.

The aim of the MOE should be to develop sufficient expertise for Ontario's circumstances without duplicating research and development carried out by other organizations. The MOE should have widely experienced people on staff who keep up-to-date with developments here and abroad and who evaluate those developments for the MOE's standards-setting and approvals processes. The ministry's staff should provide expert advice on whether material,

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68 Harry Baker, NRC, CITAC, 2002, personal communication, January.
69 See the ETV program Web site <http://www.etvcanada.com/English/e_home.htm> [accessed May 5, 2002].
70 Ibid.

machinery, or water quality standards that have been developed in other leading jurisdictions can and should be adopted in Ontario. They will need funds to attend conferences, to travel, and occasionally to host expert workshops on matters of Ontario interest: cold-water chemistry and the boreal source waters of much of Ontario will not attract as much attention outside our borders as we might hope. Some funding should also be made available to sponsor Ontario utilities, university scientists, and engineers in collaborative research projects of the sort that the AWWARF organizes, and resources should be available for archiving and disseminating the results of the work to interested parties in Ontario.

One implication of this approach is that the MOE staff should be allowed and encouraged by, among other things, their salary structure to develop a high level of technical proficiency, rather than relying on advancement to management as the only route to career progression.

A benefit of this approach is that it will allow the creation of an environment in which innovative Ontario companies will not have to go abroad for trials and first orders. The MOE currently applies a cautious approach in recognizing new technology, an approach that is perhaps too cautious in failing to recognize pilot plants operated in other jurisdictions. Current policy is as follows:

> Since new technologies pose a higher risk of failure, the Ministry's role is to protect public and environmental safety by ensuring that the risk of failure is reduced to an acceptably low level. This is achieved through the approvals process where the site specific application of new technology is reviewed by an engineer. Pilot plant installations are approved provided that acceptable safeguards are designed into the system to eliminate any degradation of treated water quality. Technology is considered by the Ministry to be proven usually when at least three separate installations can operate at near design capacity for three years without major failures of the process, unit or equipment to perform as designed.[71]

Given the infrequency with which wholly new installations are undertaken in Ontario, this process can take far too long. In some cases, it may be appropriate simply to adopt approvals given in other provinces or U.S. states that apply rigorous standards.

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[71] Ontario, Ministry of the Attorney General, 2001, memorandum, Fran Carnerie to Jim Ayres, December 14.

6.7 Ontario Regulation 459/00

Treatment technologies are driven by regulatory requirements. I conclude this chapter with observations on Ontario Regulation 459/00, the current regulation addressing large waterworks, and suggestions for its improvement. I discuss Ontario Regulation 505/01, which regulates smaller systems, in Chapter 14 of this report.

Ontario Regulation 459/00, the basic regulation for larger waterworks, was created shortly after the tragic events in Walkerton. Its commendable results were that it made enforceable in law the standards for quality and sampling that hitherto had been guidelines or objectives, and it improved information management, including public access to information. The main changes introduced by the regulation are summarized here:

- Groundwater must be disinfected – in practice, with chlorine (s. 5).
- Surface water must be subjected to chemically assisted filtration and disinfection or, in the view of the MOE Director, be given equivalent or better treatment (s. 5).
- An exemption from disinfection may be made only if the equipment and chemicals for disinfection are installed and available for instant use if needed (s. 6).
- A more onerous sampling regime is enacted (s. 7) that requires, among other things, that testing be done either in a laboratory accredited for the particular test by the Canadian Association for Environmental Analytical Laboratories, operating under the aegis of the Standards Council of Canada (s. 2), or by staff certified for the procedure in question (s. 7).
- Notification requirements are formalized (addressing the non-notification problem that contributed to the severity of the Walkerton outbreak), and requirements to take any necessary corrective action and to inform the public are introduced (ss. 8–11).
- An exhaustive quarterly public reporting of test results and the actions taken are to be made available to the public (s. 12).

- Consulting engineers are to be retained every three years to make a detailed examination of the works and to prepare reports according to an MOE outline.

I pause to introduce certain documents and their customary abbreviations. The old "Ontario Drinking Water Objectives" (ODWO)[72] and the technical bulletin "Chlorination of Potable Water Supplies" (the Chlorination Bulletin)[73] are now contained in a document entitled "Ontario Drinking Water Standards" (ODWS) and referred to in Ontario Regulation 459/00, now called "Drinking Water Protection – Larger Water Works."

