4 Water Treatment Technologies

4.1 Introduction

Treatment of municipal drinking water, which only became widespread in the latter part of the 19th century, provided one of history's more significant advances in public health protection. Prior to routine treatment, waterborne diseases such as cholera and typhoid were common; today such outbreaks are rare in Canada.[47] Nevertheless, the safety of our drinking water should not be taken for granted. Better techniques of analysis and improved medical testing frequently uncover new health dangers, some of which may be transmitted through water. We must therefore continue to develop the technology of drinking water treatment to combat these dangers and to ensure we can provide safe and acceptable drinking water.

4.1.1 Why We Treat Water

Water in the environment is never pure. All natural water contains impurities; some are innocuous, or even beneficial, and some are harmful. Ideally, to minimize health risks and the cost of treatment, we draw water from surface or groundwater sources that are as clean and as safe as possible. However, as populations grow and pollution increasingly stresses watersheds, we will become ever more dependent on treatment technologies for safe drinking water.

Because it is not usually necessary to control all contaminants found in source water, it is important to classify the different types. In general, contaminants divide into two categories, although some compounds belong to both:

- those that affect the *aesthetic* or *operational* characteristics of water, and
- those that affect *health*.

Many substances affect aesthetic or operational characteristics of water. Dissolved calcium and magnesium salts, for example, cause flow-restricting scale in hot-water heaters and appliances. Dissolved minerals also prevent soap and detergent lathering. It is desirable to remove these impurities from water even if they are not harmful to health. Other contaminants that affect the aesthetic quality of

[47] Canada, Health Canada, 2000a, *Canada Communicable Disease Report,* vol. 26 [online], [cited July 2001], <www.hc-sc.gc.ca/hpb/lcdc/publicat/ccdr/00vol26/index.html>.

water include compounds that cause unpleasant colour or taste, again without necessarily being harmful to health. Nevertheless, such colour- and taste-producing compounds often generate complaints because the public typically assumes that unpleasant looking or smelling water is unsafe.

While treatment facilities must deal with the aesthetic characteristics to satisfy the public's *perception* of safe drinking water, facilities must also provide water that is *actually* safe. This requirement is stipulated by law. Regulatory requirements typically divide health-related contaminants into two categories: those that present acute or short-term health risks, and those that present chronic or long-term health risks.

Contaminants that present acute health risks are typically biological rather than chemical. Micro-organisms such as *Escherichia coli,* hepatitis viruses, *Vibrio cholerae,* and *Cryptosporidium parvum* can infect a person through a single drink and cause severe illness within days. Furthermore, because illnesses caused by micro-organisms in drinking water can spread through person-to-person contact, a relatively small amount of contaminated drinking water can easily lead to widespread outbreak of disease. For these reasons, control of acute health risks generally takes precedence over chronic health risk concerns.[48]

Chronic risks are typically associated with chemicals that, when ingested at low concentrations over a long period of time, can cause an illness such as cancer. Many organic compounds – in particular certain pesticides and organochlorines – fall into this category. A number of metals such as lead, copper, and mercury can also cause long-term health effects by accumulating in the body to cause brain, liver, and kidney damage.[49]

In treatment process design, it is important to distinguish between acute health risks and chronic health risks. Treatment must *always* control contaminants

[48] Ontario, Ministry of the Environment, 2000d, *Ontario Drinking Water Standards*, PIBS #4065e [online], revised January 2001 [cited July 2001], <www.ene.gov.on.ca/envision/WaterReg/Pibs4065.pdf>; United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991, *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* ([Washington]: EPA).
[49] United States, Environmental Protection Agency, 2000a, *Copper* [online], (consumer factsheet) [cited July 2001], <www.epa.gov/safewater/dwh/c-ioc/copper.html>; United States, Environmental Protection Agency, 2000c, *Lead in Your Drinking Water* [online], EPA/810-F-93-001 [cited July 2001], <www.epa.gov/safewater/Pubs/lead1.html>.

that present an acute health risk, since even a brief lapse can cause immediate illness. Concentrations of contaminants associated with chronic health effects, in contrast, may occasionally exceed the predetermined safe thresholds, which are based on long-term exposure assessments. However, the average concentration over time must remain acceptably low. Regulations take these issues into account. Limits on acute health risks are typically accompanied by a requirement to "never exceed." Limits on chronic risks are usually based on a running average of measured concentrations, over a period of time, which tolerates occasional instances when an average limit is exceeded.

Nevertheless, good treatment adequately controls all risks associated with contaminants, both acute and chronic, while also providing water with aesthetic and operational qualities that are acceptable to the consumer. This requires a thorough understanding of treatment technologies and their limitations. The following sections discuss some of the technological options available, with an emphasis on how best to apply them to provide safe drinking water. Figure 4-1 shows a typical surface water treatment plant process layout.

4.2 Solids Removal

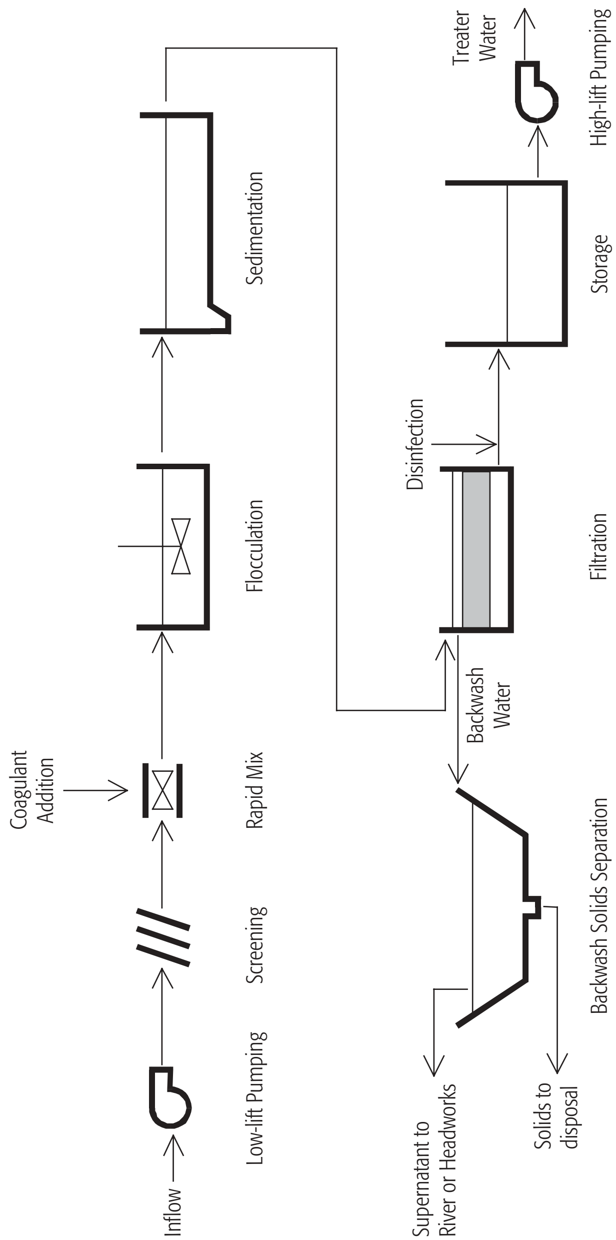
Any contaminants present in water that are not gases are commonly called solids. Solids can be in either dissolved or particulate form. They can consist of inorganic materials such as salts and minerals, nonliving organic materials such as humic acids leached from soils, or living matter such as algae and bacteria. Many solids are undetectable and have no effect on aesthetic, operational, or health qualities of water. Others, however, have an adverse impact on drinking water quality and must be removed. This section discusses various methods used to remove different types of solids.

4.2.1 Coagulation, Flocculation, and Sedimentation

General Description

The simplest method to remove solids from water is to allow the water to stand until all particles denser than water settle to the bottom (sedimentation). Then the clear overlying supernatant can be removed. Unfortunately, many particles do not settle fast enough for this process to be practical, so treatment steps are

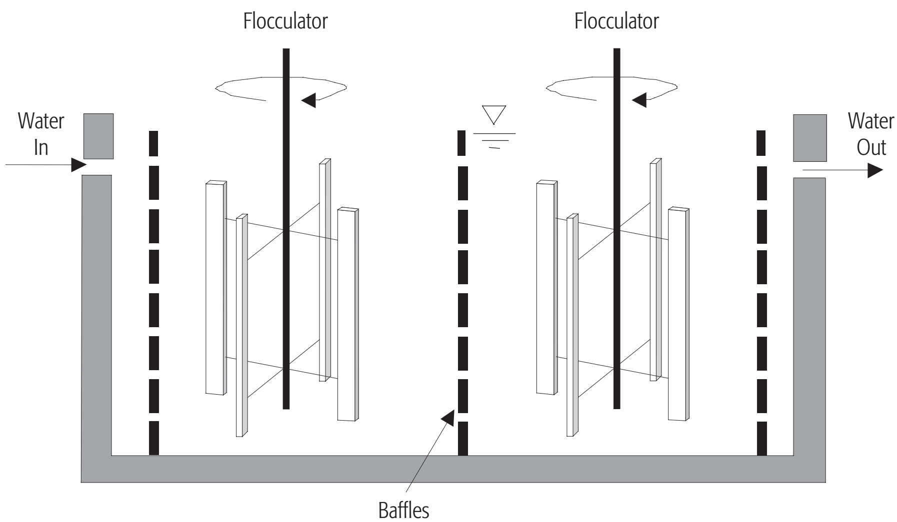
Figure 4-1 Typical Surface Water Treatment Plant Process Train



taken to accelerate their settling rate. This requires the addition of a chemical coagulant (usually aluminum sulphate or ferric salts) that allows small particles to become attached to one another, thus forming larger agglomerations. Gentle mixing encourages this coalescence of smaller particles into larger aggregates (flocculation). The G-value or velocity gradient is a measure of the degree of mixing taking place, with a higher value representing more aggressive mixing. The GT-value is the product of the velocity gradient (G) and the mixing time (T) and is a measure of the overall mixing energy applied. Because larger particles settle more quickly than smaller particles, coagulation and flocculation increase the speed and effectiveness of subsequent sedimentation. Figure 4-2 shows a typical flocculator layout.

For some waters, coagulation/flocculation is the only treatment step applied before filtration. Sedimentation is not used. In this process, called "direct filtration," coagulation and flocculation make particles bigger so that filtration is more effective, since larger particles are less likely to pass through the filter pores. Direct filtration is normally practised in waters that are relatively free of turbidity (the presence of suspended material) to begin with. Most of the drinking water treatment plants along the Great Lakes are direct filtration plants. "In-line" filtration is a similar process in which the flocculation step is also omitted.

Figure 4-2 Schematic of a Typical Flocculator



Impact on Health Risks

The coagulation/flocculation/sedimentation sequence is not designed to remove all particles, but rather only those that settle most easily (which tend to be the largest and densest). The goal is to polish the water in an economical way before it is directed through filters, which are more costly to operate. Many pathogens and chemical contaminants remain in the water following sedimentation, which therefore cannot provide complete protection against all health risks. Nevertheless, coagulation, flocculation, and sedimentation do provide some benefit in making the water safer to drink. The Ontario drinking water standards for disinfection indicate that where coagulation, flocculation, and sedimentation are operated correctly prior to filtration (as opposed to coagulation and filtration alone), subsequent disinfection need only provide 0.5-log (67%) of a total required 3-log (99.9%) *Giardia* inactivation, and 1-log (90%) of a total required 4-log (99.99%) virus inactivation.[50] These more lenient requirements for disinfection reflect research results that show some pathogen removal occurring through sedimentation. Furthermore, pathogens that escape sedimentation are more readily removed by filtration, because coagulation and flocculation cause small pathogens to become attached to larger, more filterable agglomerations of matter.

One further benefit of coagulation/flocculation/sedimentation is that it can lower the amount of organic matter in the water. Reduction varies, but typically ranges from 10% to 50%.[51] Organic matter is a precursor to many of the chlorination by-products that are known or believed to be harmful, such as trihalomethanes and haloacetic acids. These by-products form when organic matter reacts with chlorine that is added as a disinfectant or oxidant. If organic matter is partially removed (e.g., by sedimentation) before the addition of chlorine, the concentrations of the resulting by-products will be proportionally lower. Further benefits accrue because organic matter typically reacts with and consumes chlorine. With less organic matter in the water, less chlorine should achieve the same amount of disinfection, which in turn results in even less by-product formation.

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[50] Ontario, Ministry of the Environment, 2000d. See section 4.3.4 of this paper for an explanation of the terminology.

[51] United States, Environmental Protection Agency, 1998a, *Disinfectants and Disinfection ByProducts Final Rule* [online], 40 CFR Parts 9, 141, and 142 [cited July 2001], <www.epa.gov/safewater/mdbp/dbpfr.html>.

4.2.2 Filtration

General Description

Filtration separates solid particles from drinking water by passing it through a porous medium. The pores in the medium are small enough to prevent the passage of most particles, but not so small that water cannot flow through. As particles collect on the filter surface, the flow of water becomes more restricted until the filter must be washed. The wash process normally involves sending water back through the filter (backwash) to dislodge the particles; the dirty backwash water goes to a separate treatment process.

Of the many different types of filters, the common ones can generally be divided into three categories:

- granular media filters (rapid and slow)
- diatomaceous earth filters (or, more generally, "precoat" filters)
- membranes

The majority of drinking water treatment plants use rapid granular media filters, but some smaller communities may opt for slow media filtration or diatomaceous earth. Membranes are a relatively new technology in drinking water treatment, but, by providing more control over filter performance, they hold a great deal of promise for the future.

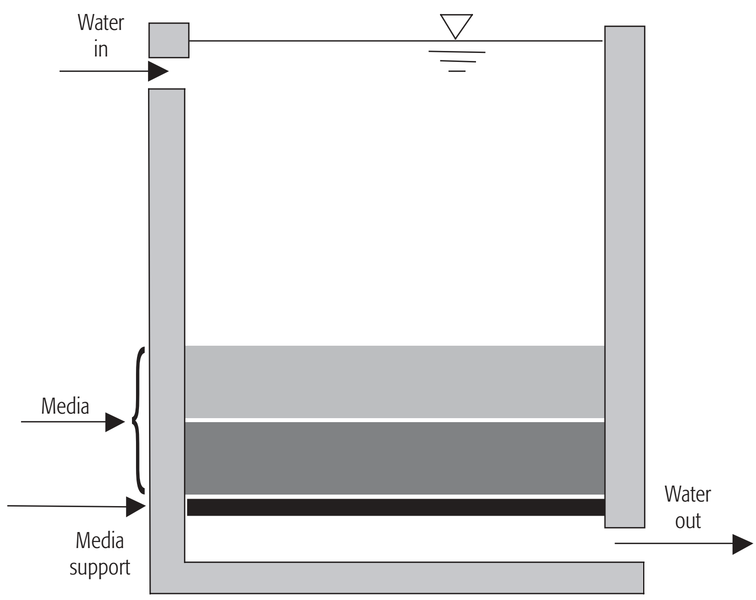
Granular Media

A rapid granular media filter is typically a basin that contains a 1.0–1.5 m bed of sand or anthracite (a type of coal). Alternatively, a combination of media – such as a layer of sand with an overlying layer of anthracite – can be used to increase filter performance. Water enters the basin and flows downward through the media into an underdrain collection system. The media (sand, anthracite, or other material) are selected so that the pore sizes are small enough to collect much of the particulate material in the water, ideally allowing only clean water to pass through. Figure 4-3 shows a typical layout for a granular media filter.

It is a common misconception that particle removal during granular media filtration occurs only through straining (like a sieve). In fact, many particles that are small enough to fit through the pores in the media are removed, simply by randomly running into the filter media during their passage and becoming attached.[52] Granular media filtration is therefore useful against a wide range of particulate contaminant sizes, from relatively large particles that are visible to the eye to small particles such as viruses and bacteria.[53]

Once water begins to flow through a filter, more and more particles become lodged on the surface of the medium and begin plugging the channels through which the water flows. This restricts flow through the filter and causes a pressure or *head* loss through the medium. If the flow restriction becomes unacceptable, or the loss in pressure too great, the filter must be taken out of service for cleaning. Also, if the filter is left in service for too long, particles that were entrapped near the surface are pushed deeper and deeper through the bed, eventually breaking through the bottom and into the treated water.

Figure 4-3 Typical Granular Media Filter Layout



[52] James M. Montgomery, 1985, *Water Treatment Principles and Design* (New York: John Wiley & Sons).
[53] United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.

Deciding when to remove a filter from service for cleaning is an important consideration. It is not practical to allow a filter-run to progress until flow restriction or head loss is so great that insufficient water can be produced to meet the demand of the community. However, a more important consideration is the quality of filtered water. It is possible, if not common, that particle breakthrough can occur before filter hydraulics become unacceptable. Therefore the operator must have a mechanism in place to avoid particle breakthrough.

The most common method to monitor filter discharge quality is to measure turbidity. Guidelines or standards in Canada and the United States specify that filter discharge turbidity must remain below a certain limit, commonly 1.0 NTU (nephelometric turbidity unit).[54] Evidence over the last decade has shown, however, that a correlation does not necessarily exist between turbidity and the passage of pathogens through a filter.[55] Partly in response to that evidence, many water treatment facilities have recently installed particle counters downstream of their filters. Particle counters provide a more accurate indication of filter performance than turbidimeters, allowing, for instance, measurement of the number of particles that fall within the size range of target pathogens. It is believed that during good filter operation, particle counts will remain at a steady, low value, but when filter performance begins to degrade, particle counts will show an immediate increase, alerting personnel to remove the filters from service for cleaning.

Filter Loading

The rate at which granular filters process water is termed the filter loading or filter rate. It is specified as the flow rate (in m^3/h) filtered by the surface area of the filter bed (m^2). The equation becomes $m^3/h/m^2$, or m/h. Thus, the filter loading rate is the average *velocity* (expressed in metres per hour) at which the column of water moves through the filter bed.

Rapid Granular Filtration

Rapid granular filtration is the most common form of filtration. The filter consists of a media bed supported by an underdrain system in a basin. Water

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[54] Ontario, Ministry of the Environment, 2000d.

[55] O. Schneider, J.K. Schaefer, and W. Kurtz, 1998, "Identification and prevention of particle breakthrough at low filtered water turbidities," in vol. D of *Proceedings of the American Water Works Association Annual Conference, Dallas* (Denver: AWWA), pp. 245–54.

enters the top of the basin, flows downward by gravity through the media, and collects in the underdrains. Different types of media can be used. Sand is the most common; however, it is now standard to overlay the sand with a layer of anthracite or other medium, creating two or perhaps three layers of media. The advantage of this approach is that the selected media are of different sizes, with the largest medium – having the largest pore spaces between grains – on top, and the smallest medium (with the smallest pore spaces) on the bottom. This way, only the largest particles are removed in the top portion of the filter, while smaller particles can penetrate deeper before being removed by the smaller filter medium on the bottom. This lets the entire filter volume remove impurities. If the filter medium were all of one size, the top would become clogged before the bottom, resulting in a waste of filter volume. Selecting appropriately sized filter media is therefore a critical step to ensure good filter performance.

This process is called "rapid" filtration because by housing the filter in a relatively deep basin (often several meters), a deep water column can be applied above the filter to 'push' the water through the media, accelerating the overall purification process to rates more rapid than were possible in earlier "slow" sand filters. This is important for treatment facilities that must provide a high flow rate of water to a community. However, faster filtration rates come with a price; there is a greater risk that impurities, and, more importantly, pathogens, can break through the filter because of the higher flow rates and pressures. For this reason, rapid granular filters must be more carefully operated and monitored than slow sand filters. The greater filtration flow rates (5–20 m/h for rapid filtration versus 0.1–0.2 m/h for slow sand filtration) also mean that the filters require more frequent cleaning, often in the order of once a day. All treatment systems contain several filters operated in parallel so that as individual filters are removed from service for cleaning, other filters continue to operate.

Cleaning of rapid granular filters is accomplished by a procedure known as backwashing. A stored volume of clean water flows back (upwards) through the filter bed, fluidizes the media, and allows trapped impurities to be released. Often, the backwash water is injected with air to enhance turbulence and to improve cleaning effectiveness. The upward flow of water carries the debris from the filter into backwash troughs, located above the media, that discharge to a wastewater collection system. There are several methods of handling this dirty backwash water. In the past it was often directed back to the original water source (river or lake) without treatment, or to a wastewater treatment plant. There is now considerable interest in cleaning the water on site, and redirecting the clean water back to the front end of the treatment train. Since it is normal for as much as 5% of the total treated water to be used for filter backwashing, reclaiming this water can lead to considerable savings in cost and water. The major complication with filter backwash reuse is the potential for concentrated amounts of pathogens, originally removed by the filter, to be reintroduced to the treatment process. Research is currently examining the disinfection requirements for backwash water to render it safe for recycle.

Rapid granular filtration is a very effective method of pathogen control, especially when preceded by coagulation and flocculation to render particulates (including micro-organisms) more amenable to filtration. Studies that led to the U.S. Surface Water Treatment Rule found that properly operated rapid sand filtration can conservatively be estimated to remove 2-log (99%) of *Giardia* cysts, and 1-log (90%) of viruses.[56] Filtration is therefore an important element in the multiple-barrier approach to making water safe to drink.

Slow Sand Filtration

Slow sand filters are conceptually similar to rapid granular filters in that water flows by gravity through a layer of sand and collects underneath. The main difference between slow and rapid filters is their rates. Because slow sand filters maintain a low flow rate, typically less than 0.2 m/h, the risk of particle breakthrough is much lower. A slow sand filter is also easier to operate, and is often suitable for smaller communities that may not have the resources to operate a more complex filtration system. The drawback of slow sand filtration is the slow water production rate. To compensate, the required surface area for a slow sand filter is generally much greater than that of the corresponding rapid filter. This results in significantly greater capital cost if the filter must be housed. Slow sand filters are therefore generally used only in smaller communities where the demand for water is likely to be proportionally lower.[57]

A slow sand filter can typically operate for months before it needs to be cleaned. During this time, a biological layer called the *schmutzdecke* forms on the surface of the sand and provides some particle removal. Most of the particles in fact are

[56] United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.

[57] Canada, Health Canada, Health Protection Branch, Environmental Health Directorate, 1993, *Water Treatment Principles and Applications* (Ottawa: Supply and Services Canada).

removed in the very top layer of the sand, or above the top of the bed.[58] To clean a slow sand filter, the top layer of sand must be physically removed and replaced.

Slow sand filters provide good pathogen control. *Ontario Drinking Water Standards* assumes that these filters can routinely remove 2-log (99%) of *Giardia* cysts and 2-log (99%) of viruses.[59] Studies also suggest that they can remove 2-log (99%) of *Cryptosporidium*.[60]

A commonly recognized weakness of slow sand filters is their inability to control colour and turbidity caused by fine colloids that are not effectively removed.[61] This is partially because slow sand filters are rarely preceded by coagulation. Slow sand filters are therefore only appropriate for systems whose source water is clear and free of colour, unless additional treatment is provided.

Granular Activated Carbon

Rapid granular filters may employ granular activated carbon (GAC) as a medium, either alone or in combination with layers of other media such as sand. GAC is a form of charcoal that, rather than physically trapping particles, acts by adsorbing organic compounds onto its surface. (GAC should be familiar to those who own an aquarium – it is the black material commonly used in aquarium filters.) Many toxic chemicals such as pesticides and organic disinfection by-products are effectively adsorbed by GAC, along with many nuisance compounds that cause offensive tastes and odours. Many of the water treatment plants along Lake Ontario have responded to the recent increase in summer taste and odour events by adding a layer of GAC to existing filters.

GAC has limited capacity to adsorb organic impurities; once saturated, it must be removed from the filter. The material can be either disposed of or regenerated in a process that essentially involves heating it to drive off the adsorbed material. The useful life of a GAC layer in a filter is a function of many variables, including the amount of organic impurities present in the water being filtered, temperature, filtration rate, and specific GAC characteristics. Typically, GAC becomes 'exhausted' within a matter of months – it is no longer able to remove

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58 Ibid.
59 Ontario, Ministry of the Environment, 2000d.
60 S. Tanner, 1997, "Slow sand filtration: still a timeless technology under the new regs?" *Journal of the American Water Works Association,* vol. 89, no. 12, p. 14.
61 Canada, Health Canada, Health Protection Branch, 1993.

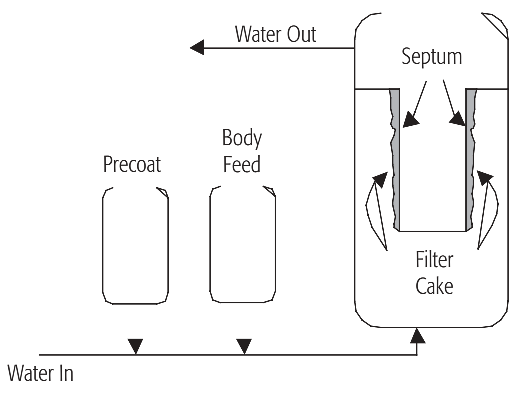
organic impurities efficiently – and must be replaced. The relatively high cost of GAC and its limited service life make it a practical treatment alternative only in specific cases.

Diatomaceous Earth

Diatomaceous earth (DE) filters are very rare, and are generally used only in very small systems. DE filters typically consist of a pressurized vessel or an open filter bed with a vacuum applied to the underside of a septum. The septum is a porous structure designed to support a thin layer (2–5 mm) of DE.[62] The filter operates by first coating the septum with a layer of DE (injected onto the septum as a slurry). The water to be filtered is then applied. The DE is a very fine medium that strains out most particles in the water. As the water is filtered, it is customary to apply a small amount of the DE slurry (called a "body feed") to build up a fresh layer of DE and prevent clogging. Once the flow becomes too restricted as a result of the trapped impurities, the filter is backwashed to remove the trapped impurities and the built-up DE layer. Backwash is required every 24 to 150 hours under normal conditions.[63] Figure 4-4 shows a typical DE filter.

DE filters are considered effective for pathogen control. The U.S. Surface Water Treatment Rule credits DE filters with removing 2-log (99%) of *Giardia* cysts

Figure 4-4 Typical DE Filter Layout



[62] Ibid.
[63] Montgomery, 1985.

and 1-log (90%) of viruses.[64] Recent research has shown as much as 6-log (99.9999%) removal of *Cryptosporidium* using DE filtration under routine operating conditions.[65] Drawbacks associated with DE filtration include a relatively complex operating cycle and a lower capability, relative to traditional granular media filters, of handling large variations in influent water quality.[66]

Membranes

Membrane filtration is a process by which a pressure gradient drives water through a semi-permeable membrane. Water can pass through the membrane material, but impurities larger than the pore size of the membrane cannot. The advantage of membrane filtration over granular media filtration is that, by manufacturing membranes with a fixed and predetermined pore size, a much higher level of control over the quality of the filtered water can be achieved. One disadvantage is that the costs of membrane filtration are typically higher than for granular media filtration. However, as regulatory requirements become stricter, the superior performance of membranes could make the economics more attractive.

Membranes vary greatly in their materials of construction and how they are designed to filter water, and this report cannot present a comprehensive discussion. To illustrate the principle, however, the operation of a typical "outside-in" hollow-fibre system is described. In such a system, thousands of hollow fibres, normally less than one or two millimetres in diameter and one or two metres long, are arranged in a closely bunched group and connected at both ends to a filtered-water collection header. Tiny pores in the fibre walls allow water to pass through while rejecting impurities that are larger than the pore diameter. The group of fibres is immersed in the water to be filtered. A pressure gradient is applied across the fibre surface either by adding pressure to the water outside the fibres (in which case the membrane system must be contained in a sealed pressure vessel), or by applying a vacuum to the interior of the fibres (in which case they are simply placed in an open-water basin). In either case, water flows from outside into the hollow interior space of the fibres and travels to a filtered-water collection header.

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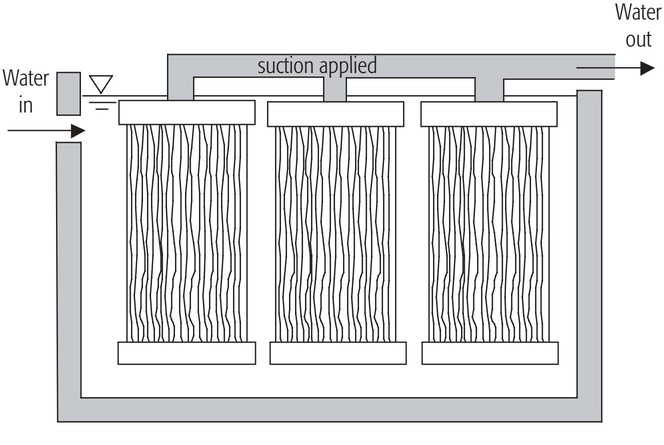
[64] United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.
[65] J.E. Ongerth and P.E. Hutton, 1997, "DE filtration to remove *Cryptosporidium*," *Journal of the American Water Works Association*, vol. 89, no. 12, pp. 39–46.
[66] Montgomery, 1985.

Over time, the surface of the fibres becomes clogged with rejected material, and they must be cleaned by briefly reversing the flow to dislodge the debris. Membranes are generally cleaned in this manner several times every hour.[67] Depending on influent water quality and operating conditions, the fibres are cleaned more thoroughly every few months using a mild acid wash to dissolve encrusted scale deposits and other debris. Figure 4-5 shows a membrane filter layout.

Four membrane categories – based on decreasing size of the pores – are generally recognized for drinking water treatment: *microfiltration* (0.05–5 μm), *ultrafiltration* (0.001–0.05 μm), *nanofiltration* (0.0005–0.005 μm), and *reverse osmosis* (<0.001 μm).[68] These pore-size differentiations are largely arbitrary, but allow distinctions in the type of membrane required to remove certain classes of contaminants. In general, microfiltration can effectively remove visible or colloidal particulate matter, but provides only partial protection against pathogens. The smaller pore sizes in ultrafilters allow an extremely high level of protection against bacteria, cysts, and viruses – typically orders of magnitude better than conventional granular media filters.[69] Ultrafilters provide excellent removal of other particulate matter and may also remove substantial amounts of dissolved natural organic matter, especially if preceded by coagulation.[70]

Figure 4-5 Membrane Filter Schematic Layout



[67] J.S. Taylor and M. Wiesner, 1999, " Membranes," in *Water Quality and Treatment,* 5th ed. (New York: McGraw Hill), 11.1–11.71.
[68] National Academy of Sciences, 1999, *Identifying Future Drinking Water Contaminants* (Washington, D.C.: National Academy Press).
[69] J.G. Jacangelo, S.S. Adham, and J.-M. Laine, 1995, "*Cryptosporidium, Giardia,* and MS2 virus removal by MF and UF," *Journal of the American Water Works Association,* vol. 87, no. 9, pp. 107–21.
[70] Taylor and Wiesner, 1999.

However, nanofiltration is required for effective removal of dissolved organics. Most dissolved organic compounds, such as humic acids, are too large to pass through the pores of such filters. Nanofiltration also rejects certain dissolved salts and metal ions. Reverse osmosis, using the smallest pore sizes, is the most effective but most expensive form of membrane filtration, and is employed to obtain fresh water from salt water.

As the pore sizes in membranes are made smaller, not only is the quality of the filtered water improved but the required pressure gradient becomes greater. The relatively large-pore micro- and ultrafiltration units often use pressure gradients in the range of 1 to 2 atmospheres. In contrast, reverse osmosis often employs pressure gradients in the 30 to 40 atmosphere range.[71] The lower pressures required by micro- and ultrafiltration make these technologies more easy to implement in treatment plants, but at the cost of less effective performance. Nevertheless, the ability of ultrafiltration to control effectively all pathogens while also reducing the concentration of organic matter makes it an attractive compromise between small pore size and pressure requirements.

One of the operational challenges with membranes is to keep them clean and undamaged. While the filtration process itself covers the membrane surfaces with rejected debris, the surfaces may also experience scale buildup, fouling by microbial buildup or metal oxide formation, or damage by disinfectants such as chlorine. The normal membrane cleaning routine of backwashing and acid washing may need pretreatment steps to make the water less challenging to the membranes. Pretreatment processes such as pH adjustment, chlorination, dechlorination, coagulation and sedimentation, and activated carbon adsorption can be employed.[72]

Although membrane filters provide water free of impurities, the process also produces a waste stream that contains the rejected material. In many cases this waste stream is a highly concentrated solution that includes potentially harmful contaminants, and therefore is governed by strict controls on handling and disposal.[73] Waste stream handling must be carefully considered in the design of a membrane filtration system.

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[71] Ibid.
[72] Ibid.
[73] M. Mickley, R. Hamilton, and J. Truesdall, 1993, *Membrane Concentrate Disposal* (Denver: AWWA Research Foundation).

Summary

Filtration is a process by which impurities are removed from the water either by straining or by attachment to the filter media. Major types of filtration include granular media filtration (rapid or slow sand), diatomaceous earth filtration, and membranes. Each has advantages and disadvantages, and the type of filter that is best for one community might not be best for another. The one factor common to all filters is that to be most effective, they must be properly operated and maintained. Filters are not simple devices, and knowledge of how operating conditions enhance or detract from filter performance is essential for good filtered water quality.

4.3 Disinfection

4.3.1 Disinfection Basics

Experience has shown that most natural water sources contain pathogens, either continuously or intermittently, due to contamination by human or animal waste.[74] A wide variety of micro-organisms, including bacteria, viruses, and protozoa, cause illness. An American database compiled by the Centers for Disease Control reported that between 1980 and 1996, 401 waterborne outbreaks of disease caused more than 750,000 illnesses in the United States.[75] The diseases in this database included several of chemical origin, but most were caused by microbial pathogens. Common pathogens responsible included *Giardia lamblia, Shigella sonnei, Campylobacter jejuni, Cryptosporidium parvum,* Hepatitis A, and Norwalk virus.[76] The cause of many outbreaks of disease, though identified as being waterborne, could not be traced to specific organisms.

It is common practice to disinfect drinking water to control pathogens. Common disinfectants used in drinking water treatment are chlorine,

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[74] M. Abbaszadegan et al., 1998, "Microbial & chemical measurements for ground water vulnerability assessment," in *Proceedings of the Water Quality Technology Conference, San Diego* [CD-ROM] (Denver: AWWA); M.W. LeChevallier and W.D. Norton, 1995, "*Giardia* and *Cryptosporidium* in raw and finished water," *Journal of the American Water Works Association,* vol. 87, no. 9, pp. 54–68.
[75] United States, Environmental Protection Agency, Office of Water, 1998, *Interim Enhanced Surface Water Treatment Rule* [online], EPA 815-F-98-009, U.S. Federal Register, vol. 63, no. 241, pp. 69477–521 [cited July 2001], <www.epa.gov/safewater/mdbp/ieswtr.html>.
[76] O. Schneider, 1998, *US Waterborne Diseases (Drinking Water Systems)* [online], [cited July 2001] <http://water.sesep.drexel.edu/outbreaks/US_summaryto1998.htm>.

chloramines, chlorine dioxide, and ozone. These are all strong chemicals that act either by destroying important constituents in the pathogen cell or by disrupting essential metabolic activities.[77] It is important that, while controlling pathogens, disinfectants do not present a significant health risk or nuisance to humans or the environment. Drinking water disinfectants have been subjected to considerable scrutiny to ensure that they are not harmful to humans.[78] Regulatory limits restrict disinfectant concentration in drinking water to ensure public safety. In Ontario a new maximum limit for free chlorine of 4 mg/L (or 3 mg/L combined chlorine) has been introduced, along with a limit for chloramine of 3 mg/L.[79] No limits are specified for chlorine dioxide at this time, although an American limit has been set at 0.8 mg/L.[80] Ozone is not regulated because its inherent characteristics preclude a stable residual in drinking water.

While disinfectants are generally effective because of their strong chemical reactivity toward cellular structures in the target pathogens, this strong reactivity causes problems. Natural waters contain various impurities, including inorganic species, such as iron and manganese, and organic material collectively referred to as natural organic matter. Disinfectants react with these impurities and with pathogens. As a result, disinfectant concentration decreases with time. The difference between the applied disinfectant dosage and the remaining concentration at any time is called the "disinfectant demand." Waters containing a high concentration of impurities often exert a high disinfectant demand, with the result that high dosages of disinfectant must be added to ensure that an adequate amount remains to control pathogens. While this disinfectant demand has a financial cost, perhaps a more serious consequence is the formation of disinfection by-products (DBPs).

Chemical reactions between the disinfectant and natural impurities in water often result in DBPs, many of which are known or suspected to be toxic. Consequently, the concentrations of certain DBPs are limited in drinking water. Engineers and water treatment professionals therefore face the challenge of providing enough disinfectant to control pathogens, while minimizing DBP

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77 Montgomery, 1985.
78 R.J. Bull and F.C. Kopfler, 1991, *Health Effects of Disinfectants and Disinfection By-Products* (Denver: AWWA Research Foundation).
79 Ontario, Ministry of the Environment, 2000d.
80 F.W. Pontius, 1997a, "Future directions in water quality regulations," *Journal of the American Water Works Association,* vol. 89, no. 3, pp. 40–54.

formation. A properly designed disinfection process must address both issues simultaneously.

4.3.2 Disinfection By-products

Surveys of drinking water around the world have identified hundreds of individual DBPs. Many additional species exist but have not yet been identified.[81] Because studies to investigate the health effects of these DBPs are time-consuming and costly, the health impacts of only a relatively few of the compounds have ever been studied.[82]

Fortunately, while the *number* of DBP types formed in water may be large, the total *amount* is typically composed of only a few types. This implies that by recognizing the health impact of these few major DBP species, one can extrapolate the overall health risk of the water, provided that none of the minor (in concentration) DBPs has an inordinately high toxicity. Regulations assume that limiting the concentration of the major DBPs also limits the concentration of minor DBPs. While this may be true in general, there are specific cases in which strategies to minimize the formation of one type of DBP may actually increase the formation of another. For example, pH affects the formation of trihalomethane (THM) and haloacetic acid (HAA) during chlorination. To control THM formation (which is regulated in Ontario), it is best to lower the pH.[83] However, lowering pH enhances HAA formation (which is not regulated in Ontario, but is in the United States).[84] For this reason it is important to be aware that DBPs include species beyond those few that are regulated. Ideally, DBP minimization strategies should attempt to focus on all DBPs, not just the regulated ones.

To control DBP concentrations, a few fundamental steps can be taken:

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[81] R. Minear and G.L. Amy, 1995, *Disinfection By-Products in Water Treatment* (Boca Raton: CRC Press).
[82] Bull and Kopfler, 1991.
[83] G.L. Amy, P.A. Chadik, and Z.K. Chowdhury, 1987, "Developing models for predicting trihalomethane formation potential and kinetics," *Journal of the American Water Works Association,* vol. 79, no. 7, pp. 89–97.
[84] Z.K. Chowdhury, K. Dickerson, and G.L. Amy, 1993, "Modeling the formation of haloacetic acids and trihalomethanes in chemically coagulated waters," in part 1 of *Proceedings of the Water Quality Technology Conference, Miami* (Denver: AWWA), pp. 493–512.

- *Remove DBP precursors (impurities in the water)before disinfection.* DBPs form when disinfectants react with impurities in the water. By delaying disinfection until after solids removal (e.g., by sedimentation or filtration), fewer impurities will exert a disinfectant demand. The disinfectant dose can therefore be lowered, resulting in lower DBP concentrations.

- *Avoid overdosing with disinfectant.* The primary goal of disinfection – pathogen control – should never be sacrificed solely to minimize DBP formation. Nevertheless, a poorly designed disinfection process can apply unnecessarily high disinfectant doses and form correspondingly high DBP concentrations. To provide the correct level of pathogen control and avoid overdosing, the correct dose should be accurately determined on a year-round basis.

- *Select the appropriate disinfectant.* A number of disinfectants are available, including chlorine, chloramines, chlorine dioxide, ozone, and ultraviolet radiation. Experience has shown that there is no best disinfectant for all applications. Instead, one disinfectant might be preferable to others for specific water quality and treatment conditions. If simultaneous compliance with both pathogen control and DBP requirements is not possible for a given disinfectant, another might be more suitable.

- *Control pH.* pH strongly influences formation of many DBPs. Most, though not all, chlorine, chlorine dioxide, and ozone-related DBPs tend to form more readily at higher pH. It is possible that a treatment facility can minimize DBP formation by pH adjustment.

4.3.3 Other Uses for Disinfectants

The common chemical disinfectants act by oxidizing and disrupting cellular activities. The strong oxidizing property that makes these chemicals such effective disinfectants also may be used for other beneficial purposes.

Taste and Odour Control

Disinfectants can oxidize many taste and odour-causing contaminants. Common groundwater contaminants include hydrogen sulphide – a compound with a rotten egg or swampy odour, produced by anaerobic microbial activity

– and iron and manganese, which in high concentrations can impart a detectable taste. Chlorine, chlorine dioxide, and ozone effectively oxidize these compounds, although the effectiveness varies with the specific disinfectant and conditions. In surface waters, common taste- and odour-causing contaminants are often metabolic products of micro-organisms, particularly algae and actinomycetes.[85] Two such compounds are geosmin and methylisoborneal, which cause very strong earthy and musty tastes and odours. Chlorine is less effective at controlling these compounds, and in some instances may accentuate the problem.[86] Chlorine dioxide and ozone are considered more effective.[87]

Colour

After contact with organic debris, water often contains tannins, humic acid, and humates, which can impart yellowish-brown hues.[88] Iron and manganese oxides can cause reddish and blackish water. In general, these compounds can all be oxidized by disinfectants, the effectiveness depending on the conditions and the disinfectant used.

Iron and Manganese

Iron and manganese are soluble in water in the reduced form (Fe^{2+} and Mn^{2+}). Under anaerobic conditions iron and manganese can dissolve into groundwater from the surrounding soil. Stagnant impounded surface water can also contain these compounds if the bottom layer of water is anaerobic, allowing iron and manganese to dissolve from the bottom sediment. High levels of iron and manganese can stain plumbing fixtures and laundry; they can also impart an objectionable taste to the water. The presence of iron can also promote the growth of iron-oxidizing bacteria in water mains, which can cause pipe incrustation and offensive tastes and odours.[89]

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[85] W. Viessman Jr. and M.J. Hammer, 1998, *Water Supply and Pollution Control,* 6th ed. (Menlo Park, Calif.: Addison Wesley Longman Inc.).

[86] W.H. Glaze et al., 1990, "Evaluating oxidants for the removal of model taste and odor compounds from a municipal water supply," *Journal of the American Water Works Association,* vol. 82, no. 5, pp. 79–84.

[87] Ibid.; S. Lalezary, M. Pirbazari, and M. J. McGuire, 1986, "Oxidation of five earthy-musty taste and odor compounds," *Journal of the American Water Works Association,* vol. 78, no. 3, pp. 62–69.

[88] Viessman and Hammer, 1998.

[89] Ibid.

Iron and manganese can be removed from water by oxidizing the dissolved compounds (Fe^{2+} and Mn^{2+}) into their insoluble states (Fe^{3+} and Mn^{3+}) and removing the precipitates by filtration. It is possible to aerate the water and achieve the oxidation by straightforward exposure to the atmosphere, often accelerated by catalysts such as copper ions or silica. Water softening and manganese zeolite processes may also be employed. An alternative approach is to apply a chemical oxidant. Potassium permanganate and chlorine are commonly used because they are relatively inexpensive and well understood.[90] Chlorine dioxide and ozone are considered to be extremely effective.[91]

4.3.4 Primary Disinfection

Historically, disinfection was considered to be effective if water samples showed an acceptably low count of certain indicator bacteria, typically coliforms. This was generally achieved simply by ensuring that a disinfectant (usually chlorine) was present throughout the distribution system. It is now recognized that this approach cannot ensure safe drinking water because many pathogens are more resistant than coliform bacteria to disinfection. The absence of coliforms therefore cannot guarantee the absence of all pathogens. In the United States, regulations introduced in the early 1990s required that waters at risk of contamination (surface waters or groundwater under the influence of surface waters) be disinfected sufficiently to control *Giardia lamblia* cysts and certain viruses. These organisms were believed at the time to be among the most resistant to disinfection and certainly more resistant than coliform bacteria.[92] A complication with this approach is that these organisms, unlike coliforms, are extremely difficult to measure. Therefore, rather than require drinking water providers to actively monitor these target organisms, regulatory compliance would be achieved by providing an appropriate concentration of disinfectant C for an adequate length of contact time T that would be *calculated* to ensure sufficient control of *Giardia* and viruses. This is called the CT approach, and it has now been adopted in the new *Ontario Drinking Water Standards* (ODWS).[93]

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[90] Ibid.

[91] D.A. Reckhow et al., 1991, "Oxidation of iron and manganese by ozone," *Ozone Science and Engineering,* vol. 13, no. 6, pp. 675–95; D. Gregory and K. Carlson, 1996, "Oxidation of dissolved manganese in natural waters," in *Proceedings of the American Water Works Association Annual Conference, Toronto* (Denver: AWWA), pp. 453–70.

[92] United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.

[93] Ontario, Ministry of the Environment, 2000e.

The CT Approach

The CT approach is based on the observation that as disinfectant concentration applied to water increases, or contact time lengthens, fewer micro-organisms remain. However, those survivors represent the fraction of the initial microbial population most resistant to the disinfectant and consequently harder to inactivate. For example, if a given disinfectant dose and contact time combination inactivates 90% of the micro-organisms, leaving 10% alive, doubling the dose/time combination will inactivate 90% of the initial survivors, resulting in an overall inactivation rate of 99% (= 90% + 90% of 10%). If the dose/time combination is doubled again, 99.9% of the organisms will be inactivated, and so on.

Mathematically, this phenomenon can be expressed as follows:

$$CT = k\left(-\log \frac{N}{N_o}\right)$$

where CT is the mathematical product of disinfectant concentration C and contact time T; k is the coefficient of specific lethality (a measure of the strength of a given disinfectant toward a specific micro-organism),[94] N is the number of surviving micro-organisms at time T, and N_o is the initial number of micro-organisms in the water. Often, the left-hand side of the equation, CT, is written as C^nT^m, where n and m are constants, determined by experiments, which reflect that either the disinfectant dose or contact time is more important for inactivating a specific organism.[95] As written in Equation (1), both C and T are equally important, meaning that doubling either the disinfectant concentration or the contact time will result in exactly the same impact on the inactivation level. This is a common simplifying assumption that has been shown to be reasonably accurate in practice.[96]

The new Ontario disinfection standard was adapted from the U.S. Surface Water Treatment Rule.[97] When it was written, the rule involved an analysis of

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[94] Montgomery, 1985.
[95] L.W. Hom, 1972, "Kinetics of chlorine disinfection in an ecosystem," *Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers,* vol. 98, no. SA1, pp. 183–94.
[96] United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.
[97] Ontario, Ministry of the Environment, 2000e.

the measured concentrations of pathogens in waters, based on historical surveys and the susceptibility and tolerance of the population to illness.[98] The conclusion was that as a general rule treatment facilities at risk of source-water contamination should ensure that their treatment processes were capable of providing a *minimum* of 3-log (99.9%) *Giardia* removal or inactivation and 4-log (99.99%) virus removal or inactivation. Higher levels could be required, depending on historical influent concentrations. 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 (see discussion on coagulation and flocculation in section 4.2.1). 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, and includes the same CT tables.

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.

In practice, CT is calculated using allowable simplifying assumptions. In Ontario the standards specify that the value for C in a treatment process should be taken as the discharge disinfectant concentration for that process. Hence, if chlorine enters a sedimentation basin at a concentration of 0.3 mg/L and leaves at 0.2 mg/L, the value for C will be taken as 0.2 mg/L. This provides a conservative estimate of C because most of the water in the basin would actually have a higher concentration. The contact time T is defined as T_{10}, which is the time for 10% of the water to pass through the process (i.e., the fastest 10% of the flow). This means that 90% of the water actually spends longer travelling through the process than the characteristic time T and is therefore more thoroughly disinfected. The value for T_{10} is best obtained by conducting a tracer test.

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[98] United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.

The important implication of these simplifying assumptions for C and T is that while they provide a conservative underestimation of *Giardia* and virus inactivation, they consequently tend to promote addition of more disinfectant than may in fact be necessary, thus increasing DBP formation. It is therefore perhaps not in the best interests of public health to be too conservative in calculating CT. Arguably, a better approach would be to make as accurate an assessment of the true CT as possible so that the disinfectant dose required to provide the desired level of pathogen control is known precisely, thereby avoiding overdosing. While ODWS makes no mention of more sophisticated and accurate methods to calculate CT, the equivalent U.S. regulation encourages such approaches, recommending the simplistic T_{10} and "C effluent" approach for only those treatment facilities without the means to employ the better methods.[99]

4.3.5 Description of Disinfectants

Chlorine

Chlorine can be applied to drinking water as a gas (Cl_2), a solid (calcium hypochlorite), or a liquid (often sodium hypochlorite). In every case chlorine dissolves in the water to form two species: hypochlorous acid and hypochlorite ion (together called free chlorine). The balance between the two species is primarily a function of pH, with hypochlorous acid the dominant species at a pH of less than about 7.5, and hypochlorite predominating at higher pH values.[100] The speciation is extremely important because hypochlorous acid is a much stronger disinfectant than hypochlorite. This is reflected in the CT tables of the Ontario Drinking Water Standards, with significantly lower chlorine CT requirements at lower pH values to achieve the same level of *Giardia* or virus inactivation (e.g., for 1-log *Giardia* inactivation at 20°C, the required CT at pH 6.5 is 16 mg·min/L, and at pH 8.5 it is 33 mg·min/L).

Chlorine is the most common disinfectant used in North America, in part due to its low cost and proven effectiveness.[101] It is extremely capable of controlling bacteria and most viruses; however, it has difficulty inactivating certain protozoa. This is reflected in the Ontario drinking water standards: to provide the same inactivation level, the CT requirements for *Giardia* are typically 20 to 30 times

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[99] Ibid.

[100] Viessman and Hammer, 1998.

[101] American Water Works Association, 1992, *Water Industry Data Base* (Denver: AWWA).

higher than for viruses. Chlorine is also ineffective at controlling *Cryptosporidium parvum* oocysts.[102] A treatment system that chlorinates must therefore rely exclusively on filtration to remove *Cryptosporidium*.

One of chlorine's main drawbacks is the formation of halogenated organic DBPs. As noted in section 4.3.2, chlorine reacts with natural organic matter (NOM) in water to form such species as trihalomethanes (THMs) and haloacetic acids (HAAs). These by-products are implicated in a range of adverse health effects, including cancer and birth defects.[103] Total THM concentrations in drinking water are limited to 0.1 mg/L in Ontario,[104] while both THMs and HAAs are regulated in the United States. Typically, waters with high NOM concentrations are at greater risk of exceeding chlorine-related DBP limits.

Chloramines

The term 'chloramines' refers collectively to three individual compounds: monochloramine, dichloramine, and trichloramine. These compounds form when free chlorine reacts with ammonia that is either naturally present in the water or added intentionally to form chloramines. Chloramine speciation depends primarily on the ammonia to chlorine ratio, pH, and reaction time.[105] Monochloramine is predominant at the higher ammonia:chlorine ratios, higher pH, and shorter contact times; the di- and tri- species become more predominant under the opposite conditions. Monochlormaine is typically the preferred species, since di- and trichloramine can cause significant chlorinous taste and odour problems when present in drinking water.[106]

Chloramines are useful for secondary disinfection because they are very stable and can often last in water for weeks.[107] Furthermore, they have a reported

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[102] D.G. Korich et al., 1990, "Effects of ozone, chlorine dioxide, chlorine and monochloramine on *Cryptosporidium parvum* oocyst viability," *Applied Environmental Microbiology,* vol. 56, no. 5, pp. 1423–28.
[103] Bull and Kopfler, 1991.
[104] Ontario, Ministry of the Environment, 2000d.
[105] G.C. White, 1992, *The Handbook of Chlorination and Alternative Disinfectants,* 3rd ed. (New York: Van Nostrand Reinhold).
[106] Ibid.
[107] K. Ozekin, R.L. Valentine, and P.J. Vikesland, 1995, "Modeling chloramine decay in natural waters," in part 2 of *Proceedings of the Water Quality Technology Conference, New Orleans* (Denver: AWWA), pp. 1441–48.

ability to penetrate into biofilm, helping to prevent its growth in distribution systems.[108] Chloramines also do not form high concentrations of DBPs, an important property given the long periods of time that water may spend in distribution systems.[109] As a result, many facilities in the United States are responding to tougher DBP limits by switching from free chlorine to chloramines for secondary disinfection.

While chloramines may be appropriate for secondary disinfection, they are weak disinfectants and do not provide adequate primary disinfection. This is reflected in the CT requirements reported in the U.S. Surface Water Treatment Rule for chloramines: they can be approximately 20 to 200 times less effective at controlling *Giardia* and viruses than free chlorine, given the same concentration and contact time, and depending on operating conditions.[110] The Ontario Drinking Water Standards do not list CT criteria for primary disinfection using chloramines, assuming that such practice would be impractical.

Chlorine Dioxide

Although chlorine dioxide has traditionally not been applied as a primary disinfectant, this situation is now changing. A 1992 survey reported that approximately 15% of roughly 1,000 drinking water treatment facilities (mostly in the United States) used chlorine dioxide, mainly to control taste and odours, colour, and manganese, rather than as a disinfectant.[111] However, use of chlorine dioxide at large and medium-sized plants in the United States is reported to have approximately doubled in the last 10 years.[112]

Chlorine dioxide is a gas that cannot be transported and must be generated on site. It is generated by reacting chlorine with aqueous sodium chlorite, although

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[108] M.W. LeChevallier, C.D. Lowry, and R.G. Lee, 1990, "Disinfecting biofilms in a model distribution system," *Journal of the American Water Works Association,* vol. 82, no. 7, pp. 87–99.
[109] J.M. Symons et al., 1998, *Factors Affecting Disinfection By-Product Formation During Chloramination* (Denver: AWWA Research Foundation).
[110] United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.
[111] American Water Works Association, 1992.
[112] G.F. Connell et al., 2000, "Disinfection at large and medium-size systems," *Journal of the American Water Works Association,* vol. 92, no. 5, pp. 32–43.

variations involving electrochemical technologies exist.[113] The reaction forms chlorine dioxide gas that is then injected into the water.