In considering an application for an approval, the director must now have regard to the ODWS (s. 4(2)). Although portions of the ODWS relating to sampling and analysis, standards, and indicators of adverse water quality are schedules to the new regulation, the ODWS as a whole is not part of Ontario Regulation 459/00. In the discussion that follows, I summarize the provisions of the regulation and the ODWS and make a few relatively minor suggestions for improvements.

6.7.1 The Application of Ontario Regulation 459/00

The regulation applies to all water treatment and distribution systems requiring approval under section 52(1) of the *Ontario Water Resources Act* (OWRA), which states that no person shall establish, alter, extend or replace new or existing waterworks without a Certificate of Approval granted by a director (s. 3(1)).[74]

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[72] Ontario, Ministry of the Environment, Water Policy Branch, 1994, "Ontario Drinking Water Objectives" (1994 revision).
[73] Ontario, Ministry of the Environment, Water Policy Branch, 1987, "Chlorination of Potable Water Supplies," Technical Bulletin 65-W-4 (updated March 1987); the old Chlorination Bulletin has been replaced by "Procedure B13-3: Chlorination of Potable Water Supplies in Ontario," at p. 59 of the ODWS.
[74] Ontario Regulation 459/00, s. 3(1).

The following systems are exempt from approval under the OWRA:

- waterworks used only for supplying water that is required for agricultural, commercial, or industrial purposes and that is not required under any Act or regulation made under any Act to be fit for human consumption (s. 52(8)(a));

- waterworks not capable of supplying water at a rate greater than 50,000 L per day (s. 52(8)(b));

- privately owned waterworks that supply five or fewer private residences (s. 52(8)(c)); and

- waterworks that may be exempt by regulations made under the OWRA (s. 52(8)(d)).

In addition, Ontario Regulation 459/00 exempts the following water treatment and distribution systems from regulation:

- systems that obtain their water from another water treatment or distribution system. This exemption does not apply if the system obtaining the water is owned or operated by a municipality or the Ontario Clean Water Agency (OCWA), nor does it apply if the system obtaining the water supplies water to a municipality or the OCWA. In addition, systems that rechlorinate or otherwise treat their water do not qualify for this exemption (s. 3(2));

- systems that supply 50,000 L of water or less during 88 days or more in a 90-day period, unless the system serves more than five residences (s. 3(3)); and

- systems that do not have a capacity of supplying more than 250,000 L per day, unless the system serves more than five residences (s. 3(4)).

If any of the exemptions under section 52 of the OWRA or Ontario Regulation 459/00 are met, the system is exempt[75] from the requirements in the regulation.

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[75] Some water treatment systems or distribution systems not covered by O. Reg. 459/00 fall under O. Reg. 505/01, Drinking Water Protection: Smaller Water Works Serving Designated Facilities.

6.7.2 Minimum Level of Treatment and Chlorination Requirements

Section 5 of Ontario Regulation 459/00 sets out the minimum requirements for water treatment. Disinfection by chlorination or an equally effective treatment is now mandatory for all water works captured by the regulation, unless a variance is granted (ss. 5(3) and 6). Groundwater sources must be treated by disinfection (s. 5(1)), whereas surface water sources must be treated by chemically assisted filtration and disinfection or other treatment capable, in the Director's opinion, of producing water of equal or better quality (s. 5(2)).

The minimum treatment requirements once found in MOE policy documents[76] are now law. However, Ontario Regulation 459/00 contains an exemption for water obtained exclusively from groundwater sources (s. 6(2)). Water obtained exclusively from groundwater sources may not require disinfection or chlorination if, among other things, the Medical Officer of Health consents, standby disinfection equipment and chemicals are readily available, and a public meeting has been held on the issue (s. 6(2)(ii),(v),(vii)).

According to Procedure B-13-3, groundwater supplies must maintain a minimum chlorine residual of 0.2 mg/L after 15 minutes of contact time prior to reaching the first customer. This minimum residual is lower than the minimum level of 0.5 mg/L identified in the Chlorination Bulletin, which allowed a 0.2 mg/L residual only in circumstances of uniformly low turbidities and in supplies that were proven free of hazardous bacterial contamination.[77]

Procedure B-13-3 sets the same minimum requirement of 0.2 mg/L after 15 minutes of contact time for surface waters. This minimum residual level is in addition to a level of treatment determined on the *CT* basis. A minimum 3-log inactivation is required for *Giardia* cysts, and a minimum 4-log inactivation is required for viruses.