Evidence suggests that chlorine dioxide is overall a more powerful disinfectant than either chlorine or chloramines. For example, the CT requirements to achieve a given level of *Giardia* control with chlorine dioxide are typically in the order of one-quarter those required when using free chlorine (although chlorine dioxide is reported to be slightly less effective against certain viruses than free chlorine).[114] Unlike chlorine and chloramines, though, chlorine dioxide can inactivate *Cryptosporidium*.[115] The doses and contact times required to achieve a substantial level of *Cryptosporidium* inactivation are likely higher than would be practical (e.g., 1-log inactivation at 20°C requires a CT of approximately 50 mg·min/L).[116] However, the inactivation achieved at more typical doses and contact times should not be ignored, as it forms part of a multiple-barrier approach to controlling *Cryptosporidium*. This is a definite advantage of chlorine dioxide over free chlorine or chloramines.

An additional advantage of chlorine dioxide is that it forms very low concentrations of halogenated organic DBPs, such as THMs and HAAs.[117] Using a small amount of chlorine dioxide prior to chlorination for secondary disinfection has also been observed to dramatically reduce subsequent THM and HAA formation, likely by destroying the THM and HAA precursor material.[118] However, chlorine dioxide produces other DBPs. Studies have consistently shown that approximately 70% of the chlorine dioxide applied to water is ultimately reduced to chlorite, while approximately 10% is oxidized to chlorate.[119] Chlorite and chlorate, at high concentrations, have been observed

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[113] G. Gordon and A. Rosenblatt, 1995, "Gaseous, chlorine-free chlorine dioxide for drinking water," in part 1 of *Proceedings of the Water Quality Technology Conference, New Orleans* (Denver: AWWA), pp. 457–66.
[114] United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.
[115] K.M. Ruffell, J.L. Rennecker, and B.J. Mariñas, 1998, "Inactivation kinetics of *Cryptosporidium parvum* oocysts with chlorine dioxide," in *Proceedings of the Water Quality Technology Conference, San Diego* [CD-ROM] (Denver: AWWA); C.P. Chauret et al., 2000, "Chlorine dioxide inactivation of *Cryptosporidium parvum* oocysts and bacterial spore indicators," in *Proceedings of the Water Quality Technology Conference, Salt Lake City* [CD-ROM] (Denver: AWWA).
[116] Ruffell, Rennecker, and Mariñas, 1998.
[117] R. Savoir, L. Romnee, and W.J. Masschelein, 1987, "Assessment of chlorine dioxide as a means of limiting the formation of organohalogenated compounds," *Aqua,* vol. 2, pp. 114-17.
[118] R. Hofmann, R.C. Andrews, and Q. Ye, 1999, "Impact of *Giardia* inactivation requirements on ClO_2 by-products," *Environmental Technology,* vol. 20, pp. 147–58.
[119] C. Korn and R.C. Andrews, 1999, "Development of chlorine dioxide-related by-product models for drinking water treatment," in *Proceedings of the Water Quality Technology Conference, Chicago* [CD-ROM] (Denver: AWWA).

to cause several adverse health effects, although the data are incomplete.[120] The regulatory limit on chlorite concentrations in drinking water in the United States is 1.0 mg/L.[121] The Canadian guideline is set at the same level; however, Ontario has not yet set a chlorite standard.[122] Given that approximately 70% of the applied chlorine dioxide normally reduces to chlorite, this means that the maximum chlorine dioxide dose that may be applied without exceeding the chlorite limit is approximately 1.4 mg/L. Beyond this dosage, chlorite removal could be required.

Ozone

Ozone is the strongest oxidant of the disinfectants discussed so far. It reacts very quickly with a wide range of organic and inorganic compounds, and is an extremely powerful disinfectant. Because of its reactivity, ozone cannot be stored and must be generated at its point of use. This is accomplished by passing dry oxygen-bearing gas between electrodes that emit a high-energy spark, ionizing the oxygen and resulting in ozone formation. The ozone-containing gas is then injected into the water, typically in a special ozone contact chamber, which is sealed to prevent the toxic ozone off-gas from entering the ambient air in the treatment facility.

Historically, ozone has been used mainly in Europe for applications including colour removal, taste and odour control, oxidation of organics, iron and manganese oxidation, and primary disinfection.[123] Its instability makes it unsuitable for secondary disinfection. Hence, facilities that use ozone for primary disinfection must apply a different secondary disinfectant. As ozone decays, hydroxyl radicals are formed. These species are even more reactive and stronger oxidants than ozone, and are useful for destroying many organic contaminants

[120] Bull and Kopfler, 1991; Chemical Manufacturers Association, 1996, *Sodium Chlorite: Drinking Water Rat Two-Generation Reproductive Toxicity Study* (Quintiles Report Ref. CMA/17/96).
[121] United States, Environmental Protection Agency, 1998a.
[122] Ontario, Ministry of the Environment, 2000d.
[123] B. Langlais, D. Reckhow, and D. Brink, 1991, *Ozone in Water Treatment: Application and Engineering* (Denver: Lewis Publishers, Inc.).

such as pesticides. However, limited studies have indicated that they are not effective disinfectants.[124]

Ozone is a far more powerful disinfectant than chlorine, chloramines, or chlorine dioxide. The CT requirements to inactivate *Giardia* or viruses using ozone are approximately two orders of magnitude lower than for free chlorine, according to the U.S. Surface Water Treatment Rule.[125] Ozone can also achieve significant *Cryptosporidium* inactivation at doses that are typical of drinking water treatment.[126] For this reason, the number of facilities using ozone in the United States increased substantially during the 1990s when the threat of *Cryptosporidium* in drinking water supplies was identified.[127]

When using ozone, it is considered an advantage to provide biological filtration at some point downstream. This is because ozone reacts with natural organic matter to form small organic compounds such as carboxylic acids and aldehydes, which, although not harmful to humans, are excellent nutrients for micro-organisms.[128] If left uncontrolled, these nutrients can promote biofilm growth in distribution systems. A biological filter provides support for a large population of micro-organisms to flourish, consuming the nutrients before the water leaves the treatment facility, thereby protecting the distribution system.[129] At one time it was feared that the growth of micro-organisms on filter media could cause increased microbial counts in the finished water due to sloughing of the organisms from the filter into the water. Studies have given no indication that this is a problem.[130]

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124 K.N. Scott, R.L. Wolfe, and M.H. Stewart, 1992, "Pilot-plant-scale ozone and Peroxone disinfection of *Giardia muris* seeded into surface water supplies," *Ozone Science and Engineering,* vol. 14, no.1, pp. 71–90.
125 United States, Environmental Protection Agency, Office of Water, Science and Technology Branch, 1991.
126 J.L. Rennecker et al., 1999, "Inactivation of *Cryptosporidium parvum* oocysts with ozone," *Water Research,* vol. 33, no. 11, pp. 2481–88.
127 International Ozone Association newsletter (January 1998).
128 K.H. Carlson, G.L. Amy, and G. Blais, 1996, "Integration of the ozone and biofiltration processes to provide optimum NOM removal and biostability," in *Proceedings of the Water Quality Technology Conference, Toronto* (Denver: AWWA), pp. 223–48; S.D.J. Booth et al., 1995, "A mechanistic approach for modeling the removal of ozonation byproducts in biologically active filters," in *Proceedings of the Water Quality Technology Conference, New Orleans* (Denver: AWWA), pp. 725–39.
129 P.M. Huck et al., 1998, *Design of Biological Processes for Organics Control* (Denver: AWWA Research Foundation); M.W. LeChevallier et al., 1998, *Microbial Impact of Biological Filtration* (Denver: AWWA Research Foundation).
130 Ibid.

Ozone cannot form chlorinated DBPs such as THMs and HAAs. However, it does react with naturally occurring bromide to form bromate, which is believed to be a potential carcinogen.[131] As a result, the regulatory limit for bromate is 10 mg/L in the United States,[132] and a similar limit is recommended by the Canadian *Guidelines*.[133] Ontario has not adopted a bromate standard.[134] Experience suggests that for most waters that contain only low or moderate amounts of bromide (< 50 mg/L), bromate formation should not be a problem. However, in coastal areas where saltwater intrusion could occur, bromide levels may be substantially higher, and ozonation could create bromate at concentrations exceeding the regulatory limit. To minimize bromate formation, water should be ozonated at low pH values (<pH 8).[135]

Ultraviolet (UV) Radiation

UV radiation works by destroying vital elements of the microbial cell, specifically nucleic acids. Water routed through a chamber is exposed to UV radiation emitted from lamps. This form of disinfection is used in more than 2,000 drinking water treatment facilities in Europe. However, its applications in North America have traditionally been limited to wastewater.[136] The specific wavelengths observed to be effective for disinfection range from 200 nm to 300 nm, with a maximum effectiveness near 265 nm. The most common type of UV lamp for disinfection uses mercury vapour that emits at 254 nm. Emissions at 254 nm are about 85% as effective as those at 265 nm.[137]

The energy output of a UV lamp is measured in watts per square metre (W/m^2). In simplistic terms, overall dosages are then calculated by multiplying the lamp output by the time the water is exposed to the light, with the final dosage commonly expressed as millijoules per square centimetre (mJ/cm^2). This

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[131] Y. Kurokawa et al., 1986, "Long-term *in vivo* carcinogenicity test of potassium bromate, sodium hypochlorite and sodium chlorite conducted in Japan," *Environmental Health Perspectives,* vol. 69, pp. 221–35.
[132] United States, Environmental Protection Agency, 1998a
[133] Canada, Health Canada, 2000b, *Drinking Water Guidelines* [online], [cited July 2001], <www.hc-sc-.gc.ca/ehp/ehd/catalogue/general/iyh/dwguide.htm>.
[134] Ontario, Ministry of the Environment, 2000d.
[135] R. Song et al., 1997, "Bromate minimization during ozonation," *Journal of the American Water Works Association,* vol. 89, no. 6, pp. 69–78.
[136] L.D. DeMers and R.C. Renner, 1992, *Alternative Disinfection Technologies for Small Drinking Water Systems* (Denver: AWWA Research Foundation).
[137] Ibid.

expression is analogous to CT values, and the UV dosage is considered to be directly proportional to microbial inactivation levels.[138]

UV is a proven and effective technology for inactivating bacteria. It can control viruses at doses in the order of 80 to 90 mJ/cm^2.[139] However, research in the 1980s and early 1990s suggested that UV was ineffective at inactivating protozoa such as *Giardia* and *Cryptosporidium,* and for this reason UV disinfection of drinking water was normally only applied for groundwater sources, where protozoan contamination was believed to be unlikely. Recent evidence suggests, however, that these earlier studies may not have properly measured the inactivation of protozoa.[140] The latest evidence shows that UV can, in fact, very effectively control *Cryptosporidium.*[141]

To disinfect water, emitted UV radiation must reach the target pathogens. Unfortunately, material in the water such as iron, sulphides, nitrites, and various forms of organic matter, can absorb the radiation. Water with a low transmittance (<75%) might not be suitable for UV disinfection, although suitability is a function of many other factors as well.[142]

Fouling of the UV lamps can be expected over a period of time, gradually decreasing their effectiveness. In particular, scale formation on the lamp surface can be a problem if iron concentrations are greater than 0.1 mg/L, hardness is greater than 140 mg/L, or hydrogen sulphide exceeds 0.2 mg/L. UV lamps must be cleaned periodically – scum and scale buildup is to some degree unavoidable.[143]

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[138] Strictly speaking, the term 'dosage' is a misnomer, as it implies absorbed light; the correct term should be 'fluence,' which refers to all incident light upon an organism. However, this term is not yet widely used.

[139] F. Soroushian and W.D. Bellamy, 2000, "Assessment of ultraviolet technology for drinking water disinfection: facts of light," in *Proceedings of the American Water Works Association Annual Conference* [CD-ROM] (Denver: AWWA).

[140] J.R. Bolton et al., 1998, "Inactivation of *Cryptosporidium parvum* by medium pressure ultraviolet light in finished drinking water," in *Proceedings of the American Water Works Association Annual Conference, Dallas* (Denver: AWWA).

[141] G. Shin, K.G. Linden, and M.D. Sobsey, 2000, "Comparative inactivation of *Cryptosporidium parvum* oocysts and coliphage MS-2 by monochromatic UV radiation," in *Proceedings, Disinfection 2000, WEF Specialty Conference, New Orleans* [CD-ROM] (Alexandria, Va.: WEF); Z. Bukhari, T. Hargy, and J. Clancy, 1999, "Medium-pressure UV for oocyst inactivation," *Journal of the American Water Works Association,* vol. 91, no. 3, p. 86.

[142] DeMers and Renner, 1992.

[143] Ibid.

The potential for interference by dissolved matter suggests that UV radiation should ideally be applied at the end of treatment, where water is cleanest. Note that, unlike the situation for chlorine and ozone, contact time is not an issue for UV radiation (beyond the exposure time in the UV lamp chamber), and so there is little advantage to be gained by applying UV further upstream.

Unlike the other disinfectants discussed, UV radiation is not believed to form any chemical by-products of concern. However, since UV does not leave any disinfection residual, a secondary disinfectant such as chlorine must be applied to prevent microbial re-growth in the distribution system.

4.3.6 Summary

In the past, disinfection as a treatment process was arguably often underdesigned, in part due to limited regulatory criteria such as simply ensuring low coliform counts, without considering more resistant organisms. Disinfection is now considered to be one of the more important processes in drinking water treatment. As such it should be designed to meet treatment objectives that take into account the range of pathogens that might be present in natural water sources, including those that are known to be very resistant. The new Ontario drinking water standards require disinfection to provide adequate control of *Giardia lamblia* cysts and viruses, among the most resistant organisms to disinfection. At the same time, however, formation of potentially toxic disinfection by-products must be minimized.

Giardia and viruses are difficult and costly to measure routinely. Therefore, a CT calculated to achieve adequate *Giardia* and virus inactivation is used to achieve regulatory compliance. The methods for defining C and T as described in *Ontario Drinking Water Standards* are simplistic, and will likely result in a conservative underprediction of the actual amount of inactivation achieved. While this is desirable in terms of protecting the public from pathogens, it also follows that higher than necessary doses of disinfectant may unfortunately be applied, with resulting higher concentrations of disinfection by-products. The comparable American regulation recommends that facilities use more accurate methods of defining C and T to avoid overdosing and to minimize by-product formation.

5 United States of America

5.1 Introduction

Drinking water in the United States is primarily regulated at the federal level. Laws originate with a member of Congress proposing a bill, which, once approved by Congress and the president, becomes a law (called an act) and is published in the United States Code.[144] The main act that deals with drinking water is the *Safe Drinking Water Act* (*SWDA*) of 1974.

The text of an act is too general to be put into immediate practice. Instead, specific regulations that define rules for what is legal and what is not must be developed. Congress authorizes government agencies to develop and administer these regulations. The Environmental Protection Agency (EPA) was authorized to develop and administer regulations for the *SDWA*.[145]

To introduce a regulation under the *SDWA,* the EPA lists a proposal in the *Federal Register* for public consideration and comment. The proposal is generally developed in consultation with stakeholders. One formal mechanism for this consultation is through the National Drinking Water Advisory Council. The council, comprising members of the general public, state and local agencies, and private groups concerned with safe drinking water, works with the EPA during the rule-making process to try to develop regulations that reflect the interests of all stakeholders.[146] The EPA is also directed by the Science Advisory Board, an independent scientific and engineering body that offers technical advice to the EPA administrator.[147]

Once public comments are taken into account and a final rule is developed, it is published in the Code of Federal Regulations (CFR). The CFR is divided into 50 volumes, called titles. Title 40 contains most environmental regulations, including those for drinking water. The printed CFR is revised yearly, title 40 every July 1, while the Internet version is updated more frequently.

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[144] United States, Environmental Protection Agency, 2000b, *Introduction to Laws and Regulations* [online], [cited December 2000], <www.epa.gov/epahome/lawintro.htm>.
[145] See 42 CFR, chap. 6a, sec. 300f (1974).
[146] United States, Environmental Protection Agency, Office of Water, 2000a, *National Drinking Water Advisory Council* [online], [cited December 2000], <www.epa.gov/safewater/ndwac/council.html>.
[147] United States, Environmental Protection Agency, Science Advisory Board, 2000, *About the SAB* [online], [cited December 2000], <www.epa.gov/sab/about.htm>.

While the EPA has been authorized by Congress to develop drinking water regulations, it can delegate enforcement of the regulations to state, territorial, or tribal governments. These governments are then said to have primacy. As of 2000, all states and territories except for Wyoming and the District of Columbia had primacy.[148] Primacy agencies typically receive grants from the EPA to help in their efforts to administer the regulations.

The EPA's mandate to promote safe drinking water does not stop at overseeing the *SDWA* regulations. The EPA also develops or coordinates voluntary programs designed to encourage higher professional standards. An example is the Wellhead Protection Program, whereby states develop and implement a comprehensive program to protect from contamination the land areas around water supply wells.[149]

5.2 The *Safe Drinking Water Act*

The *SDWA* is the main act dealing with drinking water in the United States. The goal of the act is to ensure that drinking water supplies meet national standards designed to protect consumers from harmful contaminants. The EPA's Office of Ground Water and Drinking Water has been authorized to administer the act.[150]

The *SDWA* applies only to public water systems, defined as systems with at least 15 service connections or serving at least 25 people for a minimum of 60 days a year. In 1999 the act applied to roughly 85% of the American population; the remainder of the population received water primarily from personal wells not subject to drinking water regulations.[151]

Public water systems are divided into two main categories: community and non-community. Community systems are those that provide water year round to the same people. Non-community systems serve water to people who are

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[148] United States, Environmental Protection Agency, Office of Water, 1999a, *25 Years of the Safe Drinking Water Act: History and Trends* [online], EPA 816-R-99-007 [cited July 2001], <www.epa.gov/safewater/consumer/trendrpt.pdf>.
[149] Ibid.
[150] United States, Environmental Protection Agency, Office of Enforcement and Compliance Assurance, 2000, *Water Enforcement Division: Overview* [online], [cited December 2000], <http://es.epa.gov/oeca/ore/water/overview.html>.
[151] United States, Environmental Protection Agency, Office of Water, 1999a.

assumed to drink water from other sources for part of the year. A non-community system can be transient, meaning that water is provided year round to different people (such as at campgrounds), or non-transient, meaning that water is provided to the same people for less than 12 months per year (such as in schools having their own water supplies). Non-community systems are generally subject to less stringent regulations for long-term health risks because it is assumed that individuals consume less water from these systems over time.

The *SDWA* requires the EPA to regulate contaminants that are known or likely to present health risks in drinking water. For each contaminant, the EPA sets a maximum contaminant limit goal (MCLG) based on health risks. The MCLG is not enforceable. Instead, the EPA must also set a maximum contaminant level (MCL), which is enforceable and is developed by considering, among other factors, technological constraints, costs, and anticipated benefits. If analytical methods are not available to allow the ready measurement of contaminants, the EPA can require that appropriate treatment technologies be used instead of requiring compliance with MCLs.

Standards, once defined, must be continually reassessed for their suitability. The EPA is required to review each standard every six years and decide whether or not it should be maintained or changed.[152]

Almost all standards having to do with water quality are listed in two sets of regulations – the National Primary Drinking Water Regulations (40 CFR Parts 141 and 142) and the National Secondary Drinking Water Regulations (40 CFR 143) – which define health-based and aesthetic guidelines, respectively. The primary regulations are enforceable; the secondary regulations are standards that primacy agencies may choose to enforce or not.

5.3 The National Primary Drinking Water Regulations

The NPDWR is divided into sections that are customarily called standards, or rules, each one dealing with a particular area of importance. Overall, 92 contaminants are currently regulated – including turbidity, 60 organic compounds, 19 inorganic compounds, four radionuclides, and eight micro-organisms – while regulation of several others has been proposed. In addition, secondary standards for 15 contaminants have been recommended. Tables 5-1

[152] Ibid.

to 5-5 summarize both current and proposed drinking water standards.[153] A brief summary of some of the more important standards follows.

5.3.1 Organic and Inorganic Contaminants

Because of known or suspected toxicity, certain organic and inorganic chemicals are regulated by the NPDWR in the form of MCLs and MCLGs (see tables 5-1 and 5-2). The EPA is responsible for keeping this list up to date with current science. To that end, every five years the EPA must publish a list of contaminants that may require regulation, and decide whether or not to regulate at least five of them. The decision to regulate a contaminant is based on evidence that it has an adverse human health effect at the concentration and frequency of occurrence likely to be encountered, and that the regulation would provide a meaningful opportunity to reduce the health risk for the population served.[154] Any proposed MCL or treatment technology must also include a cost/benefit evaluation to prove that the anticipated health benefits justify the costs of compliance.

5.3.2 Disinfectant Residuals, Disinfection By-products, and Precursors

Chemical disinfectants destroy micro-organisms and prevent disease. However, the disinfectants themselves may be toxic at high concentrations, or they may react with natural matter in the water to form potentially toxic by-products. The NPDWR has established maximum residual disinfectant levels and goals (MRDLs and MRDLGs, respectively) for chlorine-based disinfectants (table 5-6), as well as MCLs and MCLGs for the disinfection by-products. These rules apply to all community water systems and non-transient non-community systems. Transient non-community systems that use chlorine dioxide must also comply.

Chlorine and chloramine residuals are generally measured in the distribution system at least once per month for every 1,000 people served by the system. The MRDL is calculated as a running annual average of monthly averages of

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[153] F.W. Pontius, 2000, "Regulations in 2000 and beyond," *Journal of the American Water Works Association,* vol. 92, no. 3, pp. 40–54.
[154] F.W. Pontius, 1997b, "Implementing the 1996 SDWA amendments," *Journal of the American Water Works Association,* vol. 89, no. 3, pp. 18–54.

Table 5-1 Current and Proposed EPA Drinking Water Standards – Organic Compounds

Contaminant	MCLG (mg/L)	MCL (mg/L)	Contaminant	MCLG (mg/L)	MCL (mg/L)
Acrylamide	zero	TT	Endrin	0.002	0.002
Alachlor	zero	0.002	Epichlorohydrin	zero	TT
Aldicarb [a]	0.001	0.003	Ethylbenzene	0.7	0.7
Aldicarb sulfone [a]	0.001	0.002	Ethylene dibromide	zero	0.00005
Aldicarb suloxide [a]	0.001	0.004	Glyphosate	0.7	0.7
Atrazine [a]	0.003	0.003	Haloacetic acids (5)	NA	0.06
Benzene	zero	0.005	Heptachlor	zero	0.0004
Benzo(a)pyrene	zero	0.0002	Heptachlor epoxide	zero	0.0002
Bromodichloromethane	zero	NA	Hexachlorobenzene	zero	0.001
Bromoform	zero	NA	Hexachlorocyclopentadiene	0.05	0.05
Carbofuran	0.04	0.04	Lindane	0.0002	0.0002
Carbon tetrachloride	zero	0.005	Methoxychlor	0.04	0.04
Chlordane	zero	0.002	Monochlorobenzene	0.1	0.1
Chloroform	zero	NA	Oxamyl	0.2	0.2
2,4-D	0.07	0.07	Pentachlorophenol	zero	0.001
Dalapon	0.2	0.2	Picloram	0.5	0.5
Di(2-ethylhexyl)adipate	0.4	0.4	Polychlorinated biphenyls	zero	0.0005
Di(2-ethylhexyl)phthalate	zero	0.006	Simazone	0.004	0.004
Dibromochloromethane	0.06	NA	Styrene	0.1	0.1
Dibromochloropropane	zero	0.0002	2,3,7-TCDD	zero	$5x10^{-8}$
Dichloroacetic acid	zero	NA	Tetrachloroethylene	zero	0.005
p-dichlorobenzene	0.075	0.075	Toluene	1	1
o-dichlorobenzene	0.6	0.6	Toxaphene	zero	0.005
1,2-dichloroethane	zero	0.005	2,4,5-TP	0.05	0.05
1,1-dichloroethylene	0.007	0.007	Trichloroacetic acid	0.3	NA
Cis-1,2-dichloroethylene	0.07	0.07	1,2,4-trichlorobenzene	0.07	0.07
Trans-1,2-dichloroethylene	0.1	0.1	1,1,1-trichloroethane	0.2	0.2
Dichloromethane	zero	0.005	1,1,2-trichloroethane	0.003	0.005
1,2-dichloropropane	zero	0.005	Trichloroethylene	zero	0.005
Dinoseb	0.007	0.007	Trihalomethanes (4)	NA	0.080
Diquat	0.02	0.02	Vinyl chloride	zero	0.002
Endothall	0.1	0.1	Xylenes (total)	10	10

Source: Pontius, 2000.
MCLG = maximum contaminant level goal; MCL = maximum contaminant level; TT = treatment technique; NA = not applicable
[a] proposed regulation (not final)

Table 5-2 Current and Proposed EPA Drinking Water Standards – Inorganic Compounds

Contaminant	MCLG (mg/L)	MCL (mg/L)	Contaminant	MCLG (mg/L)	MCL (mg/L)
Antimony	0.006	0.006	Fluoride	4	4
Arsenic	NA	0.05	Lead	zero	TT
Asbestos (fibres/L>10μm)	7 MFL	7 MFL	Mercury	0.002	0.002
Barium	2	2	Nickel	0.1	0.1
Berylium	0.004	0.004	Nitrate (as N)	10	10
Bromate	zero	0.01	Nitrite (as N)	1	1
Cadmium	0.005	0.005	Nitrate+Nitrite (both as N)	10	10
Chlorite	0.8	1	Selenium	0.05	0.05
Chromium (total)	0.1	0.1	Sulfate [a]	500	500
Copper	1.3	TT	Thalium	0.0005	0.002
Cyanide	0.2	0.002			

Source: Pontius, 2000.
MFL = million fibres per litre
[a] proposed regulation (not final)

Table 5-3 Current and Proposed EPA Drinking Water Standards – Radionuclides

Contaminant	MCLG	MCL
Beta-particle and photon emitters	zero	4 mrem
Alpha emitters	zero	15 pCi/L
Radium 226 + 228	zero	5 pCi/L
Radium 226 [a]	zero	20 pCi/L
Radium 228 [a]	zero	20 pCi/L
Radon [a]	zero	300 pCi/l; alternative 4,000 pCi/L
Uranium [a]	zero	20 μg/L

Source: Pontius, 2000.
[a] proposed regulation (not final)

Table 5-4 Current and Proposed EPA Drinking Water Standards – Micro-organisms

	MCLG	MCL
Cryptosporidium parvum [a]	zero	TT
Escherichia coli	zero	TT
Fecal coliforms	zero	TT
Giardia lamblia	zero	TT
Heterotrophic bacteria	zero	TT
Legionella	zero	TT
Total coliforms	zero	<5% of samples per month, or <2 samples per 40 per month
Turbidity	zero	PS
Viruses	zero	TT

Source: Pontius, 2000.
PS = performance standard
[a] proposed regulation (not final)

Table 5-5 Current and Proposed EPA Drinking Water Standards – Secondary Contaminants

Contaminant	SMCL (mg/L)	Contaminant	SMCL (mg/L)
Aluminum	0.05–0.2	Manganese	0.05
Chloride	250	Odour	3 TON
Colour	15 colour units	pH	6.5–8.5
Copper	1	Silver	0.1
Corrosivity	noncorrosive	Sulfate	250
Fluoride	2	Total dissolved solids	500
Foaming agents	0.5	Zinc	5
Iron	0.3		

Source: Pontius, 2000.
SMCL = secondary maximum contaminant level; TON = threshold odor number

all samples collected. MRDLs for chlorine and chloramines may be exceeded temporarily to deal with specific microbiological contamination problems; however, the chlorine dioxide MRDL of 0.8 mg/L may never be exceeded.[155] Systems using chlorine dioxide must collect a daily sample at the entrance of the distribution system to ensure that its concentration is below 0.8 mg/L.

Sampling requirements for disinfection by-products vary with the size of the system and the treatment type. It is possible, however, for systems to lower their sampling requirements by meeting specific criteria to demonstrate that by-product concentrations will likely remain well below regulatory limits.[156]

The NPDWR may also require public water systems using conventional filtration to practice enhanced coagulation or enhanced softening to remove organic matter before disinfection, since organics can be precursors to many disinfection by-products. The required percentage removal of organic matter is a function of the initial concentration of organics and the alkalinity of the water and can therefore change from time to time. Because it is more difficult to remove organics from higher alkalinity water, the required percentage removal decreases with increasing alkalinity.

5.3.3 Total Coliform Rule

The Total Coliform Rule (TCR) applies to all public water systems. The rule is based on the presence or absence (rather than a concentration) of total coliforms

Table 5-6 Current and Proposed EPA Drinking Water Standards – Disinfectants

Disinfectant	MRDLG (mg/L)	MRDL (mg/L)
Chlorine	4 (as Cl_2)	4 (as Cl_2)
Chloramines	4 (as Cl_2)	4 (as Cl_2)
Chlorine dioxide	0.3 (as ClO_2)	0.8 (as ClO_2)

Source: Pontius, 2000.
MRDLG = maximum residual disnfectant level goal; MRDL = maximum residual disinfectant level

[155] F.W. Pontius and W.R. Diamond, 1999, “Complying with the stage 1 D/DBP rule,” *Journal of the American Water Works Association,* vol. 91, no. 3, pp. 16–58.
[156] Ibid.

in a sample. Sampling requirements are a function of system size, with generally one sample per month – collected at representative locations in the distribution system – required per 1,000 people served. For systems that collect 40 or more samples per month, no more than 5% of the samples may be positive for total coliforms; for those that collect fewer than 40 samples, no more than one sample may be positive.

The TCR also requires an on-site inspection (referred to as a sanitary survey) every five years for each system that collects fewer than five samples per month. This requirement is extended to every ten years for non-community systems using only protected and disinfected ground water.

5.3.4 Filtration and Disinfection

It is recognized that coliform monitoring can provide only a partial indication of water quality. Certain pathogens are more difficult to remove during treatment than coliforms, and the absence of coliforms does not necessarily guarantee the absence of other organisms. To deal with this problem, the Surface Water Treatment Rule (SWTR) was introduced. In the SWTR, surface water and groundwater under the influence of surface water are subject to additional filtration and disinfection requirements. These requirements are designed to provide a minimum of 3-log (99.9%) *Giardia lamblia* inactivation and removal, and 4-log (99.99%) virus inactivation and removal. *Giardia* and viruses were targeted because at the time the regulation was developed they were believed to be among the most difficult pathogens to control using conventional treatment. More recently, it has been learned that other pathogens, notably *Cryptosporidium parvum,* are even more difficult to control. As a consequence, an enhanced version of the SWTR rule is under development.[157]

Because it is not feasible to routinely monitor *Giardia* and viruses in treated water, no MCLs are given for these organisms. Instead, treatment techniques are specified. In general, conventional or direct filtration must be operated to yield an averaged finished water turbidity of less than 0.5 NTU in at least 95% of the samples collected in a month, while diatomaceous earth or slow sand filters must yield a turbidity of less than 1 NTU. Disinfectants must be applied at high enough concentration C and for long enough contact time T such that

[157] Pontius, 2000.

the mathematical product CT is greater than a specified minimum level. This minimum level is a function of the disinfectant used, pH, temperature, and the presence or absence of other treatment processes that may help to remove pathogens.[158]

5.3.5 Lead and Copper

Lead and copper are not regulated by MCLs, but by treatment techniques instead. These treatment requirements are triggered if lead concentrations greater than 0.015 mg/L or copper concentrations greater than 1.3 mg/L are observed in more than 10% of tap-water samples. Potential treatment techniques include various corrosion control measures such as pH adjustment, or pipe replacement. The required treatment technique is a function of the severity of the problem, as well as the size of the public water system. It may also be required in some instances to undertake a public education program, in part to encourage people to ensure that their household plumbing is adequate.[159]

5.3.6 Non-centralized Treatment Devices

Non-centralized treatment devices, such as point-of-entry filters for individual homes, may be used to meet the National Primary Drinking Water Regulations; however, it is the responsibility of the public water system to operate the units according to very strict criteria. The devices themselves must be certified by the state.

Bottled water may not be used by public water systems to achieve compliance with the regulations.

5.3.7 Information Collection Rule

One of the complaints concerning earlier regulations was that available data were inadequate to make appropriate decisions. To this end, the Information

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[158] See sections 2.4.6 and 4.3.4 of this paper for discussion of the CT concept.

[159] Pontius, 2000; United States, Environmental Protection Agency, Office of Water, 1999b, *Lead and Copper Rule Minor Revisions* [online], (fact sheet) EPA 815-F-99-010 [cited July 2001], <www.epa.gov/safewater/standard/leadfs.html>.

Collection Rule (ICR) was developed for the sole purpose of obtaining information about water quality and treatment performance across the United States.[160] The data would then be used to help define future regulations. Monitoring for the ICR occurred over a period of 18 months, ending in 1999. The data are now being compiled and assessed.

The list of parameters monitored in the ICR was comprehensive: it generally addressed basic water quality parameters (pH, alkalinity, total organic carbon, etc.), disinfection by-products, and microbiological parameters (viruses, coliforms, fecal coliforms or *E.coli, Giardia, Cryptosporidium*).

The ICR also required larger systems to conduct tests to explore alternative treatment technologies for meeting future proposed disinfection by-product regulations. The tests ranged from simple bench-scale experiments to complex pilot-scale investigations, depending on system size.

5.3.8 Consumer Confidence Reports and Notice of Violations

All community water systems must publish, in an understandable manner, annual reports that describe water quality and any associated risks. Any violations of the regulations must be reported immediately to the public and to the primacy agency.

5.3.9 Small System Variance

The EPA recognizes that systems serving small populations may find it difficult to meet certain regulations. To this end, small systems (<10,000 people) can apply for variances to the regulations, except for microbiological criteria. The general requirement for obtaining a variance is to show that the system cannot afford to comply with the regulation, having exhausted all options. A variance results in a prescribed treatment technology that need not meet the regulatory requirements, but provides the maximum protection affordable.

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[160] See 40 CFR 141 (1996).

5.3.10 Proposed Arsenic Rule

The arsenic rule, scheduled to be made final in June 2001, proposes to lower the current arsenic MCL from 50 μg/L to 5 μg/L.[161] This proposed new MCL is noteworthy because it is the first instance in which the proposed MCL is higher than technically feasible because a lower value could not be cost-justified. Even so, the cost of the new 5 μg/L MCL is projected to be approximately US$1.3 billion per year.[162]

5.3.11 Proposed Radon Rule

Radon is reportedly the second leading cause of lung cancer in the United States, contributing to an estimated 20,000 deaths each year.[163] Drinking water is only a small source of radon (1–2%), the major source being ambient indoor air. The proposed radon rule is unique in that, along with proposing an MCLG of zero and an MCL of 300 pCi/L, there is also a proposed alternate maximum contaminant level (AMCL) of 4,000 pCi/L that a state can implement if it also introduces other programs to mitigate radon exposure from non-drinking-water sources. This is called a multimedia mitigation approach.

5.3.12 Proposed Ground Water Rule

The Ground Water Rule (GWR) establishes multiple barriers to protect against bacteria and viruses in drinking water from groundwater sources. The multiple barrier approach has four main components: (1) on-site inspections of the system, (2) source-water monitoring, (3) a requirement for correcting deficiencies, and (4) a requirement for treatment when deficiencies cannot be corrected and alternative sources of drinking water are not available.[164] The

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[161] United States, Environmental Protection Agency, Office of Water, 2000c, *Proposed Revision to Arsenic Drinking Water Standard* [online], EPA 815-F-00-012 [cited July 2001], <www.epa.gov/safewater/ars/proposalfs.html>.

[162] M.M. Frey et al., 2000, "Cost impacts of a lower arsenic MCL," in *Proceedings of the Water Quality Technology Conference* [CD-ROM] (Denver: AWWA).

[163] United States, Environmental Protection Agency, Office of Water, 2000b, *Proposed Radon in Drinking Water Rule,* [online], EPA 815-F-99-009 [cited July 2001], <www.epa.gov/safewater/radon/fact.html>.

[164] Pontius, 2000.

GWR also proposes to establish a strategy to identify groundwater systems at high risk for fecal contamination.

5.4 Other Federal Rules

The National Primary Drinking Water Regulation focuses mainly on treatment and performance standards for public water systems. However, other regulatory elements arising from the *SDWA* directly affect the production of safe drinking water. One such element is the Drinking Water State Revolving Fund Rule (DWSRFR).

The DWSRFR instructs the EPA to provide capitalization grants to the states, which in turn provide low-cost loans or other forms of assistance to public water supplies so that they can comply with the *SDWA*.[165] States are also authorized to set aside a portion of their capitalization grants to fund a range of activities including source-water protection, capacity development, and operator certification. At least 15% of the money must go to small systems.

Another important element in water treatment and supply – operator certification – is not addressed in the water quality regulations. The *SDWA* requires all states to carry out an operator certification program. The program does not have to require certification for every water system operator; rather, every water system must have a certified operator to perform certain key functions. For systems serving fewer than 3,300 people, the EPA is required to provide reimbursement for the cost of training and certification of the operators.

5.5 State Rules

The regulations developed by the EPA are minimum requirements. Primacy agencies such as state governments may adopt stricter regulations or regulate contaminants in addition to those in the NPDWR. A good example is the state of California, which, due to its high population and unique environment, faces a number of drinking water problems that do not exist elsewhere in the country. Regulations are introduced at the state level to deal with these local

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[165] F.W. Pontius, 1998, "State revolving fund outlook," *Journal of the American Water Works Association,* vol. 90, no.5, pp. 23–24. See also 40 CFR Parts 9 and 35 (2000).

problems. For example, California has introduced an MCL for methyl-*tert*-butyl ether, a compound present in many California waters from its use as an automobile fuel additive.[166] California also develops action levels (ALs) for certain contaminants for which MCLs may eventually be introduced. State ALs are not enforceable, but when they are exceeded certain requirements and recommendations – including notification of the public, reporting to the state government, or removal of a water source from service – may apply.[167]

5.6 Compliance and Enforcement

In most cases the EPA has delegated to the individual states responsibility for overseeing the *SDWA*. The states, in turn, ensure that local public water systems comply with all relevant regulations. State compliance efforts may include

- conducting on-site visits,
- providing financial assistance for improvements through the DWSRF and other programs,
- holding public information meetings,
- conducting training sessions, and
- reviewing plans and specifications for public water suppliers.[168]

It is common to delay formal enforcement following a violation unless there is a health risk that requires immediate action. This is to allow informal actions such as reminder notices and field visits to try to get suppliers back into compliance. If formal enforcement is required, actions could include

- bilateral compliance agreements,
- citations,
- administrative orders,
- criminal complaints,
- civil referrals to state Attorneys General or to the Department of Justice,

[166] California, Department of Health Services, 2000b, *Primary Standards – Organic Chemicals* [online], [cited December 2000], <www.dhs.ca.gov/ps/ddwem/publications/Regulations/4-17-00MTBEreg.PDF>.
[167] California, Department of Health Services, 2000a, *Drinking Water Action Levels* [online], [cited December 2000], <www.dhs.ca.gov/ps/ddwem/chemicals/AL/actionlevels.htm>.
[168] United States, Environmental Protection Agency, Office of Enforcement and Compliance Assurance, 2000.

- emergency orders,
- criminal cases,
- fines or administrative penalties, and
- other sanctions such as denying permission for supplier expansion.[169]

Any violations require public notification within 24 hours if the violation has the potential for serious health effects.[170] Notice of less serious violations may take up to a year, with notification through water bills, in an annual report, or by mail. Violations must also be reported to the state, which in turn must notify the EPA. The EPA assembles violations in the Safe Drinking Water Information System, a database used to monitor compliance.

It is the EPA's objective that by 2005, 95% of community systems will meet 1994 health-based standards, and that the same percentage of systems will comply with any new regulations within five years.[171] For reference, 89% of community systems reported no violations of health-based standards in 1998. Nevertheless, a recent audit by the EPA reported that almost 90% of violations that should have been reported were reported incorrectly or not at all, and that about half of MCL violations were not reported. The audit did not suggest an explanation for this lack of proper reporting.[172]

5.7 Comparison of U.S. and Ontario Approaches

In the United States, drinking water standards are determined at the federal level, while in Canada individual provinces set standards. It could be argued that when responsibility lies with a lower level of government, there is more flexibility to address regional concerns than when a nation-wide standard has to be established. It could also be argued that federal standards ensure greater uniformity in drinking water quality for the population as a whole by preventing the misuse of regulatory flexibility. Despite the constitutional differences, however, in practice there are many similarities between the two countries. The United States permits substantial downloading of responsibility for overseeing drinking water standards from the EPA to the state governments. Many state governments also introduce regulations over and above those

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[169] Ibid.
[170] See 42 CFR, Ch. 6a, Sec. 300f (1974); 40 CFR 141 (1996).
[171] United States, Environmental Protection Agency, Office of Water, 1999a.
[172] Ibid.

required by the *SDWA*. Likewise in Canada, while provinces are responsible for enacting standard-setting regulations, these standards are typically defined through nation-wide consultation under the umbrella of the Federal-Provincial Subcommittee on Drinking Water.

Perhaps the most significant difference between the United States and Ontario, at least historically, was the existence of the U.S. *Safe Drinking Water Act,* a single act that unified almost all issues pertaining to drinking water. This act clearly defined rules and responsibilities, and provided the regulatory framework for requiring proactive programs to improve drinking water quality and services. In Ontario, the *Water Resources Act* was not specifically focused on drinking water. However, the new Drinking Water Protection Regulation is a significant move in this direction.

One other difference between the U.S. and Ontario approaches is the American commitment to fund research to improve drinking water quality and service. The EPA is a major sponsor of such research and serves as a central repository of knowledge. It is recognized that the Ontario Ministry of the Environment does not have the same resources to provide research funding as does the EPA. However, with drinking water in Canada being a provincial jurisdiction, and with little funding if any provided by the federal government for drinking water research, this is an area in which the American system is clearly more advanced.

6 European Union

6.1 Structure of EU Regulations

The European Commission holds responsibility for initiating and implementing new European legislation. The Commission, the civil service arm of the EU government, comprises 24 directorates, each of which is responsible for specific areas of EU policy. The management plan of the Environment Directorate General, which administers water policy, includes this mission statement:

- To maintain and improve the quality of life through a high level of protection of our natural resources, effective risk assessment and management and the timely implementation of Community legislation.

- To foster resource-efficiency in production, consumption and waste disposal measures.

- To integrate environmental concerns into other EU policy areas.

- To promote growth in the EU that takes account of the economic, social and environmental needs both of our citizens and of future generations.

- To address the global challenges facing us notably combating climate change and the international conservation of bio-diversity.

- To ensure that all policies and measures in the above areas are based on a multi-sectoral approach, involve all stakeholders in the process and are communicated in an effective way.[173]

The path to new legislation begins with a proposal from the commission to the Council of Ministers and the European Parliament. For a proposal to become law it must receive approval from both these decision-making bodies. This may take several revisions, since each can request modifications to the original proposal. On occasions when the council and parliament cannot find agreement, a Conciliation Committee, comprising representatives from both, is charged with finding an acceptable compromise. If the committee fails, the proposal is not adopted into law.

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[173] European Union, Environment Directorate General, 2000, *Environment DG Mission* [online], [cited December 2000], <http://europa.eu.int/comm/dgs/environment/mission_en.htm>.

Once a proposal gains joint approval it is passed as an EU directive published in the *Official Journal of the European Communities;* it becomes law and a deadline is set for the member states to adopt its provisions into their national legislation. The directives implemented by the Environmental Directorate represent the minimum standards that member states of the EU must adopt into their own regulations.

The Environmental Directorate, through its directives, has adopted a policy of integrated water quality management. This unified approach integrates legislation designed to protect consumers with legislation designed to protect and manage source waters. Consumers are protected through The Bathing Water and Drinking Water directives, which deal with water for consumption. Water source management divides into two domains: protection of raw-water quality and control of emissions to surface and groundwater. The new Water Framework Directive, enacted in October 2000, consolidates a series of previous directives passed to ensure good water quality and good habitat for fish life, in addition to ensuring high-quality source water for abstraction. A series of emission control directives limit discharge of wastes and potentially harmful substances to European surface or groundwater. Figure 6-1 illustrates the EU integrated water quality management approach.

In accordance with the objective of this paper to examine drinking water treatment and production in jurisdictions outside Canada, we will explore how EU regulations influence final drinking water quality in the member states. We will examine standards for treated water quality and standards designed to protect raw water resources.

6.2 Drinking Water Directive

In November 1998 the EU enacted "Council Directive 98/83/EC on the Quality of Water Intended for Human Consumption."[174] This directive replaced an earlier one of the same name enacted in 1980. The European Commission notes that it was necessary to update the directive since "it was both out of date as concerns scientific/technical basis (original proposal was made in 1975) and the managerial approach."[175]

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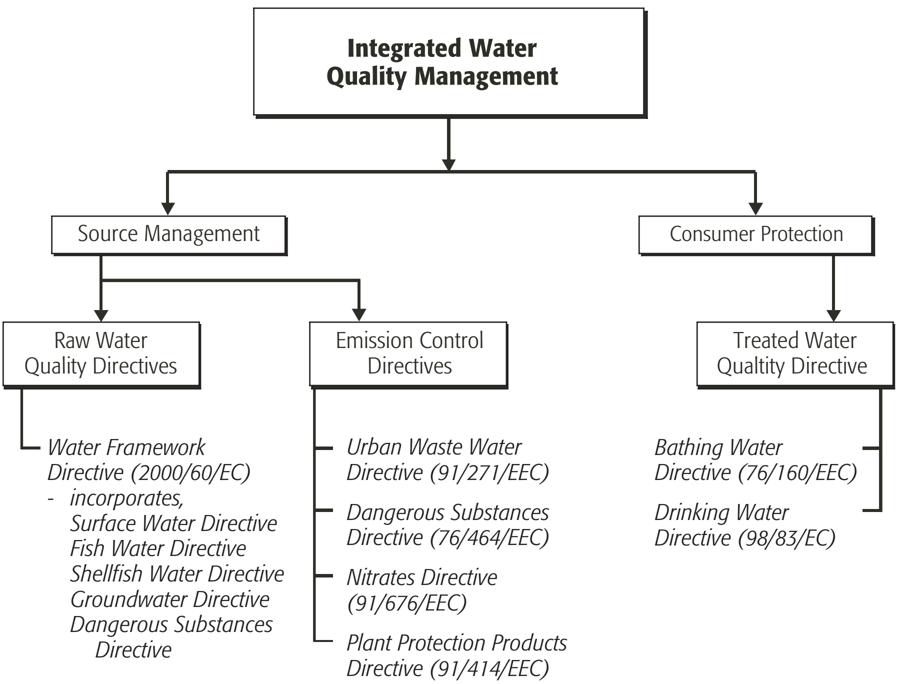
[174] European Union, 1998, "Council directive 98/83/EC of November 1998 on the quality of water intended for human consumption," *Official Journal of the European Communities* (5.12.98).
[175] European Union, 2000c, *New Drinking Water Directive* [online], [cited December 2000], <http://europa.eu.int/water/water-drink/index_en.html>.

Article 1 of the new directive notes that its objective "shall be to protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean." The directive applies to waters intended for human consumption whether supplied from a distribution network, from a tanker, or in bottles or containers. Excepted are natural mineral waters and waters that are medicinal products. Member states are also allowed to exempt waters whose quality, in the opinion of competent local authorities, will have no influence on consumer health. Member states may also exempt an individual supply that provides less than 10 m^3/d on average or serves fewer than 50 people. The served population must be informed of this exemption.

Directive 98/83/EC identifies a baseline series of parameters and parameter values that are legally binding throughout the EU. Subsection 6 of the preamble refers to these as the "essential quality standards with which water ... must comply."

Figure 6-1 EU Integrated Water Quality Management Approach



Source: various European Union Web sites. See <http://europa.eu.int/comm/environment/water/>.

6.2.1 Standards and Obligations

Directive 98/83/EC notes that the minimum requirement for water intended for human consumption is that it be wholesome and clean. Article 4 states that water shall be wholesome and clean if it is free from micro-organisms and parasites and any other substances at a concentration sufficient to present a potential danger to human health. It must also, at minimum, meet the values listed for microbiological and chemical parameters. The commission requires member states to set values into local legislation for the parameters given in annex I of the directive, and it requires that those values not be less strict than those shown in the annex. An additional three parameters apply to bottled water offered for sale. The directive divides the list into microbiological parameters, chemical parameters, indicator parameters, and radioactivity (see tables 6-1 through 6-4). Subsection 16 of the preamble notes that the parameters and their values are based on the World Health Organization's "Guidelines for drinking water quality." Article 11 of the directive requires the commission to review the parameters at least every five years and to amend provisions to take into account any relevant scientific and technical progress.

Article 5 also assigns responsibility to member states to consider parameters not specifically listed, where the protection of human health requires it. The article notes that the values set for these additional parameters should, at minimum, ensure that the water is free of micro-organisms and parasites. This

Table 6-1 EU Drinking Water Directive – Microbiological Parameters

Parameter	Value
Escherichia coli (E. Coli)	zero per 100 mL
Enterococci	zero per 100 mL
The following apply to water offered for sale in bottles or containers:	
Escherichia coli (E. Coli)	zero per 250 mL
Enterococci	zero per 250 mL
Pseudomonas aeruginosa	zero per 250 mL
Colony count 22°C	100 per mL
Colony count 37°C	20 per mL

Source: European Union, 1998.

Table 6-2 EU Drinking Water Directive – Chemical Parameters

Parameter	Value	Unit
Acrylamide	0.1	μg/L
Antimony	5.0	μg/L
Arsenic	10	μg/L
Benzene	1.0	μg/L
Benzo(a)pyrene	0.01	μg/L
Boron	1.0	mg/L
Bromate	10	μg/L
Cadmium	5.0	μg/L
Chromium	50	μg/L
Copper	2.0	mg/L
Cyanide	50	μg/L
1,2-dichloroethane	3.0	μg/L
Epichlorohydrin	0.1	μg/L
Fluoride	1.5	mg/L
Lead	10	μg/L
Mercury	1.0	μg/L
Nickel	20	μg/L
Nitrate	50	mg/L
Nitrite	0.5	mg/L
Pesticides	0.1	μg/L
Pesticides – total	0.5	μg/L
Polycyclic aromatic hydrocarbons	0.1	μg/L
Selenium	10	μg/L
Tetrachloroethene and trichloroethene	10	μg/L
Trihalomethanes – total	100	μg/L
Vinyl chloride	0.5	μg/L

Source: European Union, 1998.

Table 6-3 EU Drinking Water Directive – Indicator Parameters

Parameter	Value	Unit
Aluminum	200	µg/L
Ammonium	0.50	mg/L
Chloride	250	mg/L
Clostridium perfringens	0	number/100 mL
Colour	Acceptable to consumers and no abnormal change	
Conductivity	2,500	μScm^{-1} at 20°C
Hydrogen ion concentration	≥6.5 and ≤9.5	pH units
Iron	200	µg/L
Manganese	50	µg/L
Odour	Acceptable to consumers and no abnormal change	
Oxidizability	5.0	mg/L O_2
Sulphate	250	mg/L
Sodium	200	mg/L
Taste	Acceptable to consumers and no abnormal change	
Colony count 22°C	No abnormal change	number/100 mL
Coliform bacteria	0	
Total organic carbon (TOC)	No abnormal change	
Turbidity	Acceptable to consumers and no abnormal change	

Source: European Union, 1998.

Table 6-4 EU Drinking Water Directive – Radioactivity

Parameter	Value	Unit
Tritium	100	Bq/L
Total indicative dose	0.10	mSv/y

Source: European Union, 1998.

effectively requires member states to enact steps to protect against parasites such as *Giardia* and *Cryptosporidium,* even though they are not specifically mentioned in the directive. Because the directive covers water delivered by tanker and bottles, in addition to water delivered through the distribution mains, it clarifies the point at which its provisions must be met. Compliance is required at the point where water emerges from the tanker for tanker-supplied water; at the filling point for bottled or container water; at the point where water is used for food production; and at the point where it emerges from taps for normal consumption. The provisions do recognize, however, that maintenance of the distribution system and domestic plumbing might not always be under the control of the supplier. Under these circumstances the requirement of compliance at the consumers' taps does not apply, except where water is supplied to the public such as in schools, hospitals, and restaurants.

6.2.2 Monitoring

The directive requires that member states institute a monitoring program to ensure that water intended for human consumption meets the minimum requirements outlined in its provisions. This program must include check monitoring of 15 named parameters and audit monitoring of all parameters, unless it can be demonstrated that a parameter is unlikely to be found in the water at a significant concentration (see table 6-5). Annex II of the directive states that check monitoring provides information on the organoleptic and microbiological quality of the water, in addition to confirming the effectiveness of treatment, especially disinfection. Audit monitoring provides information to determine whether the minimum required parameter values, set by the directive or the member state, are being met. The directive also specifies the minimum number of samples that must be analyzed for each monitoring type. That number depends primarily on the volume of water treated (see table 6-6).

Monitoring is also required for those additional parameters for which no value is indicated in the directive, but which must be adopted if they present a significant risk to human health. As noted previously, they would include pathogens such as *Giardia* and *Cryptosporidium.*

Table 6-5 Parameters Subject to Check Monitoring

Aluminum	necessary only when used as a flocculent
Ammonium	
Colour	
Conductivity	
Clostridium perfringens (including spores)	necessary only if the water originates from or is influenced by surface water
Escherichia coli (E. coli)	
Hydrogen ion concentration	
Iron	necessary only when used as a flocculent
Nitrite	necessary only when chloramination is used as a disinfectant
Odour	
Pseudomonas aeruginosa	necessary only in the case of water offered for sale in bottles or containers
Taste	
Colony count 22°C and 37°C	necessary only in the case of water offered for sale in bottles or containers
Coliform bacteria	
Turbidity	

Source: European Union, 2000c, annex II.

Table 6-6 Sampling Frequency Required by EU Drinking Water Directive

Water production (m^3/d)	Check monitoring samples (per annum)	Audit monitoring samples (per annum)
<100	decided by the member state	decided by the member state
100–1,000	4	1
1,000–10,000	4 + 3 for each additional 1,000 m^3/d	1 + 1 for each additional 3,300 m^3/d
10,000–100,000	4 + 3 for each additional 1,000 m^3/d	3 + 1 for each additional 10,000 m^3/d
>100,000	4 + 3 for each additional 1,000 m^3/d	10 + 1 for each additional 25,300 m^3/d

Source: European Union, 2000c, annex II.