The inactivation requirements for surface water also apply to groundwater under the direct influence of surface water, but under certain circumstances, inactivation may be achieved by disinfection only. However, a definition for

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[76] Ontario, Ministry of the Environment, Water Policy Branch, 1994, pp. 8–9.
[77] Ontario, Ministry of the Environment, Water Policy Branch, 1987, p. 9.

groundwater sources under the direct influence of surface water is not included in Procedure B-13-3, the ODWS, or the regulation. The government has used a fairly complex definition in a policy document.[78]

6.7.3 Sampling and Analysis Requirements

Ontario Regulation 459/00 makes mandatory the old sampling recommendations of the ODWO (s. 7 and Schedule 2). Generally, the sampling and analysis requirements for chemical and physical parameters under the regulation are either the same as, or more stringent than, those of the ODWO. Where the ODWO only recommended continuous chlorine monitoring for surface water sources serving a population over 3,300, continuous monitoring is now mandatory for service water sources serving populations of 3,000 or more. In addition, more pesticides and volatile organics must be monitored under the regulation than under the ODWO.[79] The regulation also allows for additional sampling requirements, if necessary (s. 7(1)(b)).[80]

The regulation states that "ground water under the direct influence of surface water is considered to be surface water" for the purpose of sampling and analysis,[81] but the absence of a legal definition for such a source may make the enforceability of this provision difficult. I prefer that treatment requirements be determined on a case-by-case basis, as I laid out in section 6.2.

Under Ontario Regulation 459/00, waterworks must now use an accredited laboratory (s. 7(3)) unless they are using continuous monitoring equipment to measure operational parameters.[82] An accredited laboratory is one that has either been accredited by the Standards Council of Canada (SCC) or has obtained accreditation for analysis that, in the director's opinion, "is equivalent to accreditation" by the SCC (s. 2(1)).

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[78] Ontario, Ministry of the Environment, 2001, "Terms of Reference for Hydrogeological Study to Examine Groundwater Sources Potentially under Direct Influence of Surface Water" <http://www.ene.gov.on.ca/envision/techdocs/4167e.pdf> [accessed April 30, 2002].

[79] Epoxide is no longer included on the list of monitored pesticides in Table D of Schedule 2 of O. Reg. 459/00.

[80] This section could theoretically be used to monitor new chemical or physical parameters that pose a health-related threat to water quality.

[81] This designation makes a continuous chlorine residual monitoring system mandatory; see Schedule 2 of O. Reg. 459/00.

[82] Operational parameters such as turbidity, pH, and chlorine residual do not have to be measured by an accredited laboratory.

An operator must ensure that the MOE has been notified of a laboratory's name (s. 7 (5)), and the laboratory cannot subcontract the analysis unless specific requirements have been met (s. 7(7)). Copies of water analysis reports submitted by a laboratory to the owner of a water treatment or distribution system must also be sent to the MOE (s. 7(10)).

Section 7(4)(c)(i) of the regulation allows holders of class 1, 2, 3, or 4 water treatment or water distribution licences to test for the operational parameters listed in Schedule 3. These operational parameters include pH, turbidity, chloramine, alkalinity, and residual chlorine. Section 7(4)(c)(ii) allows people with one year of laboratory experience or those who have passed a water quality analysis course to test for Schedule 3 operational parameters. In practice, this water quality analysis course requirement has been interpreted as a water quality analyst licence.[83] The director has a discretionary power to deem someone a water quality analyst if, in the director's opinion, the person has the necessary experience, education, and training (s. 7(4)(c)(ii)).

6.7.3.1 *Maximum Acceptable Concentrations*

The maximum acceptable concentration (MAC) and interim maximum acceptable concentration (IMAC) standards for chemical and physical parameters in Ontario Regulation 459/00 remain virtually unchanged from the standards outlined in the ODWO. One improvement is that more pesticides and volatile organics are now monitored under the regulation. Also, the list of radiological MACs has expanded from five to 78. However, radiological parameters are not measured as part of the mandatory sampling program outlined in Schedule 2 of Ontario Regulation 459/00. Radiological sampling is mentioned in section 4.4 of the ODWS, but a specific program is not identified.[84]

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[83] See <http://www.oetc.on.ca/wqaqa.html> [accessed May 5, 2002].