6.2.3 Remedial Actions and Derogations

If water intended for human consumption should for any reason fail to meet the listed standards or the stricter standards set by member states, the directive requires (1) immediate investigation to identify the cause of the failure, (2) remedial action as soon as possible to restore the required quality, and (3) that consumers be informed promptly and advised of the necessary precautions to ensure health is not endangered. These requirements do not apply if the failure to meet the standard is trivial.

The overriding principle of the directive is outlined in article 8 and states that "member states shall ensure that any supply of water intended for human consumption which constitutes a potential danger to human health is prohibited ..."

Member states are allowed to provide exemptions, or derogations, to some of the provisions of the directive. Article 9 allows member states to provide derogations from the chemical parameter values, or equivalent stricter national standards, as long as they do not constitute a potential danger to human health and provided that the required quality cannot reasonably be maintained otherwise. Such a derogation is not to exceed three years, although a second three years can be allowed, provided that the member state communicates its intention to the European Commission. In rare circumstances, a third three-year derogation can be granted, but only by the commission. When allowing derogations, member states must inform the commission within two months for any supply that provides greater than 1,000 m^3/d of water on average or where the system serves more than 5,000 people.

6.2.4 Reporting and Public Notification

The EU Drinking Water Directive requires member states to publish a report every three years on the quality of water for human consumption. The purpose of the report is to inform consumers. It must cover all supplies that on average provide more than 1,000 m^3/d or serve more than 5,000 people. The report must address the parameters and values adopted in the member state in accordance with the directive, any additional parameters adopted, details of monitoring programs, any remedial actions taken or required, any derogations to the provisions of the directive, and any changes to the compliance deadline outlined. The commission will publish a synthesis report every three years based on the reports supplied by the member states.

Member states are also required to provide a second report to the commission that describes measures taken or planned to (1) inform and advise consumers in circumstances where supplied water may not meet standards due to suspect distribution, even when the distribution system is not under the control of the supplier, and (2) ensure that total trihalomethane concentration in supplied water is at most 150 μg/L five years after implementation of the directive and at most 100 μg/L ten years after implementation of the directive.

The Drinking Water Directive is strongly oriented toward providing information to consumers, particularly if this information warns of a potential risk to human health. Subsection 32 of the directive's preamble states that

> consumers should be adequately and appropriately informed of the quality of water intended for human consumption, of any derogations granted by the member states and of any remedial action taken by the competent authorities ... furthermore, consideration should be given both to the technical and statistical needs of the Commission, and to the rights of the individual to obtain adequate information concerning the quality of water intended for human consumption.

This approach is reinforced throughout the articles of the directive, which go so far as to require member states to inform consumers of potential risks arising from, for example, the distribution system even if its maintenance is not under their direct control.

6.2.5 Compliance

Member states must ensure that water intended for human consumption within their boundaries complies with the provisions of the Drinking Water Directive within five years of its entry into force. Member states have two years during which the appropriate laws and regulations must be enacted nationally to ensure compliance with the directive, and during which the text of these laws must be provided to the commission. Allowances are made for staged implementation of the parameter values for bromate, lead, and total trihalomethanes.

The directive does provide for circumstances through which a request may be made to the commission for a longer period for implementation. This period cannot exceed three years, although application may be made for a second three-year period. The public must be informed of the outcome of such requests.

6.3 Water Framework Directive

In September 2000 the European Parliament and Council of Ministers adopted the "Directive of the European Parliament and of the Council 2000/60/EC Establishing a Framework for Community Action in the Field of Water Policy." The Water Framework Directive, as it is more commonly known, was published in the *Official Journal of the European Communities* and became law in October 2000.[176]

This directive is the European Union's blueprint for protection, preservation, and improvement of all raw waters within the member states, including water bodies from which drinking water will be abstracted. As a result of prolonged human use and activity, many of Europe's water resources have been seriously degraded. This directive aims to inhibit further degradation and to protect and improve aquatic ecosystems, both in quality and quantity. In addition to water quality protection and improvement, its provisions address pollution prevention through enforcement of emission control standards.[177]

6.3.1 Purpose

The key aims of the Water Framework Directive are to

- expand the scope of water protection to all waters, surface waters, and groundwater,
- achieve "good status" for all waters by a set deadline,
- manage water, based on river basins,
- adopt a "combined approach" of emission limit values and quality standards,

[176] European Union, 2000a, "Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy," *Official Journal of the European Communities.*
[177] European Union, 2000b, *The EU Water Framework Directive* [online], [cited December 2000], <http://europa.eu.int/water/water-framework/index_en.html>.

- adopt the principle of cost recovery for water services,
- involve the public in water management planning, and
- streamline legislation.

6.3.2 River Basin Districts

The central theme of the directive is management of river basin districts. Article 3 requires member states to identify all river basins within their national boundaries and to assign them to individual river basin districts. Groundwater and coastal water must also be assigned to the nearest or most appropriate river basin district and, where water bodies cross national boundaries, an international river basin district must be formed. Member states must then assess the characteristics of each river basin, establish a "programme of measures" to be enacted, and produce a river basin management plan for each district. This plan must be published within nine years. It must be updated within 15 years and every six years thereafter.

6.3.3 Environmental Objectives

Article 4, Environmental Objectives, outlines the central intent of the directive for European surface water, groundwater, and protected areas.

Surface Water

Member states are required to prevent further deterioration of surface water (i.e., rivers, lakes, transitional, and coastal waters) and to ensure through protection, enhancement, and restoration that all surface water bodies achieve the designation of "good surface water status" within 15 years. The directive defines good water status of a surface water body as the combination of its ecological status and its chemical status. Ecological status reflects the state of waterborne fauna and the hydromorphological and chemical elements that support it. The standard is set by comparing the current ecological state of the surface water with its expected state had it remained undisturbed and pristine.

Chemical status considers the acute and chronic effects of listed toxins. When the body of water meets the environmental quality standards identified in a series of daughter directives and in a list of priority pollutants to be identified by the commission, it will receive the "good chemical status" designation.

Groundwater

Similarly, member states must implement the necessary measures to prevent deterioration and to protect, enhance, and restore all bodies of groundwater so as to achieve "good groundwater status" within 15 years. States must also prevent or limit groundwater pollution and reverse any upward trend in pollutant concentration resulting from human activity.

Good groundwater status is based on quantitative status and chemical status. The directive maintains quantitative status by ensuring that the level of groundwater in each groundwater body is such that the long-term annual average rate of abstraction does not exceed the available groundwater resource. Thus, the volume of water extracted will not adversely affect ecosystems – in surface water or wetlands – that depend on groundwater recharge.

Protected Areas

Member states are required to meet standards and objectives for protected areas such as those designated for abstraction of drinking water, those designated for protection of economically significant aquatic species, those designated as recreational waters or nutrient-sensitive areas, and those designated for the protection of habitats or species. Compliance is required within 15 years of the directive's coming into force.

The timing for compliance with listed environmental objectives may be extended if it is not technically feasible to achieve them within the allowed time frame, or if the necessary improvements would be disproportionately expensive, or if natural conditions would not allow them. Similarly, article 4 allows for temporary deterioration in the quality of source waters as long as it results solely from exceptional natural causes.

6.3.4 River Basin Characterization, Monitoring, and Protected Areas

The directive requires each member state, as part of its river basin management plan, to complete an analysis of basin characteristics, to review the impact of human activity on surface water and groundwater, and to perform an economic analysis of water use in the basin. These analyses must be completed within four years and reviewed initially within 13 years, and every six years thereafter.

This provision establishes the current status of all water bodies in the European Union. Each member state must also establish a registry of its protected areas. The directive gives particular emphasis to protection of water bodies used or intended for use as drinking water sources. All such water bodies from which abstraction exceeds 10 m^3/d must be identified in the management plan. Water bodies that provide more than 100 m^3/d of drinking water must be monitored. Article 7 of the directive requires also that waters used for consumption meet the provisions of the Drinking Water Directive and that member states ensure those water bodies are protected against deterioration in quality.

Article 8 of the directive requires member states to establish monitoring programs for surface water, groundwater, and protected areas within each river basin. For surface water, the program must include volume and rate of flow, ecological elements, and chemical parameters; for groundwater it must monitor chemical and quantitative status; and for protected areas, the program must include monitoring of the parameters used – in the national legislation of the member state – to designate the area as protected. The directive stipulates the standard methods and technical specifications that member states must use to carry out the analysis and monitoring required by article 8.

6.3.5 Water Service Costing

The EU has adopted a policy of full cost recovery for water services. The intent of this policy is to promote efficient use of water resources and to enact the "polluter pays" principle. The directive acknowledges this strategy and requires member states to adopt water-pricing policies that induce efficient use of water. States must also ensure that at least industry, households, and agriculture contribute adequately to the real cost of water service. This cost will be generated through the economic analysis required in the river basin management plans. However, the directive recognizes that models for water cost recovery differ between member states. For example, some states do not apply direct costing to water use and prefer to recover these costs through taxation. Therefore the directive allows such states to continue this practice in preference to a direct cost recovery method. The method of cost recovery must be reported in the river basin management plan.

6.3.6 Programme of Measures

In accordance with the directive, each member state must put into place a "programme of measures" designed to implement environment and costing objectives for each river basin. The minimum requirements, termed "basic measures," must include

- requirements outlined in previous EU water protection legislation,
- steps to recover cost of water,
- measures required to prevent deterioration of the water resource,
- procedures to meet the requirements of protected areas,
- controls over abstraction of water,
- constraints on groundwater artificial recharge,
- controls over polluting discharges,
- a prohibition on direct discharges of pollutants to groundwater,
- elimination of discharge of listed priority pollutants to surface water, and
- prevention of pollutants from technical installations.

Member states may also adopt "supplementary measures" as part of the program. The directive gives a list of some such measures, which range from legislation and economics to construction and education. The form of the supplementary measures and their adoption are at the discretion of the member state. The directive requires that programmes of measures be in place within nine years and that they be reviewed within 15 years, and every six years thereafter.

6.3.7 River Basin Management Plan

Each river basin must have a management plan. The plan must include location information and mapping, a status assessment of the water source, the programme of measures, an economic analysis together with proposed steps to recover water costs, pollution prevention measures, a summary of public information and consultation measures, and other requirements as listed in annex V of the directive. Management plans must be completed within nine years. They must be updated within 15 years, and every six years thereafter.

6.3.8 Public Consultation and Reporting

The European Commission considers public input to the implementation of the Water Framework Directive to be vital. This approach is reinforced in the directive. Article 14 requires member states to encourage public participation, particularly in all aspects of the river basin management plans. States are also required to release their production timetables and work programs to the public at least three years before adopting a final plan. An interim overview must be available for review at least two years before the plan is adopted, and a draft version of the plan must be available for at least one year. All background material and information used in development of the plan must also be made available upon request. Interested parties will have a six-month period for written comment.

Member states must submit the river basin management plans to the commission within three months of publication. They must also send summary reports of the current status of the basins and details of the monitoring program. An interim progress report must be submitted within three years of adopting the management plan.

6.3.9 Requirements of the European Parliament and Council

The directive also obliges EU regulators to carry through on a number of measures designed to reduce pollution of water resources and reverse the existing effects of human activity on those resources. The measures include generating a list of priority hazardous substances and maximum permitted concentrations of these substances in resource waters, and adoption of measures to prevent and control groundwater pollution. The commission is also required to publish a series of reports that indicate the progress in implementing the directive.

6.3.10 Repeals and Penalties

The directive lists several previous directives that will be repealed as its provisions become widely adopted. They include directives relating to surface water quality, exchange of information and analysis, groundwater protection, and protection of aquatic life forms.

The directive does not stipulate specific penalties for breaches of its provisions, as enforced through member state legislation. It leaves the member states to determine the appropriate penalties, noting only that they “shall be effective, proportionate, and dissuasive.”

6.4 Comparison of EU and Ontario Approaches

Perhaps the main difference between regulations in Ontario and those in the European Union is one of target audience: Ontario regulations are aimed at water utilities, EU directives are aimed at the governments of member states. Consequently, although they are now embedded in legislation, the Ontario drinking water standards are written for ease of use. Because the EU directives represent fundamental law on which national regulations must be built, in 15 countries and 11 different official languages, they tend to be legalistic in their writing and difficult to interpret for specific instances of supply. They must also allow for differing cultures and approaches to drinking water throughout the EU and therefore must incorporate means by which member states can fashion the directives to their own situations. This is done primarily by allowing “derogations,” as previously discussed. Ontario also allows a degree of “non-compliance” upon approval by the Ministry of the Environment; however, this is not readily achieved.

The EU regulations also recognize the time required for implementation in the member states, and therefore allow several years for their adoption. Overall, the approach to water quality regulation is similar. However, for microbiological standards the EU regulations deal with *E.Coli* and enterococci as indicator parameters. They do not directly address standards for *Giardia* or *Cryptosporidium* inactivation but rather note that member states must consider parameters not specifically listed in the directives, if public health requires it. The Ontario standards, by adopting the disinfection approach of the U.S. Surface Water Treatment Rule, do address inactivation of viruses and *Giardia* cysts.

7 England and Wales

7.1 Structure of England and Wales Regulations

Regulations in England and Wales are embodied in acts of parliament and as such are enforceable by law, with fines and imprisonment possible for those who contravene them. Because the United Kingdom is a member state of the European Union its national legislation must incorporate the requirements of EU directives as minimum enforceable standards. Thus, regulations in England and Wales combine nationally derived standards with those originating with the European Union.

Water regulation in England and Wales, though similar, is separate from that of Scotland and Northern Ireland. Those countries, through their own legislation, are responsible for their own water quality and resources.

7.2 The Water Supply (Water Quality) Regulations 1989

Drinking water quality in England and Wales is regulated according to the provisions of The Water Supply (Water Quality) Regulations 1989 (WS(WQ)R), an act of parliament.[178] The regulations, which came into force between September 1989 and January 1990, are legally binding. The act is divided into nine parts, each of which presents one or more regulations.

Part I – General

Part I of the regulations provides definitions that are used in the rest of the document.

Part II – Wholesomeness

Part II defines the conditions under which water supplied for drinking, washing, or cooking is considered wholesome. In addition to stating that water must

[178] United Kingdom, 1989, *The Water Supply (Water Quality) Regulations 1989* [online], Statutory Instruments, 1989, no. 1147 (London: Her Majesty's Stationary Office) [cited December 2000], <www.hmso.gov.uk/si/si1989/Uksi_19891147_en_1.htm>.

not contain anything deleterious to health, this section discusses the parameters and values that water must meet. Table 7-1 shows parameters with maximum allowable values; table 7-2 shows parameters with minimum allowable values; and table 7-3 shows parameters for which the average concentrations over the previous 12 months must not exceed the stated values. The regulation also requires that the average concentrations of trihalomethanes over three months must not exceed 100 μg/L, except where fewer than four samples were tested, in which case no sample should exceed 100 μg/L. The regulation in this part also allows for occasional excess of sodium, which requires at least 80% compliance over the previous 36 months, and of total coliforms, which require at least 95% compliance over the previous year.

Although the regulated parameters are generally the same as for other countries, most other standards consider parameters as physical, chemical, organic (including pesticides), and microbiological. By grouping parameters in terms of how the stated values must be met, the WS(WQ)R differs from the approach adopted in Canada and Australia, for example. Similarly, the WS(WQ)R does not directly separate parameters on the basis of aesthetic or health classification.

Part III – Relaxation of Requirements of Part II

The Secretary of State in England and Wales may relax the conditions required by part II of the regulations in cases of emergency or as a result of unmanageable source conditions. This relaxation of requirements must not, however, cause unacceptable risk to public health. The Secretary of State cannot revoke the relaxation of regulations without giving at least six months notice, except in cases where public health is endangered. For private supplies, the local authority is authorized to enact relaxation of regulations, subject to the limitations noted.

Part IV – Monitoring of Water Supplies

The regulations in this part of WS(WQ)R outline requirements for monitoring water quality in samples taken from consumers' taps. The number of samples to be analyzed yearly depends on the parameter, the volume of water supplied, the population served, and whether a groundwater or surface water source is used. Tables show the standard number of samples to be taken yearly, for each combination of these factors. Numbers range from four samples in small supplies to 360 samples for some parameters in large-scale systems. The required number of samples may be reduced in situations where analysis over the previous three years has shown values of less than 50% of the prescribed value for the parameter tested, except for pH, which must have remained between 6.5 and 8.5, and hardness or alkalinity, which must have been no less than 90 mg Ca/L or 45 mg bicarbonate/L, respectively. The regulations also require suppliers to take samples

Table 7-1 Water Quality – Maximum Values

Parameter	Unit of measurement	Maximum value
Colour	mg/L Pt/Co	20
Turbidity (including suspended solids)	Formazin turbidity units	4
Odour (including hydrogen sulphide)	dilution number	3 at 25°C
Taste	dilution number	3 at 25°C
Temperature	°C	25
Hydrogen ion	pH value	9.5 to 5.5
Sulphate	mg /L SO_4	250
Magnesium	mg/L Mg	50
Sodium	mg/L Na	150
Potassium	mg/L K	12
Dry residues	mg/L	1,500 (dried at 180°C)
Nitrate	mg/L NO_3	50
Nitrite	mg/L NO_2	0.1
Ammonium (ammonia and ammonium ions)	mg/L NH_4	0.5
Kjeldahl nitrogen	mg/L N	1
Oxidizability (permanganate value)	mg/L O_2	5
Total organic carbon	mg/L C	No significant increase
Dissolved or emulsified hydrocarbons; mineral oils	µg/L	10
Phenols	µg/L C_6H_5OH	0.5
Surfactants	µg/L (as lauryl sulphate)	200
Aluminium	µg/L Al	200
Iron	µg/L Fe	200
Manganese	µg/L Mn	50
Arsenic	µg/L As	50
Cadmium	µg/L Cd	5
Cyanide	µg/L CN	50
Chromium	µg/L Cr	50
Mercury	µg/L Hg	1
Nickel	µg/L Ni	50
Lead	µg/L Pb	50
Antimony	µg/L Sb	10
Selenium	µg/L Se	10
Pesticides and related products	µg/L µg/L	0.1 0.5
Polycyclic aromatic hydrocarbons	µg/L	0.2
Total coliforms	number/100 mL	0
Fecal coliforms	number/100 mL	0
Fecal streptococci	number/100 mL	0
Sulphite-reducing clostridia	number/20 mL	1
Colony counts	number/1 mL at 22°C or 37°C	No significant increase

Source: United Kingdom, 1989.

if they consider that parameters might have exceeded, or are likely to exceed, the regulated values.

Part V – Monitoring – Additional Provisions

Part V of WS(WQ)R stipulates monitoring of water supplies at the treatment plant, at service reservoirs, and at new sources. The regulations tabulate the minimum number of samples that must be taken yearly for microbiological analysis – from 12 required samples for coliforms (fecal and total), disinfectant residual, and colony counts in small systems to 365 required samples for coliforms and residual disinfectant in large systems. Suppliers may reduce the number of samples if no fecal or total coliforms have been detected for three successive years. For systems that supply more than 2,000 m^3/d, the supplier

Table 7-2 Water Quality – Minimum Values

Parameter	Unit of measurement	Minimum value
Total hardness	mg/L Ca	60
Alkalinity	mg/L HCO_3	30

Source: United Kingdom, 1989.

Table 7-3 Water Quality – Maximum Average Values

Parameter	Unit of measurement	Maximum average value
Conductivity	µS/cm	1,500 at 20°C
Chloride	mg/L Cl	400
Calcium	mg/L Ca	250
Substances extractable in chloroform	mg/L dry residue	1
Boron	µg/L B	2,000
Barium	µg/L Ba	1,000
Benzo 3,4 pyrene	ng/L	10
Tetrachloromethane	µg/L	3
Trichloroethene	µg/L	30
Tetrachloroethene	µg/L	10

Source: United Kingdom, 1989.

may reduce the numbers of samples if assured that there is no appreciable risk of contamination. Suppliers must also sample service reservoirs at least weekly for microbiological parameters. If, as a result of change in treatment, the supplier believes any parameter value has been exceeded or is likely to be, it must increase the number of samples for that parameter until the end of the year. Part V also requires sampling of new sources to ensure they can be safely used.

Part VI – Water Treatment

The regulations specify disinfection as the minimum treatment required for any raw water (groundwater, surface water, or other). Additional treatment is specified for surface water. The extent of this treatment depends on the classification of the surface water source, in accordance with the European Union Directive 75/440/EEC, “Quality Required of Surface Water Intended for the Abstraction of Drinking Water in the Member States.” Based on the quality classification of the source, required treatment may range from filtration and disinfection to the full range of advanced treatment (e.g., coagulation, flocculation, sedimentation, filtration, adsorption, and disinfection).[179] It should be noted that the new EU Water Framework Directive (see chapter 6) will replace Directive 75/440/EEC and repeal it within seven years. This will require consequent changes to WS(WQ)R.

Part VI notes that where concentrations of lead or copper might exceed the regulated maximum value, as a result of these elements entering water from distribution piping or fixtures, the supplier must treat the water to minimize this risk. This may require, for example, control of treated water pH to more arduous limits than is normally required. The regulations in this part limit the application or introduction of “substances or products” into drinking water unless they have been approved by the Secretary of State or unless the supplier is satisfied that they will not affect water quality.

Part VI also allows the Secretary of State to require water suppliers to apply for approval before using specific processes for water treatment. Once approval is given, the secretary cannot revoke, modify, or prohibit it without giving six months notice, unless public health is endangered. Regulation 28 makes it an offence to contravene the provisions of part VI.

[179] European Union, 1975, “Council directive of 16 June 1975 concerning the quality required of surface water intended for the abstraction of drinking water in the member states,” 75/440/EEC, *Official Journal of the European Communities,* L 194, 25.7 1975.

Part VII – Records and Information

Part VII of WS(WQ)R relates to transfer of water supply information to the public and to local administrative authorities. Suppliers are required to prepare and maintain a record that must include the name of the supply zone, the name of the treatment works, the population of the zone, details of any relaxation granted in respect of the required parameter values, analytical results, and the number and extent of water quality contraventions. This record must be updated at least yearly and the information must be made available to the public. The supplier must make the public aware that such records are available for inspection.

Part VII stipulates that the water supplier must notify the local administrative authority and the district health authority in the event that a significant danger is posed to public health, and it must be prepared to supply information as required to these bodies.

The supplier must prepare and publish a yearly report that contains details similar to those noted above. The report must address water quality and must indicate the number of times and the extent to which the water failed to meet the required standards. WS(WQ)R provides two forms that address reporting requirements and that must form part of the annual report.

Part VIII – Functions of Local Authorities in Relation to Water Quality

Part VIII requires local administrative authorities, including the health authority, to arrange for notification in the event of significant public health risk occurring through supply of drinking water. It also empowers local authorities to take and analyze samples independently of the supplier.

Part IX – Enforcement

Regulation 34 establishes the right of the Secretary of State to enforce the provisions of WS(WQ)R.

7.3 The Water Supply (Water Quality) (Amendment) Regulations 1999

In June 1999 the Water Supply Regulations were amended to establish drinking water control standards for *Cryptosporidium,* a waterborne protozoan that can cause illness in consumers.[180] The amendments require water suppliers to examine their systems and determine the risk of circulating waterborne *Cryptosporidium* oocysts from the treatment works. Where a significant risk exists, the amended regulations require suppliers to install treatment that ensures the average number of oocysts per 10 litres of treated water is less than one. The supplier must also install on-line sampling equipment that samples a flow of no less than 40 L/h on average. The daily analysis of this sample must show that an average of less than one oocyst per 10 litres of treated water leaves the plant. Only approved laboratories, using approved sampling equipment and approved methods may analyze for *Cryptosporidium.*

The Drinking Water Inspectorate (DWI) prepared a guidance document on the risk assessments necessary under the amended regulations.[181] This document notes that, for the purposes of the regulation, certain circumstances always give rise to significant risk of oocyst contamination. They include

- water taken directly, or through storage of seven days or less, from a river or stream to a water treatment plant;
- fecal coliforms in the raw water; and
- previous and unexplained occurrence of cryptosporidiosis (the illness caused by *Cryptosporidium* oocysts) that is associated with the water supply and for which no specific steps have been taken to prevent a recurrence.

Supplies to which any of these circumstances apply are considered to pose significant risk of *Cryptosporidium* contamination and must always incorporate treatment and continuous sampling.

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[180] United Kingdom, Drinking Water Inspectorate, 1999a, *Water Industry, England and Wales: The Water Supply (Water Quality) (Amendment) Regulations 1999* [online], Statutory Instruments, 1999 no. 1524 [cited July 2001], <www.dwi.gov.uk/regs/si1524/index.htm>.

[181] United Kingdom, Drinking Water Inspectorate, 1999b, *Guidance on Assessing Risk from* Cryptosporidium *Oocysts in Treated Water Supplies to Satisfy the Water Supply (Water Quality) (Amendment) Regulations 1999* [online], [cited July 2001], <www.defra.gov.uk/dwi/regs/crypto/pdf/risk.pdf>.

The DWI guidance document also outlines other factors in water supply that can contribute to a significant risk of oocyst contamination. For surface water sources these include elements such as direct or short-storage abstraction, insufficient control over activity in the catchment area, and no automatic quality monitoring of raw-water intakes. For groundwater, elements presenting risk include (among others) river-aquifer connection, unconfined conditions and a shallow water table, poor wellhead construction, livestock in the area of the wellhead, slurry or sewage spreading in the vicinity of the well, changes in raw water quality after rain, and detected oocysts in the water. Water treatment plants posing significant risk also include those that

- do not have effective barriers to passage of oocysts,
- coagulate directly onto filters,
- do not monitor each filter discharge individually for turbidity,
- do not practise filter-to-waste, or
- do not have well-trained and aware operators.

The guidance document presents an extensive list of these and other factors that should be examined during the risk assessment demanded by the amended regulations.

The DWI document does note, however, that treatment works capable of continuously removing or retaining particles greater than one micron in diameter, and which are continuously monitored and have the capability of shutdown on failure, will not need continuous monitoring for oocysts, regardless of other factors in the assessment.

When a water supplier completes the required risk assessment it must prepare and submit a report to the Secretary of State. The report must state whether a significant risk exists and it must also show the methods used to arrive at the reported conclusion. The DWI, on behalf of the Secretary of State, examines the report and agrees or disagrees with the supplier's conclusion. If the supplier concludes that no significant risk exists and the DWI disagrees or believes the assessment to be incorrectly performed, the Secretary of State may require the supplier to repeat the assessment. The secretary may also require the supplier to install treatment to ensure that less than one oocyst, on average, per 10 litres of water leaves the treatment works and to initiate monitoring to comply with the amended regulations.

A supplier that is required to sample and analyze for oocysts may elect at any time to repeat the risk assessment, and, if the Secretary of State accepts that the risk of oocyst contamination is no longer significant, the secretary will remove the treatment and sampling requirements. The amended regulations stipulate that a supplier that is required to meet the treatment or monitoring regulations and fails to do so is subject to a fine.

7.4 The Water Supply (Water Quality) Regulations 2000

At the time this paper was being written, parliament passed *The Water Supply (Water Quality) Regulations 2000* in December 2000.[182] This act consolidates the 1989 and a number of amending acts, including the 1999 act. Some parameter values given in the schedules to the regulations (pH, Na, Cu, As, Ni, Sb, chloride) have been updated from those shown in tables 7-1 to 7-3. The arrangement of parameters has also been altered to reflect the EU requirements.