[84] Section 4.4.1 of the ODWS states:

> The frequency of sampling for radionuclides is dependent on the concentration present in the supply. The higher the concentration of a radionuclide the more frequent the sampling. Where water sources are subject to discharges of radioactive waste, the sampling frequency for specific radionuclides should be increased.
>
> Most radionuclides can either be measured directly or expressed in terms of surrogate measurements such as gross alpha emission (e.g., radium-226) and gross beta emission (e.g., strontium-90, iodine-131, cesium-137). The gross alpha and gross beta determinations are only suitable for preliminary screening procedures. Compliance with the standards may

Consequently, sampling requirements for radiological parameters must be included in a Certificate of Approval for their MAC or IMAC standards to be legally enforced. Once their measurement is required, corrective action becomes legally enforceable by way of section 9(a) of the regulation.

6.7.3.2 *Indicators of Adverse Water Quality*

The indicators of adverse water quality under the ODWS include the ODWO indicators of unsafe and deteriorating water quality and additional indicators regarding sodium (for persons on a sodium-restricted diet) and pesticides without a MAC.

An additional indicator of adverse water quality under the ODWS occurs when “unchlorinated” water is directed into the system where chlorination is used or required.[85] Water with a chlorine residual below 0.05 mg/L is considered unchlorinated – a level that becomes the absolute minimum residual for any system covered under Ontario Regulation 459/00.

6.7.3.3 *Notification Requirements*

The regulation clarifies the confusion about the notification of adverse results. It is now mandatory for a waterworks owner to ensure that notice is given both to the local Medical Officer of Health and the MOE’s Spills Action Centre when analysis shows that a MAC or IMAC has been exceeded or indicates adverse water quality (s. 8(1), (2), (3), (4)). The notice must be confirmed in writing within 24 hours (s. 8(4)). In addition to notifying the owner, private laboratories are now legally bound to the same notification requirements as the owner (s. 8(2)).

be inferred if these are less than the most stringent MACs … When these limits are exceeded, the specific radionuclides must be measured directly. Tritium, a gross beta emitter, must be measured separately because the screening process is not sufficiently sensitive to detect low levels of tritium.

[85] O. Reg. 459/00, Schedule 6, para. 3.

6.7.4 Corrective Action

Instead of simply recommending corrective action, the regulation makes corrective action (including resampling) mandatory and outlines the appropriate corrective action to take when an indicator of adverse quality is identified (s. 9). If a MAC or IMAC is exceeded, a second sample must be taken (s. 9(a)). The corrective action required for an indicator of adverse quality depends on the type of indicator. The detection of *E. coli* requires flushing the mains to ensure that a free chlorine residual of 0.2 mg/L is achieved in all parts of the distribution system; the flushing must continue until two consecutive samples test negative for *E. coli*.[86] In general, the corrective actions outlined in section 9 and Schedule 2 of the regulation are consistent with those previously included in the ODWO.[87]

Unfortunately, the issue of resampling is now somewhat unclear when comparing the regulation and ODWS. Section 9(a) of Ontario Regulation 459/00 specifies that “another sample” must be taken if a MAC or IMAC is exceeded. The ODWS state that “immediate resampling is required” in this instance and defines “resampling” as follows:

> Resampling should consist of a minimum of three samples to be collected for each positive sampling site: one sample should be collected at the affected site; one at an adjacent location on the same distribution line; and a third sample should be collected some distance upstream on a feeder line toward the water source … The collection of three samples is considered the minimum number for each positive sampling site.[88]

As a result of its inclusion in the ODWS, the three-sample minimum is not a legal requirement unless it is included in a Certificate of Approval or a Director’s Order. It would be preferable for the regulation to be amended to use the ODWS definition.

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[86] O. Reg. 459/00, Schedule 6, para. 1.

[87] The language has also been improved, and confusion has been removed. The two ODWO provisions previously causing confusion (two consecutive samples detecting coliforms in the same site or multiple locations from a single submission, and more than 10% of monthly samples detecting coliforms) have been removed.

[88] See the ODWS, s. 4.2.1.1. This resampling definition is consistent with the older “special sampling” requirements in the ODWO, s. 4.1.3.

Further confusion is found in Schedule 6 of the regulation, which outlines the corrective action when "Indicators of Adverse Water Quality" are detected. The schedule uses the term "resample," but no definition is provided in either the schedule or the regulation. Some of the schedule's provisions simply state "Resample and analyze,"[89] whereas others state "Resample, take a corresponding raw water sample and analyze."[90] The preceding statement from Schedule 6 and the wording in section 9(a) imply that the term "resample" requires only one sample, not three as defined in the ODWS. The resulting inconsistency should be cleared up.