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[182] United Kingdom, Drinking Water Inspectorate, 2000, *The Water Supply (Water Quality) Regulations 2000* [online], Statutory Instruments, 2000, no. 3184 [cited July 2001], <www.dwi.gov.uk/regs/si3184/3184.htm>.

8 Australia

8.1 Structure of Australian Regulations

Because each state and territorial government takes responsibility for its own water quality, Australia does not have nationally enforceable drinking water quality standards. However, to provide a framework for locally enforceable standards, the National Health and Medical Research Council (NHMRC) and the Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) produce *Australian Drinking Water Guidelines* (ADWG).[183] Versions of the guidelines were produced in 1980, 1987, and 1996.

Most state and territorial governments take the NHMRC guidelines into account when formulating water quality regulations. Through operating licences, memorandums of understanding, and contractual agreements with suppliers, most have adopted at least some of the guideline provisions. Unfortunately, many of these instruments refer only to the guidelines in place at the time of signature; consequently, many suppliers are not required to meet updated guideline values. In most Australian jurisdictions, responsibility for water safety lies with the Department of Health.

8.2 Australian Drinking Water Guidelines (1996)

A joint committee of NHMRC and ARMCANZ produced the 1996 version of the guidelines. Specialist panels comprising representatives from the NHMRC, the Australian water authorities, private industry, universities, health departments, and other interested parties prepared the guideline subsections. The guidelines, which are not compulsory standards, are intended to "represent a framework for identifying acceptable water quality through community consultation."[184]

ADWG is divided into two parts. Part I provides an overview that deals with water quality requirements, system management and performance, and small water supplies. Part II provides a series of fact sheets that discuss specific

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[183] Australia, National Health and Medical Research Council/Agriculture and Resource Management Council of Australia and New Zealand, 1996a, *Australian Drinking Water Guidelines* [online], [cited July 2001], <www.health.gov.au/nhmrc/publications/pdf/eh19.pdf> [hereinafter Australia, 1996a].

[184] Ibid.

waterborne micro-organisms, and physical and chemical contaminants. The guidelines are published in both complete and summary forms.

In common with most water quality standards, ADWG categorizes water quality parameters as

- microbial,
- physical,
- chemical, and
- radiological.

8.2.1 Guidelines for Microbial Quality

The guidelines recognize the importance of a multiple barrier system of protection against waterborne disease. The recommended combination of barriers should include at least

- water sources protected from human and animal fecal contamination and subject to an active catchment protection program,
- pre-treated source water (i.e., water that has been stored for three to four weeks to allow for bacterial die-off through ultraviolet action, settling, and natural competition),
- protected water storage,
- coagulation, settling, and filtration,
- disinfection,
- a disinfection residual during distribution, and
- a distribution system sealed against contamination.

Monitoring and System Performance

ADWG recommends regular monitoring of at least two indicator micro-organisms: total coliforms and either thermotolerant coliforms or *E. coli*. The presence of any of these organisms should be taken as indication of fecal contamination. In the event that fecal contamination is found or suspected, the guidelines require that immediate corrective action be taken and the proper health authority be informed. Owners or operators must not wait for additional laboratory testing to be completed. Heterotrophic plate counts (colony counts) may also be used, but only as an adjunct test, to indicate general treatment performance. In contrast, the Ontario drinking water standards require that a minimum of 25% of samples be analyzed for colony counts.

ADWG recommends minimum sampling frequencies, with the reservation that sampling should be increased at times of flooding or emergency operations (see table 8-1). The guidelines distinguish between system performance monitoring, which is used to check compliance, and operational monitoring, which is used to ensure that treatment is operating correctly. For operational monitoring, groundwater supplies should be sampled at least every two weeks and surface water supplies at least every week. Frequency of sampling for system monitoring depends on the population served.

ADWG also recognizes that absence of the indicator micro-organisms does not guarantee pathogen-free water; disinfectant-resistant protozoans such as *Giardia* and *Cryptosporidium* might remain viable. The complexity of testing, high cost, and poor detection reliability make routine monitoring for these micro-organisms impractical. Testing is recommended, however, for special investigations or during disease outbreak. ADWG also lists additional micro-organisms for which regular monitoring is not required but "should not be detected in water if explicitly sought."[185]

ADWG highlights a system's need to meet long-term performance guidelines for micro-organism removal. Recommendations for satisfactory performance are discussed in section 8.2.5 following.

Table 8-1 Minimum Sampling Frequency for System Monitoring

Population served	Minimum number of samples
>100,000	6 samples per week, plus 1 additional sample per month for each 10,000 above 100,000
5,000–100,000	1 sample per week, plus 1 additional sample per month for each 5,000 above 5,000
1,000–5,000	1 sample per week
<1,000	base on advice for small water supplies

Source: Australia, 1996a.

[185] Ibid., Summary of Guidelines, GL-5–6.

8.2.2 Guidelines for Physical and Chemical Quality

Physical Parameters

Guideline values for physical water quality parameters are normally based on aesthetic rather than health considerations. On aesthetic grounds, consumers would reject the water long before health-threatening concentrations were reached. This is reflected in ADWG, which sets values for physical parameters (see table 8-2) based on value judgement. Therefore, occasional or short-term failures to achieve them do not render the water unsatisfactory for consumption.

Chemical Parameters

The guidelines deal with the chemical quality of drinking water, represented by inorganic chemicals, organic compounds, and pesticides. Inorganic chemicals are of concern based on health protection and aesthetics. The guidelines also note that inorganic chemicals in drinking water can result from both natural and human origins, such as natural leaching from mineral deposits, land-use

Table 8-2 ADWG – Physical Parameters

Characteristic	Guideline values	
	Health	Aesthetic
Dissolved oxygen	**	>85% saturation
Hardness as $CaCO_3$	**	200 mg/L
pH	*	6.5–8.5
Taste and odour	**	acceptable to most people
Temperature	**	no value set
Total dissolved solids	**	500 mg/L
True colour	**	15 HU (Hazen units)
Turbidity	*	5 NTU

Source: Australia, 1996a, part 2, fact sheets.
* Insufficient data to set a guideline based on health considerations
** No health-based guideline is necessary

activities, water treatment chemicals such as chlorine and fluoride, and corrosion products in pipes and fittings.[186]

Health-related guideline values are presented for all listed inorganic chemicals (see table 8-3). Where the aesthetic quality of drinking water could be degraded by a lesser concentration than the health guideline value, this concentration is also shown.

Organic compounds are of concern because of their toxicity to humans and their potential to cause cancer. Because disinfection by-products are the most common organic compounds found in Australian drinking water, the guidelines discuss organic compounds in two sections: disinfection by-products and other organic compounds.

In considering disinfection by-products, ADWG strongly points out the relative risks posed by disinfection by-products versus waterborne pathogens. The guideline summary states: "While the presence of these compounds in drinking water should be minimized, any such action must not compromise disinfection. *It must be emphasized that water which has not been disinfected poses a far greater risk to health than disinfection by-products.*"[187] Trihalomethanes and chlorinated acetic acids are the most common by-products. The guidelines provide health and aesthetic values for several classes of disinfectant by-products and note others for which insufficient data are available to set values (see table 8-4).

ADWG includes 24 other organic compounds or groups of compounds that, although occasionally detected in European and North American supplies, are not normally found in Australian waters. The guideline values are presented in recognition of potential future contamination through spills or accidental discharges.

ADWG treats pesticides as a separate subgroup of organic contaminants. Because all pesticides are registered with the National Registration Authority for Agricultural and Veterinary Chemicals, information is available on use, toxicity, and expected residuals from normal use. Registration allows

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[186] Australia, National Health and Medical Research Council/Agriculture and Resource Management Council of Australia and New Zealand, 1996b, *Australian Drinking Water Guidelines – Summary* [online], [cited July 2001], <www.health.gov.au/nhmrc/publications/pdf/eh20.pdf> [hereinafter Australia, 1996b].

[187] Ibid.

Table 8-3 Inorganic Chemicals and Disinfection By-products

Chemical	Guideline value (mg/L)	
	Health	Aesthetic
Disinfection agents and inorganic by-products of disinfection		
Bromate	0.02	
Chlorine	5	0.6
Chlorine dioxide	1	0.4
Chlorite	0.3	
Chlorate	*	
Iodine	*	
Monochloramine	3	0.5
Ozone	no guidelline	
Other inorganic chemicals		
Aluminium	*	0.2
Ammonia (as NH_3)	*	0.5
Antimony	0.003	
Arsenic	0.007	
Asbestos	*	
Barium	0.7	
Beryllium	*	
Boron	0.3	
Cadmium	0.002	
Chloride	**	250
Chromium (as Cr(VI))	0.05	
Copper	2	1
Cyanide	0.08	
Fluoride	1.5	
Hydrogen sulfide	*	0.05
Iodide	0.1	
Iron	*	0.3
Lead	0.01	
Manganese	0.5	0.1
Mercury	0.001	
Molybdenum	0.05	
Nickel	0.02	
Nitrate (as nitrate)	50	
Nitrite (as nitrite)	3	
Selenium	0.01	
Silver	0.1	
Sodium	**	180
Sulfate	500	250
Tin	**	
Zinc	*	3

Source: Australia, 1996a, Summary of Guidelines.
* Insufficient data to set a guideline value based on health considerations
** No health-based guideline value considered necessary

"formulation of appropriate guideline levels for pesticides in drinking water and a process for their revision which includes public participation."[188] ADWG considers two categories of values: guideline values, and health values. Guideline values are used for surveillance and enforcement and are derived so as to avoid health risks and maintain good water management practice. These values are considered important indicators of contamination, but are set so that exceeding them does not necessarily constitute a danger to human health. Health values are set at about 10% of the acceptable daily intake for a 70 kg adult who consumes two litres of water daily. ADWG sets values for 121 pesticides.

Table 8-4 Organic Disinfection By-products

Compound	Guideline value (mg/L)		By-product of
	Health	Aesthetic	
Chlorinated furanones (MX)	*		chlorination
Chloroacetic acids			chlorination
Chloroacetic acids	0.15		
Dichloroacetic acid	0.1		
Trichloroacetic acid	0.1		
Chloroketones			chlorination
1,1-dichloropropanone	*		
1,3-dichloropropanone	*		
1,1,1-trichloropropanone	*		
1,1,3-trichloropropanone	*		
Chlorophenols			chlorination of water containing phenol or related chemicals
2-chlorophenol	0.3	0.0001	
2,4-dichlorophenol	0.2	0.0003	
2,4,6-dichlorophenol	0.02	0.002	
Chloropicrin	*		chlorination
Cyanogen chloride (as cyanide)	0.08		chloramination
Formaldehyde	0.5		ozonation
Haloacetonitriles			chlorination
Dichloroacetonitrile	*		
Trichloroacetonitrile	*		
Diboroacetonitrile	*		
Bromochloroacetonitrile	*		
Trichloroacetaldehyde (chloral hydrate)	0.02		chlorination
Trihalomethanes (THMs) (total)	0.25		chlorination, chloramination

Source: Australia, 1996a, part 1, Summary of Guidelines.
* Insufficient data to set a guideline value based on health considerations

[188] Australia, 1996a.

8.2.3 Guidelines for Radiological Quality

ADWG notes that human exposure to radiation in Australia originates primarily from natural sources. Radiological contamination of drinking water can occur from natural radioactivity in the source, by enhancement of natural sources through mining and processing, or through medical or industrial discharge. ADWG recommends that gross alpha and gross beta activity should first be assessed. Testing for specific radionuclides should be completed if gross alpha activity exceeds 0.1 Bq/L or gross beta activity exceeds 0.5 Bq/L. See table 8-5 for guideline values of noted radionuclides.

The complete guidelines provide an extensive examination of radioactivity in water; they cover exposure, monitoring and testing, and derivation of guideline values.

8.2.4 System Management

ADWG contains a separate section devoted to water supply system management, with particular focus on each element of the recommended multiple-barrier system. The discussion involves a more detailed examination of the points outlined in section 8.2.1. ADWG presents the concept of "Quality Systems" as "an effective and efficient way of managing a water supply system. This involves establishing a regime whereby each step of system management and performance assessment is reliably carried out …"[189] The following components are presented as necessary for a quality system:

Table 8-5 ADWG Guidelines for Specific Radionuclides

Characteristic	Guideline values
Radium-226	0.5 Bq/L
Radium-228	0.5 Bq/L
Uranium	0.02 mg/L (0.25 Bq/L)
Radon-222	100 Bq/L
Unspecified alpha- & beta-emitters	0.1 mSv (for an individual nuclide)

Source: Australia, 1996a, part 1, Summary of Guidelines.

[189] Ibid, chap. 5

- an agreed level of service
- effective treatment processes, including disinfection
- regular inspection and maintenance of the system
- practices that identify likely external sources of contamination
- ongoing evaluation and refinement of the overall operation of the system
- monitoring programs that assess water quality throughout the system, and can identify the location and nature of any water quality problem within the system
- validation procedures for sampling and laboratory testing programs
- the use of monitoring information both to facilitate day-to-day management of the supply and to assess its performance over time
- appropriate procedures for
  – immediate correction of any serious water contamination
  – resolution of longer-term water quality programs which might be costly to address
- defined lines of responsibility for remedial action
- use of appropriately skilled and trained personnel
- transparent auditing procedures
- reporting to consumers

This list summarizes the necessary steps the authors of the guidelines feel must be taken to ensure delivery of good quality water to consumers. Thus ADWG goes beyond presentation of simple values not to be exceeded and presents an overview of the management approach recommended for production of good quality water.

ADWG also provides an expansive discussion of disinfection as it relates to system management. Required values for residual contact time, pH, and turbidity are presented for various disinfectants (see table 8-6).

Table 8-6 Requirements for Effective Disinfection

	Chlorine	Mono-chloramine	Chlorine dioxide	Ozone	UV radiation
Residual (mg/L)	>0.5	1.5	0.3	n.a.	n.a.
Contact time (minutes)	30	many hours	30	n.a.	n.a.
pH	<8	8–9	<8	<8	n.a.
Turbidity (NTU)	1	1	1	1	1

Source: Australia, 1996a, table 5.1

The concept of CT is also discussed. This approach recognizes that effective micro-organism kill is determined by the residual disinfection concentration C and the effective time of contact T with the disinfectant. Although ADWG presents typical CT ranges for several common disinfectants and micro-organisms found in drinking water sources, it cautions against field application of these values. This contrasts strongly with the new Ontario drinking water standards and the EPA Surface Water Treatment Rule, both of which require water producers to meet standard values of CT in their treatment plants. For chlorine, ADWG notes that in clean water "a combined available residual chlorine level of 0.5 mg/L after a contact time of 30 minutes should be sufficient to ensure microbiological control, given a clean distribution system and no significant re-contamination."

8.2.5 System Performance

ADWG considers the significance of long-term performance in water supply and notes that it is judged both by analytical testing and by consumer satisfaction. Analytical testing should be controlled through monitoring programs: the aforementioned system performance monitoring and operational monitoring. Before a new source is considered, baseline monitoring should be completed. The aims of such monitoring are to

- define which parameters should be regularly measured,
- identify significant water quality concerns,
- show how the water should be treated,
- construct a baseline assessment against which future changes in quality can be compared, and
- allow comparison with other potential sources.[190]

An initial land-use survey is also recommended as part of the baseline monitoring. And follow-up sampling should be performed to identify changes to the source caused by abstraction, changes in land use, and longer-term natural changes.

The system performance section also introduces the idea of "key characteristics," defined as those characteristics (parameters) that require frequent monitoring. Key characteristics related to health will include

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[190] Ibid.

- microbiological indicator organisms (total coliforms and *E. coli* or thermotolerant (fecal) coliforms),
- treatment chemicals and their by-products,
- parameters that are expected to exceed the guideline,
- potential contaminants identified in the baseline monitoring, and
- pollutants that may occur but are not listed in the guidelines.

Key characteristics not related to health are noted as

- parameters that might exceed the guidelines, and
- parameters that might significantly reduce aesthetic quality.

ADWG contains a section entitled Guide to Monitoring and Sampling Frequency. This guide contains a listing, by recommended sampling frequency and location, of each guideline parameter, under the headings micro-organisms, physical characteristics, inorganic chemicals, organic compounds, disinfection by-products, pesticides, and radiological characteristics.

ADWG states that it is necessary to consider analytical results, particularly exceedences, not in isolation, but as part of a monitoring program to be assessed over a longer period (typically the previous 12 months). It recommends the following for water quality data over the preceding 12 months:

- Key characteristics should be displayed on a control chart.
- For health related parameters the 95th percentile of results for the previous 12 months should be less than the guideline value.
- For aesthetic parameters the mean value of results over the previous 12 months should be less than the guideline value. However the level to be met should be derived based on community service agreement.
- The minimum sampling frequency should be based on statistical analysis of the data.

An extensive examination of statistical analysis of water quality data gives direction as to how long-term performance can best be assessed.

ADWG emphasizes the importance to good water supply of consumer satisfaction and consultation. It presents, as examples, objectives such as achieving less than four complaints per thousand households per year for unfiltered supplies and less than two complaints for filtered supplies. A score of “good to excellent” from more than 80% of consumers is also suggested.

8.2.6 Reporting

The guidelines place a high significance on reporting, particularly to consumers. If consumer confidence is to be maintained, reporting on water quality should be open and comprehensive. The duties of those responsible for water quality reporting should be made public, as should the reporting requirements and legislative requirements of the supplier. System failures that could endanger health or have a deleterious effect on water quality for an extended period must be reported immediately to the relevant health authority. This is termed "event reporting." Public warnings must be issued, and follow-up reports of action taken to rectify the problem must be submitted.

Water authorities should provide annual reports of their performance against the guidelines and agreed levels of service. ADWG also presents situations in which the public should be notified:

- Supply is interrupted.
- Water quality fails to meet the guidelines and there is a potential to harm health.
- Water treatment or distribution fails.
- Monitoring is not performed or is not performed to required standards.
- Required levels of service are not met.

8.2.7 Guidelines for Small Water Supplies

ADWG recognizes that for small supply systems serving fewer than 1,000 people the cost of implementing all the guidelines might not represent the most efficient use of resources to guarantee safe drinking water. One chapter examines variations to the recommendations for small water supplies. While the variations are not considered optimum, they should still provide an "adequate degree of confidence that safe water is being supplied."[191]

In conditions of economic constraint some small systems might only be able to supply water with minimal or no treatment. This water may be subject to a minimum of monitoring. Noting the potential danger to human health, ADWG includes regular sanitary inspections of the supply and the use of a good quality supply source. Improvement to at least the microbiological guidelines should

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[191] Ibid, chap. 7, sec. 1

be a goal for the supply. To minimize the possibility of poor water, steps to be implemented relate primarily to ensuring that the elements of the supply system remain in good condition, including the source quality, supply equipment, and the ability to institute a more frequent sampling program during periods of poor supply quality. A minimum of one inspection per year of the catchment area is recommended. If severe problems occur that might require better treatment or use of an alternative source, the estimated costs required should be presented to the community, along with the relative advantages and disadvantages. The community must then decide on the action to be taken.

ADWG proposes that micro-organisms in small supplies be controlled by inspection of the system, by maintenance of a disinfectant residual, and by microbiological monitoring. A minimum of one sample per week is recommended for microbiological testing; a lesser frequency will cause an unacceptable statistical uncertainty about the true quality of the water. If a lesser frequency is adopted, communities must depend on sanitary inspection and maintenance of a good disinfectant residual. Where chlorine is used, a residual should be maintained between 0.2 and 0.5 mg/L, confirmed by at least daily testing. ADWG also notes that although some micro-organisms can survive normal chlorine levels, chlorination is still the most appropriate defence against contamination.

ADWG considers water supply to transient consumers in, for example, isolated service points. A minimum of microbiological testing is recommended, and, where testing is not available, either a boil water advisory should be maintained or a bottled water supply made available. Single households maintaining their own supply should obtain information on local water quality from the local or state government if possible. The householder should also have the water tested for health-related parameters.

8.3 Western Australia

8.3.1 General

Western Australia, which covers almost one-third of the country, is Australia's largest state. At 2.5 million square kilometres, its area is twice that of Ontario. It has more than 1.8 million residents, 1.2 million of whom live in Perth, the capital city (see figure 8-1). As of July 1999 the Western Australia water industry served approximately 1.7 million customers, in more than 300 towns and communities.[192]

Water supply in Western Australia faces many of the challenges experienced in Ontario. The state has large land areas interspersed with many water supply systems located in small communities far from Perth. Technical and management support for water supply in these communities has long been a concern for regulators. The legislation and practices adopted in the state to deal with these difficulties should be examined as part of Ontario's quest to best provide province-wide direction to large and small water supply utilities.

Figure 8-1 Map of Australia – Western Australia Highlighted

[192] Western Australia, Office of Water Regulation, 1999a, *Industry and Licensing* [online], [cited December 2001], <www.wrc.wa.gov.au/owr/industry/content.htm>.

8.3.2 Water Supply and Regulation in Western Australia

Before 1996 the Water Authority of Western Australia administered all aspects of water supply, including source protection and allocation. At that time the state government adopted a policy to separate responsibility for regulation from responsibility for supply. It also moved to introduce competition and ensure that suppliers operated on a commercial basis.[193] To implement this policy, the government replaced the Water Authority with three separate bodies: the Western Australia Water Corporation (WAWC), the Water and Rivers Commission (WRC), and the Office of Water Regulation (OWR). Together with the Western Australia Health Department (WAHD), the WRC and OWR oversee water supply regulation in the state, from abstraction to delivery. The Water Corporation is generally responsible for the delivery components of water supply and is the largest supplier in the state.

Waters and Rivers Commission

The WRC began operation in January 1996, having been established under the Water and Rivers Commission Act, 1995. It is a state agency whose function is to manage the state's water resources in a manner compatible with sustainable development and conservation of the environment. The WRC achieves this through administration of legislation aimed at protection and management of water resources. Its mission is "to manage the water resources of Western Australia for the benefit of present and future generations in partnership with the community."[194]

The WRC investigates groundwater and surface water and generates information about the quality, quantity, and location of these sources. It is also responsible for allocation of source water to suppliers. Although suppliers receive their licences from the OWR, the WRC first allocates the source water suppliers. The commission plays the lead role in protection of Western Australia's water resources, which are defined as "all inland surface water, which includes rivers, wetlands, and estuaries, and all underground water including that below near-

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[193] Western Australia, Office of Water Regulation, 1999b, *Water Services Regulation in Western Australia* [online], [cited December 2000], <www.wrc.wa.gov.au/owr/pubs/waterservicesregulation.pdf>.
[194] Western Australia, Waters and Rivers Commission, 1999, *About the Commission* [online], [cited December 2000], <www.wrc.wa.gov.au/about/index.html>.

coastal marine waters."[195] Through powers granted to it by the Country Areas Water Supply Act 1947, and the Metropolitan Water Supply, Sewerage and Drainage Act 1909, the WRC controls any activity that might contaminate a source, oversees land use, and works to prevent pollution. It can declare Public Drinking Water Source Areas (PDWSAs) in which it has broad power to administer land-use-control bylaws and other control mechanisms. The WRC protects water quality by

- guiding planning, development, and catchment management to protect water resources;
- responding to pollution complaints;
- cleaning up spills that threaten to pollute wetlands, waterways, or groundwater;
- assessing groundwater contamination;
- monitoring water quality in wetlands, waterways, and groundwater; and
- regulating land use in public drinking water source areas, including permits for business to operate.[196]

Office of Water Regulation

The Office of Water Regulation also began operation in 1996. Best known as the body that issues licences to water suppliers, the OWR is also expected under the Water Services Coordination Act 1995 to develop policy and advise the Minister for Water Resources, provide customer services, and manage the Farm Water Grant Scheme.[197] The OWR advises the minister on all aspects of policy development for water resources but particularly on price levels and development. It also provides service to customers of water suppliers through investigation and arbitration of complaints that cannot be settled otherwise. The Farm Water Grant Scheme provides assistance to farmers located in areas with insufficient water supply. The OWR is also expected to encourage efficiency and competitiveness in the industry.

Although the OWR takes responsibility for licensing of providers of water supply, sewerage, irrigation, and drainage, only water supply will be examined

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[195] Ibid.
[196] Ibid.
[197] Western Australia, Office of Water Regulation, 1999b.

here. In general, a provider that will be licensed must be in possession of, or be responsible for, water service infrastructure; it must provide water service for remuneration on a continuing basis; and it usually has more than 50 service connections.[198] OWR issues licences on the basis of operating areas. Within an operating area the licence holder is normally the only water provider. Before issuing a licence the OWR must be satisfied that the applicant has the financial and technical resources to provide service as outlined in the licence.

Operating Licences: Licences are granted by the coordinator of OWR, based on the provisions of the Water Service Coordination Act 1995. Although each licence demands specific conformance stipulations of the licensee, a number of global conditions apply to all providers. All licensees must

- provide water service and guarantee the required maintenance and operation of these services,
- meet prescribed standards of performance and pay a prescribed sum of money to anyone affected by failure to meet these standards,
- have in place an asset management system that will be independently assessed for effectiveness every two years,
- submit to an independent operational audit every two years, and
- meet the minimum technical standards set by the OWR.

Licences may be issued for up to 25 years, although five years is normal for smaller providers. Each licence holder must meet standards that relate to the water provided, for both quantity and quality. The licence may also contain standards for continuity of supply, and for response to complaints and consumer calls.[199] For example, the licence granted to the Water Corporation requires that the provisions of the 1987 version of the Australian drinking water guidelines be met. The intent of water reorganization in Western Australia in the mid-1990s was to introduce competition into supply. However, because most suppliers operate exclusively in a single supply area, direct competition with other suppliers is unlikely. Consequently, OWR relies on "benchmark competition" to promote service improvement. This is achieved by requiring providers to post performance reports, which may then be compared either with previous reports or reports of other providers. To promote this type of performance comparison, licensees are required to publish performance reports

[198] Ibid.
[199] Ibid.

in addition to regular compliance reports. Compliance reports are required each quarter, six months, or yearly.

Through licences, OWR emphasizes the importance of maintaining good consumer relations. Providers are required to maintain consumer consultation through consumer councils; consumer charters; provision of trained staff to handle consumer complaints, dissatisfaction, or enquiries; and availability of a system to resolve conflict.

Licensed providers must also be prepared to undergo operational audits of their systems by an independent auditor at least once every two years. Following this audit, the licence is normally reviewed for renewal; the OWR may cancel the licence in the event that the conditions have not been met and the failure has not been rectified. Providers that fail to meet the stipulations of the operating licence can be subject to a fine of up to AU$100,000.

Western Australia Health Department

Western Australia currently has no state-wide enforceable regulations that dictate a required drinking water quality standard. As noted previously, providers are required to meet specific water quality levels as conditions of their operating licences. Monitoring and enforcement of these conditions generally falls to the WAHD. Most of the duties are carried out by local government environment health officers, who monitor water supplies throughout the state. The WAHD is responsible for issuing public notifications such as boil water advisories.

The WAHD is assisted in matters relating to drinking water by the Advisory Committee for the Purity of Water. This committee, which is chaired by the WAHD, comprises representatives from the Water Corporation, Agriculture Western Australia, the Office of Water Regulation, the Department of Conservation and Land Management, and the Water and Rivers Commission.[200] It advises both the minister for health and the minister for water resources on matters relating to water supply, particularly regarding treated water quality requirements for operating areas throughout the state. It also recommends alternative guideline values to be adopted when the ADWG provisions are deemed unacceptable or inadequate. The advisory committee also receives the monitoring reports from the environment health officers.

[200] Ibid.

Water Corporation

The Water Corporation is the single largest supplier of drinking water in Western Australia. It is active throughout the state but particularly in Perth, where it supplies the capital's water demand. In the 2000/2001 reporting year the Water Corporation generated 374,000 million litres of drinking water (supplying 255 cities and towns) in addition to supplying 319,000 million litres of irrigation water.[201] It was formed through the break-up of the Water Authority of Western Australia and began operation in January 1996. The corporation operates on the basis of a licence from the OWR and is required, among other stipulations, to meet the guideline values of the 1987 version of the ADWG. The licence also stipulates how the corporation must respond to consumer complaints and calls. The corporation operates to a Customer Service Charter that outlines its goals, responsibilities, and undertakings in the service areas of water, wastewater, metering, drainage, and accounts. It also posts daily updates on the Internet of water storage in the dams that serve Perth.

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[201] Western Australia, Water Corporation, 2001, *Annual Report* [online], [cited November 2001], <www.watercorporation.com.au/annual-report/files/ann_rep00_01.pdf>.

9 Case Studies

9.1 Introduction

In previous chapters we examined the guidelines, standards, and regulations that apply to drinking water supply both in Canada and in other jurisdictions. That examination leads to several significant questions: How do regulations influence water supply? Do different regulatory approaches result in a significantly different quality of drinking water? What are the critical influences on production of good and safe water?

Through the examples of case studies, we examine the effects of regulations and other influencing factors on several operating water treatment facilities both in Canada and abroad. To capture comparable data from each of the case studies, a comprehensive questionnaire was circulated to the management staff of each facility.

Table 9-1 lists the facilities chosen for examination.

9.2 Questionnaire

The questionnaire, circulated to the management of the water treatment facilities identified in table 9-1, focused on several areas: production capacity, staffing and certification, management and best practices, unit processes, plant performance, water quality, and production cost. The results were then examined to determine

Table 9-1 Case Study Water Treatment Facilities

Facility type	Name and location	Rated treatment capacity (m3/d)
Large scale – Ontario	F.J. Horgan WTP, Toronto	459,000
Large scale – Canada	E.L. Smith WTP, Edmonton, Alta.	235,000
Large scale – United States	McCarron WTP, Saint Paul, Minn.	545,000
Small scale – Ontario	Prescott WTP, Prescott, Ont.	8,200
Small scale – United States	Camptonville, Ca.	547
Large scale – Australia	Serpentine Pipehead Dam WTP, W.A.	500,000
Large scale – Australia	Wanneroo WTP, W.A.	130,000

how variations in these factors influenced final treated water quality. The effects of regulations in force in each jurisdiction were also examined.

Unless otherwise identified, tabular information in this chapter is generated from questionnaire responses. See appendix 1 for a copy of the questionnaire.

9.3 F.J. Horgan Water Treatment Plant – Toronto

9.3.1 Role of Technology

General Description

The F.J. Horgan Water Treatment Plant is situated on the shoreline of Lake Ontario in the east Scarborough area of the City of Toronto. The third largest of four plants that serve both the city and York Region, it has a firm capacity of 459 million litres per day (ML/d). In 1999 the plant treated an average of 382 ML/d (approximately 25% of the city's total demand), equivalent to a population of 780,000 (based on an overall per capita consumption of 489 L/d). Its maximum one-day production in 1999 was 531 ML, which exceeded the firm capacity of the plant.

The plant is a direct filtration facility that takes raw water from Lake Ontario. It uses four processes: coagulation, flocculation, filtration, and disinfection (see figure 9-1). It began service in 1980.

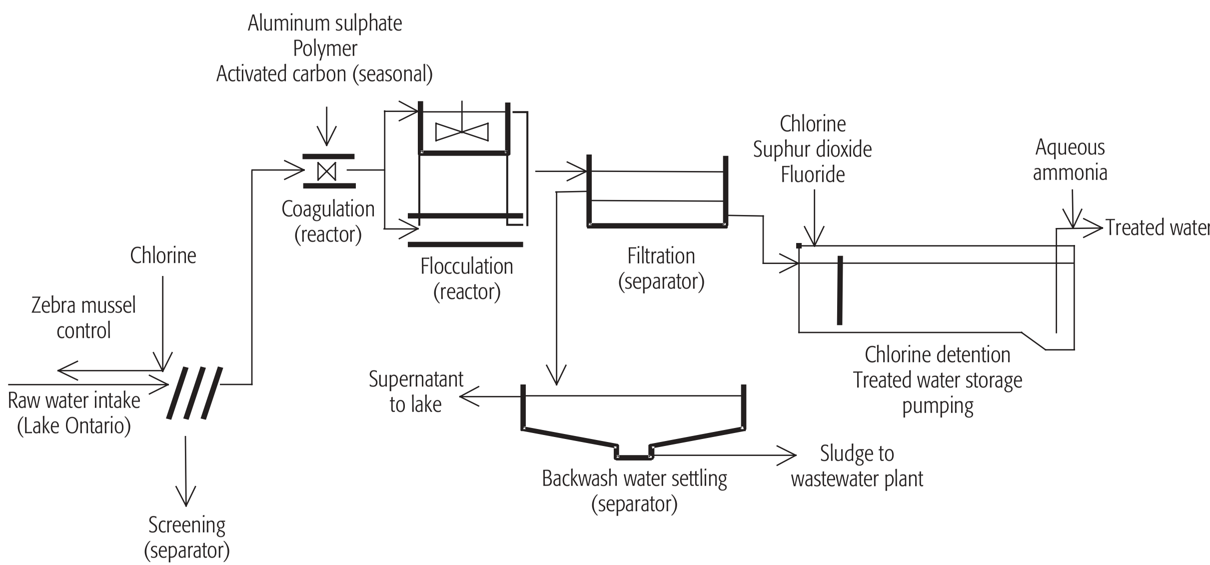
Raw-water Supply

Water enters the intake mouth located in 18 m of water about 2,960 m from shore, and reaches the plant through a 3.3-m-diameter concrete-lined tunnel in rock approximately 30 m below the lake bed.

Water quality is monitored continuously for turbidity, temperature, and pH. Grab samples are taken every shift to check that the instrumentation is recording correctly. Because these parameters remain relatively stable, no automated responses to change are used in the operation of the plant. Grab samples are also taken to determine total ammonia and bacteriological contents of the raw water.

Raw water is also sampled on a regular basis for aluminum, cadmium, calcium, chloride, chromium, copper, fluoride, hardness, iron, lead, magnesium,

Figure 9-1 F.J. Horgan Water Treatment Plant Process Layout



manganese, mercury, nitrogen (total ammonia, nitrate, nitrite, organic), biochemical oxygen demand, dissolved oxygen, total organic carbon, total phosphate, potassium, sodium, specific conductance, silica, sulphate, odour, organics, plankton, and other parameters. This sampling program is primarily aimed at detecting long-term or seasonal changes in water quality. Many of the parameters measured also indicate levels of pollution that could be attributed to wastewater discharges.

Data provided by the city (see table 9-2) highlight the fact that raw-water turbidity is generally well below the Ontario drinking water standard for treated water. The maximum value of 30 NTU suggests, however, that the plant is subject to some degree of turbidity spiking.

Raw-water pumps (two rated at 114 ML/d and four at 182 ML/d), located in a deep caisson at lake level some distance inland from the bluffs, lift the water from the lake to the flocculation area where it then flows by gravity through the plant.

Pre-chlorination

Raw water is pre-chlorinated using chlorine gas (Cl_2) as it enters the pumping station well (see table 9-3). During zebra mussel season, chlorine is applied at the intake mouth in the lake as a control measure. With the very low colour (table 9-2), there are no concerns about the formation of trihalomethanes resulting from the use of chlorine.

Coagulation

Liquid aluminum sulphate (alum) is used for coagulation, although in 1999 poly-aluminum chloride, which can be classified as a pre-formed coagulant, was used for approximately 6% of the time. In addition, polymer was used seasonally as a coagulant aid. The coagulants are injected into in-line high-energy blenders or mixers on the raw-water feed line to the flocculators at a rate proportional to plant flow. Table 9-4 shows the dosage range for coagulant and polymer in 1999. The G-value or velocity gradient through the in-line blenders is reported to be 2,500 s^{-1}, which is typical for modern treatment plants. Standby chemical feed pumps provide redundancy, reducing the probability of process shutdowns. The energy input to the mixer is not varied.

Operators, taking into consideration numerous treatment efficiency indicators, manually adjust dosage rates. One of the more unusual and interesting operating procedures is to increase the alum dosage rate to depress pH and keep it below 8.1 during periods of high pH in the raw water.

Flocculation

Half the flow into the plant passes through two 3-stage flocculation tanks equipped with variable-energy axial-flow turbines for mixing. Mixing for the other half of the flow occurs hydraulically in two 900-mm-diameter pipelines. G-values are 20 s^{-1} and 209 s^{-1}, respectively, with total energy inputs (GT values) of 63,000 and 9,860, respectively (see section 4.2.1 for discussion of these terms). There has been no demonstrated difference in performance between the two systems, supporting the notion that filtrate quality rarely depends on process optimization in the flocculation zone.

Table 9-2 Raw-water Quality – F.J. Horgan WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	0.40	0.10	30.0
Colour (TCU)	2	2	2
pH	8.1	7.5	8.8
Temperature (ºC)	7.3	0.7	23.0

Table 9-3 Chlorine Dosage – F.J. Horgan WTP, 1999

Chlorinating agent	Avg	Min	Max
Chlorine (mg/L)	0.90	0.00 [a]	1.50

[a] Minimum of zero during maintenance

Table 9-4 Coagulant Dosage – F.J. Horgan WTP, 1999

Coagulant	Avg	Min	Max
Alum (mg/L)	5.8	5.0	9.0
Polymer (mg/L)	0.7	0.5	0.9

Filtration

A direct filtration plant has no intermediate sedimentation zone, and all coagulant solids must be removed by filtration. The plant has eight dual-media (anthracite and sand) filters sized for a filter rate of 11.7 m/hr at the design flow. Under good raw-water quality conditions the filter rate can be increased by 40% without any deterioration in filtrate quality. The filters operate in a constant-rate mode in which each filter shares the plant throughput equally.

Each filter is equipped with a dedicated turbidimeter. Several of the filters are configured to measure turbidity at the interface between the anthracite and sand layers to give an earlier indication of turbidity breakthrough. Based on the success of this strategy, the remaining filters are currently being modified to suit.

Two filters are also equipped with continuous on-line particle counters. The data are archived for historical performance analysis. Turbidimeters measure water clarity by measuring the intensity of light reflected off colloidal or suspended particles. By comparison, particle counters are able to measure both the number and size of particles, which allows them to key in on particles of a size specific to *Giardia* cysts and *Cryptosporidium* oocysts and provide early warning of their possible passage through the filters.

Head or pressure loss across the filter is a measure of filter plugging and the primary initiation control for filter backwashing. Two filters are also equipped with multi-port head-loss indicators that enable the operators to monitor the penetration depth of coagulant solids and use the information for optimizing chemical dosage rates.

Alarm settings on head loss, turbidity, and time elapsed since the last backwash are used to initiate the next backwash sequence automatically. As the plant is staffed continuously, most backwash sequences are witnessed and terminated based on operator observation of wash-water clarity. In the fully automatic mode, wash-water turbidity is monitored and can be used to terminate the timed sequence early to minimize wash-water volumes. The filters have rotating surface wash arms, which spin in the suspended filter media during the wash cycle, and jets of water dislodge or scour coagulant particles that may have adhered to the surface of the media. Despite the relatively large difference between summer and winter water temperatures, there has been no perceived need to vary wash-water flow rates to prevent media loss.

Filter-to-waste valves, used to divert filtered water for the first few minutes of service, have not been implemented in the filters. Water quality is poorer during that period, but, the volume being relatively small, it has no serious detrimental effect on treated water quality.

It is apparent that the filtration system is well designed and that operators and process staff have put in considerable effort to optimize performance. For specific parameters the city has established its own water quality objectives that are more stringent than the Ontario drinking water standards. The operational limit for filtered water quality is set at 0.1 NTU, which is already one-tenth the provincial standard. Success is reflected in the fact that filtered water turbidity is consistently 20 times better than that required by the provincial standard. On this basis, plant performance is exemplary.

Post-Disinfection

Chlorine gas (Cl_2), used as the post-disinfectant, is injected into the filtered-water stream at a rate proportional to plant flow rate. The dosage rate is set to “superchlorinate” at all times, meaning that the amount of chlorine added goes beyond that necessary for complete ammonia-nitrogen oxidation (the chlorination break point). It also provides some protection against taste and odour. Superchlorination usually means that the resultant chlorine residual is higher than desired. The Horgan plant uses sulphur dioxide to reduce the excess to maintain a 1.0 mg/L residual. In addition, aqueous ammonia is added to produce a chloramine combined residual, which is inherently more stable – it has a longer ‘shelf life’ suited to large distribution systems. Table 9-5 shows the post-disinfection dosage applied in 1999.

The reservoir has a capacity of 68,000 m^3, equal to 15% of the rated plant capacity, which provides balancing storage for the distribution system and backwash water. At rated capacity the chlorine retention time is approximately 4.4 hours.

Chlorine residual is monitored continuously at several locations through the process and on the plant discharge, where it is recorded on a paper strip chart recorder (see table 9-5). This provides a tamper-proof permanent record in addition to data archived through the plant’s computerized control system. The plant also monitors disinfection effectiveness using the CT concept (see section 4.3.4). Simulation software is used for the calculations, and the results are well in excess of normal requirements.

Fluoridation

Hydrofluorosilicic acid, used to assist in the prevention of tooth decay, is added at a dosage proportional to flow rate. Fluoride concentrations are monitored continuously and alarmed for immediate response should they stray beyond allowable limits. The latest target concentration set by the city, as advised by the medical officer of health, is 0.8–0.9 mg/L, and the dosage has been reduced accordingly to 0.65 mg/L to augment the naturally occurring fluoride concentration and achieve the target values. See table 9-6 for average dosage in 1999.

Taste and Odour

Periodically, Toronto's water supply is subject to seasonal taste and odour problems arising from algal growth in Lake Ontario. Powdered activated carbon is fed manually to adsorb the organic compounds generated as a result of algae decay (see table 9-7 for 1999 dosage). The filtration process removes the carbon before it leaves the plant.

Table 9-5 Post-Disinfection – F.J. Horgan WTP, 1999

	Avg	Min	Max
Post-disinfection agent			
Chlorine (mg/L)	1.4	0.6	4.6
Sulphur dioxide (mg/L)	0.58	0.12	3.40
Aqueous ammonia (mg/L)	0.27	0.06	0.45
Parameter (measured or calculated)			
Chlorine residual (mg/L)	1.00	0.71	1.70
Summer CT – at rated capacity (mg·mn./L)	132.9		
Winter CT – at rated capacity (mg·mn./L)	123.8		

Table 9-6 Fluoridation Dosage – F.J. Horgan WTP, 1999

Source of fluoride	Avg	Min	Max
Hydrofluorosilicic acid (mg/L)	0.77	0.57	0.88

Treated-Water Monitoring

As noted, chlorine residual and fluoride concentration are monitored continuously. Turbidity of final treated water is also monitored continuously, with alarms for exceeding allowable operating objectives. Data are archived on a 15-minute sampling interval. Microbiological grab samples for fecal coliforms, total coliforms (TC), and heterotrophic plate counts are taken every four hours.

A comprehensive program is maintained for the sampling and analysis of treated water produced at each of Toronto's four water treatment plants and throughout the extensive distribution network. This program has historically exceeded Ministry of the Environment (MOE) requirements. The city's testing program significantly surpasses the monitoring requirements specified in the Ontario Drinking Water Standards. It includes quarterly analyses for 34 inorganic and 150 organic parameters, 20 disinfection by-products, and 112 pesticides and PCBs.[202] Table 9-8 shows treated water quality (tubidity, colour, and pH) from the plant in 1999.

Solids Handling and Disposal

Backwash water discharges to two clarifiers for solids removal before the settled water is returned to Lake Ontario via a natural watercourse. To achieve high settled-water quality, additional coagulants are used. Sludge is pumped to the

Table 9-7 Activated Carbon Dosage – F.J. Horgan WTP, 1999

	Avg	Min	Max
Powdered activated carbon (mg/L)	14.6	4.9	22

Table 9-8 Treated Water Quality – F.J. Horgan WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	0.05	0.02	0.18
Colour (TCU)	1	1	1
pH	7.5	7.3	7.7

[202] See the city's quarterly water quality reports at <www.city.toronto.on.ca/water/quality_report.htm>.

nearby Highland Creek Wastewater Treatment Plant. Chlorine residual in the supernatant discharge to the river is not monitored. De-chlorination was not made a requirement through the certificate of approval but could become necessary in the future should the MOE require non-toxic conditions at the point of discharge instead of at the edge of the mixing zone.

9.3.2 Plant Operations

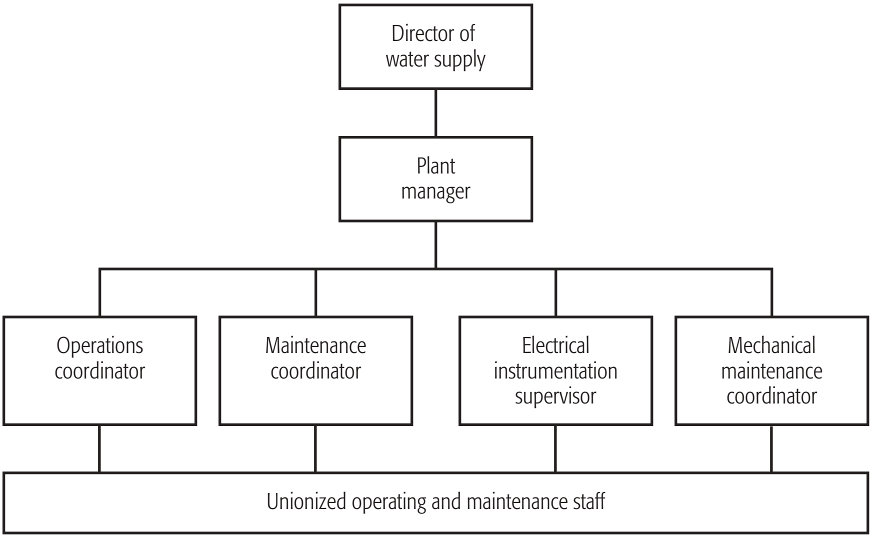
Management Structure

The current management structure of the plant is shown in figure 9-2. In part, the size of the facility is sufficient to warrant its own on-site maintenance staff. The plant manager, who holds an on-site position and reports to the director of water supply, directs both operations and maintenance staff. Laboratory staff report to the director of quality control and system planning.

Plant Operations

The plant is staffed continuously from a complement of 35 people. Table 9-9 shows a typical weekday shift schedule, together with a derived and approximate

Figure 9-2 F.J. Horgan Plant Organization



number of person-days required to operate the plant assuming a 40-hour work week (8 hours is equivalent to 1 person-day). The analysis is not rigorous, but weekday plant operations require an average of 31 person-days, equivalent to approximately 12,000 m^3/d per person-day.

Thirteen operating and supervisory staff have Ontario certification (see table 9-10), 12 of whom received their certification through written testing. The operator who qualified through experience only will complete the written examination in 2001. This degree of certification represents a high level of operator training and competence.

Staff training is formalized and ongoing. In 2000, plant staff spent a total of 114 person-days attending in-house and external courses and speciality conferences.

Role of Technology in Plant Operations

Technology introduced when the plant was constructed in 1980 made Horgan one of the early computerized facilities. By today's standards the system is primitive, but it does provide automation for various operating sequences, the most significant being filter backwashing. As part of a division-wide Best Management Practices program the process control system will be modernized in 2004. Fundamentally, when the plant is fully automated it will be able to

Table 9-9 Weekday Personnel Complement – F.J. Horgan WTP

Plant staff	Total	Scheduled		Estimated
		(no. staff day)	(no. staff night)	(person-days per day)
Plant manager	**1**	1		1
Supervisors	**5**	5		5
Operators (12-h shifts)	**10**	2	2	6
Maintenance staff	**15**	15		15
Laboratory staff	**3**	3		3
Administration	**1**	1		1
Total	**35**	**27**	**2**	**31**

operate without direct operator intervention. Continuous plant supervision, however, is still considered a necessity rather than an option.

Emergency Response Plans

The questionnaire responses on this subject indicate a very high level of attention to abnormal conditions. However, the "reliance on automated process shutdowns is minimized [based on an] operating concept [of] a qualified (class 4 licence) operator monitoring all processes on a continuous basis 7 days/week, 24 hours/day." The single automated shutdown sequence identified in the questionnaire is that for the zebra mussel control system to ensure that there are no uncontrolled discharges of chlorine into Lake Ontario.

All critical process alarms are displayed in the control room, and responding to them immediately is a fundamental duty of the operator. The plant operating manuals define specific shutdown procedures to protect water quality. They include

- filtration rate reduction and shutdown,
- primary coagulant outages,
- high filtered-water turbidity,
- fluoride overdose,
- flash mixer failure,
- F.J. Horgan emergency shutdown,
- water quality event – emergency response,

Table 9-10 Operator Certification – F.J. Horgan WTP

Certification level	Certified operators		
	Total	Testing	Experience
I	0	0	0
II	4	4	0
III	1	1	0
IV	8	7	1
Total	**13**	**12**	**1**[a]

[a] Exam scheduled for 2001

- minor and major chlorination interruptions, and
- radionuclide release emergency from the Pickering Nuclear Generating Station.

The facility also has a series of defined procedures for handling emergency situations relating to the safety of the public and plant staff:

- chlorine emergency plan
- chlorine emergency directory
- emergency plan for chlorine gas leaks
- community alarm initiation (under development)
- fire emergency plan
- chlorine and sulphur dioxide scrubber system failures
- power failure

Authority for plant or process shutdown is also clearly defined. Level III operators and above, including process supervisors and the plant manager, have full authority to shut down a process or the plant. The operators are not required to seek approval from the director or other "non-resident" staff.

Plant Security

Although the entrance is alarmed, visitors to the plant are welcome provided that they sign in on arrival and sign out when leaving the facility. Visitors must be escorted through enclosed process areas. Although protection of a vital service is the primary reason for limits on access, visitor safety is also a concern. Limited access also protects against vandalism and theft.

Quality Management and Best Management Practices

Although the city does not use written quality management plans for plant operation, the facility is operated according to a corporate vision and under some very clearly stated principles relating to water quality and customer service:

Vision:

- Customer-focused, business-based, cost-efficient public utility staffed by motivated skilled employees

Water quality principles:

- Identify customer expectations.
- Develop proactive policies.
- Assume leadership role in adopting water quality guidelines.
- Monitor beyond minimum requirements.
- Research and implement alternative treatment technologies.
- Adopt continuous improvement approach.
- Develop consumer confidence reports.

To minimize potential conflicts of interest, water quality management is kept clearly separate from operations. The water quality manager reports directly to the Water & Wastewater Division's director of quality control and system planning, who occupies a position parallel to other directors reporting to the general manager of the division.

The water quality laboratory is an accredited facility for microbiological analysis and is currently in the process of obtaining accreditation for other parameters. The plant is currently implementing ISO 14001 standards for its environmental management processes.

Formal consumer satisfaction surveys have been conducted and the plant staff are involved in numerous public awareness and involvement programs, including

- a Community Advisory Panel (CAP),
- Community Awareness – Emergency Response Association (CAER),
- plant tours for community groups,
- public meetings,
- media interviews, and
- information publications.

The city is currently mid-way through a division-wide Best Management Practices program that, when complete, will have far-reaching effects on the operation of all facilities. According to the questionnaire responses, the divisional plant staff are taking a proactive approach in seeking ways to improve the operation of the divisional facilities, including the Horgan plant:

Risk Assessment: An informal, qualitative, best judgment-based

> … high level risk assessment has been undertaken for disruption scenarios ranging from system element outages to total system outages affecting water supply and quality. Probability of occurrences, impacts and levels of response were identified.

Water Quality Data:

> Historical data are analyzed to determine trends for specific water quality parameters and to identify areas of improvement and areas that may require research and water treatment process enhancements or additions. During 1999 an assessment of all water quality parameters monitored over the previous ten years was undertaken, culminating in a summary report to the City of Toronto Works Committee (and Council). The parameters were grouped as physical, microbiological, inorganic and organic chemicals, and pesticides.

Benchmarking:

> A competitive assessment of water production and transmission … was undertaken [in] 1996 and goals were established for the Works Best Practices Program in areas of management and works practices, organization and technology. … [they] participated in a benchmarking process … during 2000 [initially focussing] on the water distribution and sewer collection areas. In 2001 the process will include water production and wastewater treatment.

Water Efficiency:

> Approximately 82% of the City [is] metered … has a water efficiency program in place and has targeted water demand reduction of more than 15% by 2011 … [and water losses are] estimated to be under 10%.

9.3.3 Local Standards and Enforcement

As at other water systems in Ontario, Horgan plant drinking water must meet the Ontario drinking water standards, which came into effect in August 2000. The operations of the plant and its management and staff are regulated by Ontario

Drinking Water Protection Regulation 459/00 under the *Ontario Water Resources Act*. The act defines maximum penalties – including fines and prison terms – for offences under the act that may include failure to comply with the regulations.

Through the reporting requirements of the regulation, the city makes performance information fully and freely available with immediate access via the Internet. From the city's 1999/2000 Review and the Water Quality Quarterly Report, which document operational performance against regulatory requirements, it is apparent that Toronto drinking water facilities exceed or surpass the regulations, especially with respect to water quality sampling and analysis.

9.3.4 Cost of Production

The annual cost of water production in 1999, including pumping into the distribution system, was \$0.10 per m^3, equivalent to 4.9¢ per capita per day or \$18 per annum. See table 9-11 for a breakdown of these costs.

Annual revenues for city-wide water services in 1999, which include water production, transmission, and local distribution, are reported as \$202 million, representing a net difference of \$48.4 million of revenues over expenses. This positive balance is applied to the Capital Financing Stabilization Reserve Fund.

Table 9-11 Costs of Water Production – F.J. Horgan WTP, 1999

	Total cost (\$)	Unit cost (\$/m^3)
Electrical power	3,195,700	0.023
Other energy sources	500	0.000
Chemicals	871,444	0.006
Sampling & analysis	300,000	0.002
Direct labour	2,025,932	0.015
Corporate charges	892,500	0.006
Contracted services	86,300	0.028
Debt repayment	6,360,000	0.046
Other	256,550	0.002
Total	**13,988,926**	**0.100**

9.4 E.L. Smith Water Treatment Plant – Edmonton

9.4.1 Role of Technology

General Description

The E.L. Smith Water Treatment Plant is located at 3900 E.L. Smith Road in southwest Edmonton, upstream of the city core and all storm sewer outlets. It is one of two plants serving a population of approximately 830,000 within the City of Edmonton and 40 surrounding communities in Alberta. The combined capacity of the Rossdale and E.L. Smith treatment facilities is 495 ML/d, while the average daily flow through the two plants in 1999 was 334 ML, equivalent to a per capita consumption of approximately 400 L/d (see table 9-12).