6.7.4.1 *New Requirements under Ontario Regulation 459/00*

The regulation also introduces a number of new requirements, many of which deal with information management:

- The owner of a waterworks is now required to post a warning when it does not comply with the sampling and analysis requirements for microbiological parameters or when corrective actions as outlined in the regulations have not been taken (s. 10).

- An owner must also make all information regarding the waterworks and the analytical results of all required samples available for the public to inspect (s. 11).

- Quarterly written reports must be prepared by the owner and submitted to the MOE that summarize analytical results and describe the measures taken to comply with the regulation and the ODWS (s. 12).

- Copies of these reports must be made available, free of charge, to any member of the public who requests a copy.

- Owners must submit an independent engineer's report according to the schedule contained in the regulation and submit triennial reports thereafter (s. 13).

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[89] O. Reg. 459/00, Schedule 6, paras. 1, 4, 5, and 6.
[90] Ibid., para. 8.

- Owners must ensure that analytical results from labs and all engineers' reports are kept for at least five years (s. 14).

Changes were also introduced with respect to sampling requirements. Sections 4.1.1 and 4.2.1 of the ODWO previously addressed the frequency and location of sampling and analysis for microbiological testing. They stated:

> Frequency of analysis and location of sampling points shall be established by the operating authority under the direction of the MOEE after investigation of the source, including source protection protocol and method of treatment …
>
> The minimum frequency and location of sampling is normally specified by the MOEE on the Certificate of Approval.

These references to the MOE are not directly included in either Ontario Regulation 459/00 or the ODWS. The regulation now states: "The owner of a water treatment or distribution system shall ensure that water sampling and analysis is carried out in accordance with" the regulation "or any additional requirements of an approval or an order or direction under the Act" (s. 7(1)). The ODWS says: "The site specific requirements for monitoring and analysis are reflected in the terms and conditions of the Certificate of Approval for the particular water supply system" (s. 4.1).

6.7.5 Issues Raised in the Part 1 Report of This Inquiry

The Part 1 report of this Inquiry mentions a number of confusing provisions in the ODWO and the Chlorination Bulletin.[91] These deficiencies were identified as follows:

1. lack of clarity in section 4.1.2 of the ODWO about whether the samples referred to include treated water samples;

2. uncertainty about the inspection required under section 4.1.4 of the ODWO when conditions of deteriorating water were detected;

[91] These references are found at the bottom of p. 357 of the Part 1 report of this Inquiry: Ontario, Ministry of the Attorney General, 2002, *Report of the Walkerton Inquiry, Part 1: The Events of May 2000 and Related Issues* (Toronto, Queen's Printer).

3. the difference between the corrective actions required by section 4.1.3 of the ODWO and section 5 of the Chlorination Bulletin; and

4. the difference in the language used in the two guidelines to set out the requirements for continuous chlorine residual monitoring.

Issue 1 concerns the section of the ODWO that listed the "Indicators of Unsafe Drinking Water" criteria. There was no definition of "distribution system." A question was raised about whether treated water samples taken from a well house were considered to be "from the distribution system." Schedule 2 of Ontario Regulation 459/00 now identifies "distribution system samples" as samples "taken in the distribution system from a point significantly beyond the point at which treated water enters the distribution system." This definition does not exactly address the question previously mentioned, but the provisions of Schedule 6 of the regulation, "Indicators of Adverse Water Quality," provide some further clarity. When identifying water samples, the Schedule 6 provisions dealing with bacteriological contamination use the following language: "any required sample other than a raw water sample." This language, in my opinion, removes any uncertainty about the location of sampling and whether a positive sample qualifies as an Indicator of Adverse Water Quality.

Issue 2 has been addressed by removing all language from the regulation and the ODWS that requires MOE inspections. I discuss the importance of inspection in Chapter 13.

Issue 3 has been dealt with by placing consistent corrective action requirements in either the regulation[92] or the ODWS.[93] However, as previously mentioned, uncertainty persists concerning the number of samples to be taken when resampling.

Issue 4 has been dealt with by including identical continuous chlorine monitoring provisions in Schedule 2 of the regulation and Table 2 of the ODWS.

I conclude this discussion of the regulation and the ODWS by observing that Ontario Regulation 459/00 represents a significant improvement in how the government addresses the treatment, monitoring, and reporting requirements. There are, however, advantages to be gained from some relatively minor changes.

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92 O. Reg. 459/00, s. 9 and Schedule 6.
93 ODWS, ss. 4.2, 4.3, and 4.4.