The E.L. Smith facility treated 63,982 ML in 1999. The plant opened in 1976 with a treatment capacity of 200 ML/d, which was later expanded to 235 ML/d under normal raw-water quality conditions. The plant practices conventional treatment processes, including coagulation, flocculation, clarification, filtration, and disinfection (see figure 9-3). Major changes in the treatment process have included discontinuation of chlorine dioxide disinfection and the elimination of the softening process in 2000.

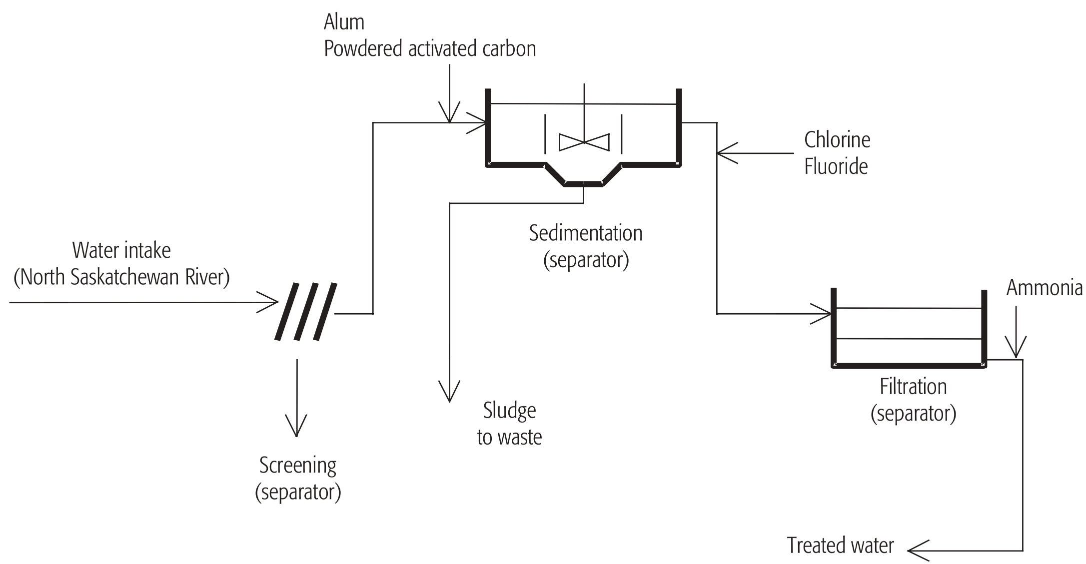
Raw-water Supply

Raw water is drawn from the North Saskatchewan River via a concrete intake structure submerged mid-stream approximately 1.1 m below the water surface (low river levels). Two 1.5-m-diameter intake pipes connect the intake structure to a low-lift pumphouse approximately 170 m away. Water flows through the

Table 9-12 Daily Water Supply – Edmonton, 1999

Water production	E.L. Smith	Combined
Firm capacity (m^3/d)	235,000	495,000
Average (m^3/d)	175,000	334,000
Maximum (m^3/d)	-	435,000
Per capita average (L/d)	400	400

Figure 9-3 E.L. Smith Water Treatment Plant Process Layout



intake pipes into two travelling water screen chambers, where the self-cleaning screens strain the water to prevent large debris from entering the treatment system. The water moves into three pump chambers for delivery to the plant via a 1.8-m-diameter pipe.

The North Saskatchewan River is susceptible to periods of heavy silting due to strong rains and spring runoff. Consequently, the rapidly changing conditions make water treatment difficult. In 1999, for example, raw-water turbidity at the E.L. Smith facility ranged between 10 and 500 NTU. Table 9-13 summarizes North Saskatchewan raw-water quality for 1999.

High *Cryptosporidium* concentration, which in 1999 averaged 411 oocysts/100 L in the raw water, also presents a serious problem. *Cryptosporidium*, a disinfectant-resistant protozoan, has been linked to numerous outbreaks of cryptosporidiosis, a severe gastrointestinal disease.

Raw-water quality is monitored continuously for turbidity, temperature, alkalinity, and pH; these parameters drive the automated coagulation and disinfection dose response.

Clarification

Aluminum sulphate (alum) coagulant is added to the water before it enters the clarifiers. The E.L. Smith facility uses a liquid alum feed system with a dry alum backup. In 1999, because of seasonal variation and changing raw-water quality, alum dosage ranged from 25 mg/L during periods of good raw-water quality to 300 mg/L during spring runoff (see table 9-14). To accommodate the wide range of dosing rates, the plant uses an innovative feed system. Rather than using a series of sequentially starting pumps to handle the range of dosages,

Table 9-13 Raw-water Quality – E.L. Smith WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	54	10	500
Colour (TCU)	13	2	100
pH	8.2	7.9	8.4
Temperature (ºC)	–	0.5	20

alum is continually pumped through a closed-looped system, from which the necessary dose is bled off.

The E.L. Smith facility uses three 15-ML solids-contact clarifiers, which are designed to produce the three zones necessary for good clarification:

- a rapid-mix zone where raw water, recirculated flocs, and fresh coagulants are quickly mixed (G-value approximately 2,500 s^{-1})
- a slow-mix zone where gentle mixing promotes aggregation of suspended material and formation of flocs
- a settling zone where upward flow is reduced (3.0 m/h at plant rating) to allow particulates to settle while clarified water exits the reactor via a collection flume

The retention time in the clarifiers is approximately 90 minutes at the plant rating. Polymers are also used in the clarification process to provide enhanced coagulation. In addition to improving flocculation, polymers can significantly increase the percentage of solids in the sludge that is drained from the clarifiers. Settled water and sludge quality are continuously monitored to provide an immediate indication of treatment effectiveness. Sludge scrapers continuously move settled material to central sumps, from which it is discharged back to the river. In times of poor raw-water quality it is often necessary to add powdered activated carbon (PAC) to remove additional particles and to control taste and odour.

Disinfection

Following clarification and before filtration, fluoride and chlorine are added to the water. The chemicals are injected at an ogee-crest-type weir, which hydraulically isolates the filter system from the upstream clarifiers. A fluoride concentration of approximately 0.8 mg/L is maintained in the finished water as a public health practice. A dual-head metering pump injects 20%

Table 9-14 Coagulant Dosage – E.L. Smith WTP, 1999

Coagulant	Avg	Min	Max
Alum (mg/L)	49	25	300

hydrofluorosilicic acid to maintain the required concentration. Continuous monitoring of the fluoride concentration in the potable water identifies when the dosage requires adjustment.

Gaseous chlorine, at an average dosage of 2.75 mg/L, provides disinfection. The chlorine residual concentration is monitored continuously. The plant achieves the required 3.0 log reduction of *Giardia* while maintaining trihalomethane (THM) concentrations below acceptable levels. See table 9-15 for the rates of chlorine and fluoride addition.

Filtration

The plant incorporates 12 dual-media filters with a total surface area of 1,520 m^2. The filters operate in a variable declining-rate mode; therefore, as they become plugged, the water level in the filters rises and the cleaner filters take a larger portion of the total load. The media in the 18.9 m x 6.7 m filter beds consist of 475 mm of anthracite coal over 300 mm of silica sand. At the rated plant capacity, the filter rate is approximately 5.2 m/hr.

Each filter is equipped with a flow meter, turbidity meter, and particle counter. Performance is determined by flow, run time, turbidity, and particle counts. Particle counting in filter effluent is used to ensure adequate removal of *Cryptosporidium* in the filters, since chlorine disinfection is not completely effective against this pathogen.

When any of the performance parameters exceeds a set point, the filter is automatically backwashed. In all cases, a filter will be backwashed after it has been in operation for 60 hours. Before a filter may be returned to active service, a filter ripening period is required, during which the filter effluent is directed to waste. Because of hydraulic constraints of the filter-to-waste system, the ripening time required for each filter at the E.L. Smith plant is approximately

Table 9-15 Fluoride and Chlorine Dosage – E.L. Smith WTP, 1999

Chemical	Avg	Min	Max
Fluoride (mg/L)	0.87	0.73	0.89
Chlorine (mg/L)	2.75	2.5	3.2

60 minutes. As the water exits the filters, ammonia – which reacts with the chlorine residual to form chloramines – is added. Chloramines, which have a more stable residual than chlorine, provide disinfection throughout the distribution system. The average total chloramine residual produced is approximately 2 mg/L. The quality of the treated water is shown in table 9-16.

9.4.2 Plant Operations

Management Structure

Responsibility for the management of the water utility of the City of Edmonton was assumed by EPCOR Water Services Inc. (formerly Aqualta Inc.), effective May 1, 1996, while legal title of assets was transferred December 31, 1998. EPCOR Water Services Inc. is a division of EPCOR Utilities Inc., of which the City of Edmonton is the sole shareholder. EPCOR – the first strategic linking of power and water utilities in Canada – is financially independent and governed by an independent board of directors. Figure 9-4 summarizes the management structure of EPCOR Utilities Inc. with respect to the Water Services division.

Operating Staff

One plant manager oversees the operation of the two plants; the E.L. Smith facility has two supervisors. Both the manager and supervisors are on duty during weekdays. The E.L. Smith plant is operated seven days a week by 16 operators, who attained certification at various levels through written testing and experience (see table 9-17). In the past year additional training has been provided as in-house and external courses in addition to speciality conferences.

Table 9-16 Treated Water Quality – E.L. Smith WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	0.04	<0.02	0.11
Colour (TCU)	1	1	2
pH	8.3	8.0	8.5

Additional employees at the E.L. Smith facility include two administration and clerical staff, as well as maintenance and laboratory staff whose duties are split between the two plants and other services.

Emergency Procedures

The E.L. Smith Water Treatment Plant has a fully automated plant control system. To protect water quality, automatic plant shutdown will occur if particle

Figure 9-4 EPCOR Utilities Organization

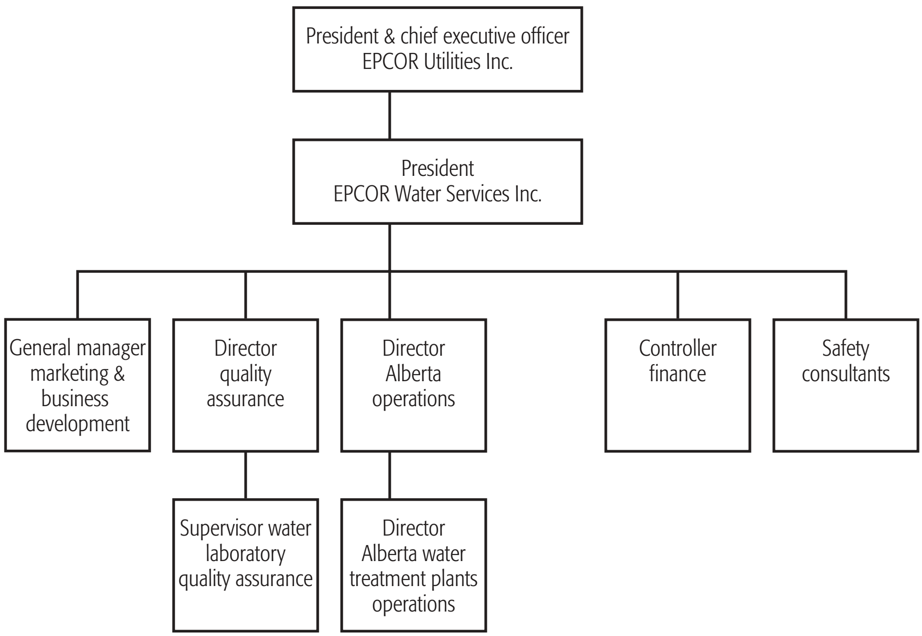


Table 9-17 Operator Certification – E.L. Smith WTP

Certification level	Operators
I	1
II	8
III	6
IV	1
Total	**16**

counts, turbidity, pH, fluoride, or chlorine levels exceed specified set points. All plant staff have full authority for manual plant or process shutdown. In accordance with the plant's approval to operate from Alberta Environment, shutdown criteria are specified for 21 parameters.

In addition, a complete emergency manual is available for the plant. The plan deals with hazard analysis, functional responsibility, initial response, emergency response, mutual aid, business protection, and recovery. In cooperation with Alberta Environment and local health agencies, EPCOR has also established a boil water emergency response plan for consumer protection in the event of microbial contamination of distributed water.

Quality Monitoring

Continuous monitoring of treated water turbidity, pH, temperature, particle counts, and disinfectant residual concentration provides continuous assurance of effective treatment procedures. Microbiological grab samples, taken at regular intervals, provide further evidence of adequate treatment.

The utility's in-house laboratory is accredited by the Canadian Association for Environmental Analytical Laboratories (CAEAL). The water quality assurance laboratory conducts more than 120,000 tests per year for more than 149 regulated and non-regulated physical, chemical, and microbial parameters. Table 9-18 gives the frequency of microbial testing in Edmonton water. In addition to laboratory testing the utility conducts quarterly customer satisfaction surveys.

Table 9-18 Frequency of Microbial Testing – E.L. Smith WTP

Parameter	Frequency
E. Coli	Daily
Total coliforms	Daily
Heterotrophic plate count	Daily
Giardia	Monthly
Cryptosporidium	Monthly
Virus	Quarterly

A formal quality management plan, as provided by the EPCOR sustainable development policy, addresses the utility's economic, environmental, and social impacts.

9.4.3 Local Standards and Enforcement

Alberta Environment regulates waterworks systems in Alberta, as part of the *Environmental Protection and Enhancement Act.* Updating of Alberta's environmental laws have led to development of the Potable Water Regulation, Alberta Regulation (AR) 122/93. This regulation replaced previously used legislation, including Clean Water (Municipal Plants) Regulations (AR 37/73), Clean Water (General) Regulations (AR 35/73), and Fluoridation Regulations (AR 38/73).

The Potable Water Regulation allows Alberta Environment to regulate the operation of water treatment plants and set standards for potable water quality. Under the regulation, waterworks systems must meet minimum water treatment design requirements as set out in *Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems,* published by Alberta Environment. The physical, chemical, microbiological, and radiological quality of water distributed must also comply with the latest edition of the *Guidelines for Canadian Drinking Water Quality,* published by Health Canada. The Potable Water Regulation directs that the director of operations and the local health board must be notified immediately of any failure or shutdown of disinfection or fluoridation equipment. In addition, the regulation requires that only certified operators be in direct supervision of the treatment facility.[203]

9.4.4 Cost of Production

According to the 1999 corporate report for EPCOR Utilities Inc., operating expenses totalled $61.1 million for the Water Services division, which includes both Edmonton treatment facilities. Based on the combined 1999 production of the two facilities (119,950 ML), the approximate production cost per cubic metre was $0.509 (before taxes), which is equivalent to $0.204 per capita per day, or $74.50 per year. Table 9-19 provides a summary of Water Services financial data for the year ending December 31, 1999.

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[203] Alberta, Alberta Environment, 1997, *Potable Water Regulation* [online], AR122/93 [cited August 2001], <www.gov.ab.ca/env/protenf/legislation/factsheets/potwater.html>.

9.4.5 Funding

Residential and commercial water customers in Edmonton have been metered for over 90 years. In addition to a fixed monthly charge, customers are billed for water usage. Table 9-20 provides a summary of 1999 water rates for Edmonton customers. In 1999 EPCOR Water Services Inc. had an operating income of $38.4 million with total assets of over $361 million. Water sales for 1999 totalled 113,268 ML, from which revenues exceeded $87.5 million.

9.5 McCarron Water Treatment Plant – Saint Paul, Minnesota

9.5.1 Role of Technology

General Description

The McCarron Water Treatment Plant, located at 1900 North Rice Street, Maplewood, Minnesota, began operations in 1922. It provides water services

Table 9-19 Financial Information – EPCOR Utilities Inc. (Water Services), 1999

	Total	Unit
Water production (ML/d)		328.6
Water sales (ML/d)		310.3
Revenues	($)	($/m^3)
Water sales	87,520,000	
Commercial and other	11,990,000	
Total	**99,510,000**	**0.879**
Expenses	($)	($/m^3)
Depreciation and amortization	10,674,000	0.089
Other	50,410,000	0.420
Total	**61,084,000**	**0.509**
Operating income	**38,426,000**	
Total assets	361,781,000	
Capital additions (1999)	15,439,000	

to the City of Saint Paul and several neighbouring communities. The plant is operated by Saint Paul Regional Water Services, which is overseen by an independent Board of Water Commissioners and uses no tax revenues. Except for water used for fire fighting, all water provided by the utility is metered. In March 2000 the utility's bond rating was upgraded from AA to AA$^+$, which places it among the top eight water utilities in the United States.

The McCarron Water Treatment Plant serves a population of approximately 395,000, and in 1999 produced a daily average of 191,527 m^3 of drinking water. The maximum daily capacity of the plant is 545,000 m^3, while the maximum daily production in 1999 was 321,726 m^3. Daily per capita consumption is 449 L (see table 9-21). The plant practises conventional water

Table 9-20 Edmonton Water Rates, 1999

Customer classification	Consumption (m^3/mo.)	Unit rate (\$/m^3)
Domestic	0–60	0.94
	>60	1.01
Multi-residential	0–100	0.86
	101–1,000	0.72
	1,000–15,000	0.67
	>15,000	0.60
Commercial	0–100	0.68
	100–1,000	0.62
	1,000–5,000	0.54
	>5,000	0.45
Wholesale		0.44
Truck fill stations		0.72

Table 9-21 McCarron WTP Production, 1999

	Production
Firm capacity (m^3/d)	545,000
Daily average (m^3/d)	191,527
Maximum day (m^3/d)	321,726
Average per capita (L/d)	449

treatment, including coagulation, flocculation, clarification, filtration, and disinfection (see figure 9-5). The utility has also implemented watershed restoration to control algal growth in its source water.

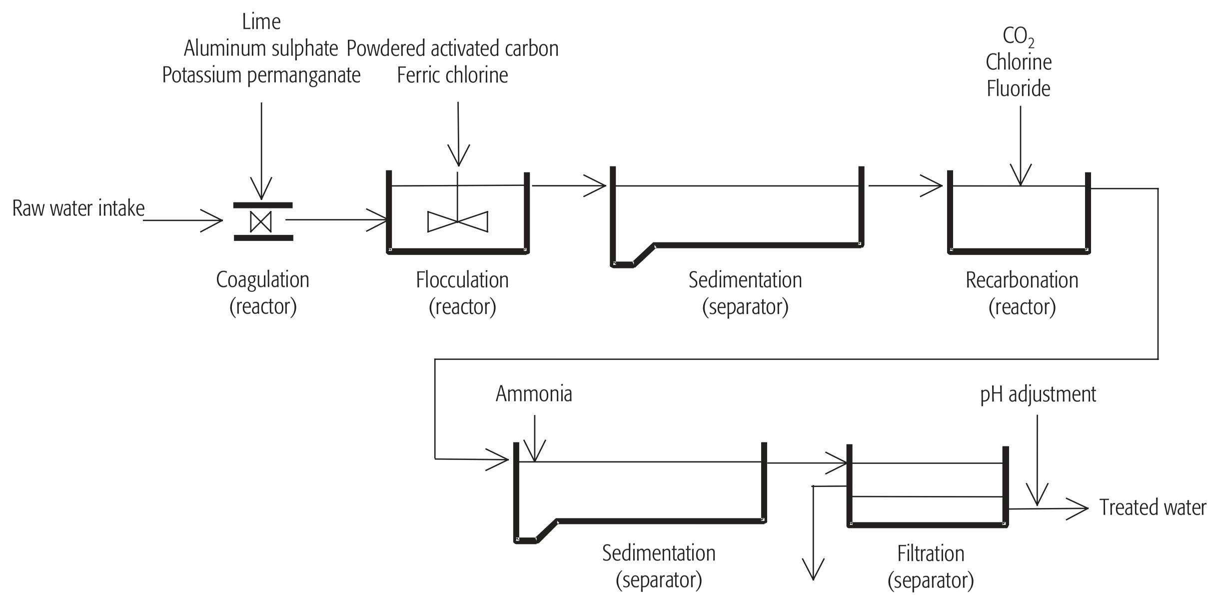
The water produced by Saint Paul Regional Water Services continually meets or exceeds state and federal drinking water standards for all parameters except lead. The U.S. Environmental Protection Agency (EPA) requires that for a given test round 90 of 100 homes must have lead levels below 15 μg/L for the first litre taken from the tap, after the plumbing system has remained unused for a minimum of six hours. Sources of lead contamination have been identified as lead services, lead solder, and brass plumbing fixtures. To remain in compliance with EPA lead regulations, the utility promotes an extensive public awareness program; it also replaces lead services to more than 1,000 homes each year. In addition, the utility has changed its corrosion control strategy and now uses phosphate-based inhibitors rather than sodium hydroxide. This limits release of lead from plumbing fixtures.

Raw-Water Supply

Raw-water sources include the Mississippi River, lake chains, and deep wells. Depending on weather conditions, the Mississippi River supplies between 65% and 90% of the total raw water used by the utility. Intake facilities, located in the City of Frindley, pump water through two 1.5-m-diameter conduits a total of 13.7 km to Charles Lake, which is located in the Impounding Reservoir Lake System. This lake system, located approximately 9.7 km north of Saint Paul, comprises a number of natural lakes (including Deep, Charles, Pleasant, Sucker, and Vadnais) connected by conduits and canals. At optimum conditions the lake system has an available water supply of 13.6 million m^3. During periods of high water demand, four wells, located at Vadnais Lake, supply water to the utility. The wells, 60 mm in diameter and 134 m deep, have a combined capacity of over 68,000 m^3/d. Located approximately 29 km north of Saint Paul, the Rice Creek chain of lakes provides a reserve water source. It can supply over 151,000 m^3/d through the Centerville pumping station.

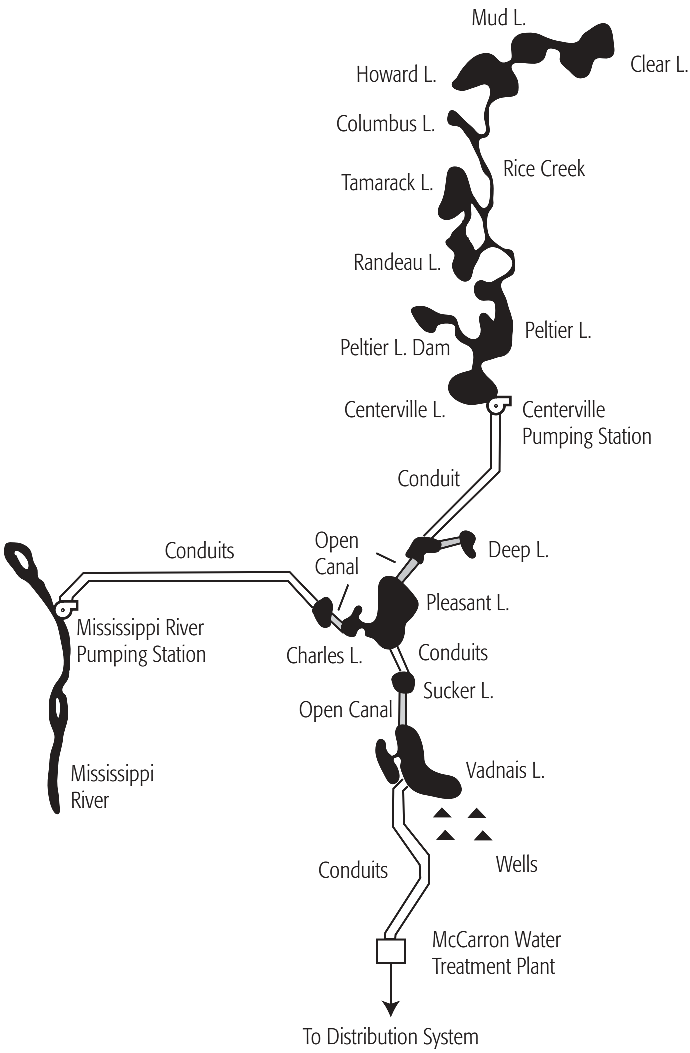
Two 2.3-m-diameter conduits connect Vadnais Lake, to which all sources eventually flow, to the McCarron Water Treatment Plant approximately 6.4 km to the south. The conduits convey water by gravity at rates up to 757,000 m^3/d. See figure 9-6 for the complete raw-water supply system.

Figure 9-5 McCarron Water Treatment Plant Process Layout



To combat taste and odour problems resulting from excessive nutrients and algal growth in the lake reservoir system, the utility has implemented several control measures. They include ferric chloride feed systems at the Mississippi River pumping station and at Vadnais Lake and Lambert Creek; aerators at Sucker and Vadnais Lakes; application of spent lime on a portion of Sucker Lake; and restoration of water levels in the Rice and Grass Lake wetlands.

Figure 9-6 Raw-water Supply – McCarron WTP



The Mississippi River source water passes through the lake impounding system, where in addition to mixing with lake water it is subjected to both natural polishing processes and the control measures noted above. This produces raw water of excellent quality, allowing easier and more cost-effective treatment than would be possible if the Mississippi River water, with its wide variations in quality, were pumped directly to the treatment plant. Raw-water turbidity, pH, and temperature are continuously monitored. These parameters drive the automated response of the treatment processes.

Clarification

Before water enters the clarifiers, chemicals are added in two rapid mixers: lime for softening, aluminum sulphate for coagulation, and potassium permanganate for oxidation of taste and odour compounds (see table 9-22). The G-value achieved in the mixers is approximately 1,000 s^{-1}.

The flocculation zone consists of three long, narrow basins in series, which provide tapered flocculation. The slowly rotating paddles create velocity gradients of 35 s^{-1}, 25 s^{-1}, and 15 s^{-1}, respectively, in the three basins. Additional chemicals added when necessary to the flocculators include powdered activated carbon for taste and odour control and ferric chloride as a flocculation aid. After flocculation the water enters one of five clarifiers, which have a combined surface area of 7,930 m^2. The flocs settle to the bottom, and clean water flows over the top of the basin. The approximate retention time in the clarifiers, at the plant rating, is 48 minutes.

Disinfection

After clarification the water flows into a recarbonation chamber, where carbon dioxide gas lowers the pH and removes caustic alkalinity caused by softening.

Table 9-22 Coagulant Dosage – McCarron WTP, 1999

Coagulant	Avg	Min	Max
Lime (mg/L)	150	110	180
Aluminum sulphate (mg/L)	18	15	19

Additional chemical addition in the recarbonation chamber includes fluoride for dental health and chlorine for primary disinfection. Fluoride is added as hydrofluorosilicic acid. An average chlorine dose of approximately 5 mg/L is applied continuously, as chlorine gas. Fluoride and chlorine doses applied in 1999 are shown in table 9-23.

After the recarbonation chamber the water enters a secondary settling basin where ammonia is added to react with the remaining chlorine. This forms chloramines, which have a more stable disinfecting residual in water than free chlorine and are used to protect the water in the distribution system. Chloramine concentration is maintained at approximately 3.5 mg/L.

Filtration

The filtration system consists of 18 dual-media filters with a combined surface area of 2,650 m^2. The filter bed consists of a 920 mm layer of anthracite placed over 100 mm of sand. The nominal water depth above the media is 3.0 m.

Previously, the utility relied on 24 sand and gravel filters. Conversion to the dual-media system began in the mid-1990s and, as a result of improved filter performance, only 18 of the original filters were converted. Table 9-24 shows the quality of water after filtration.

Table 9-23 Chlorine and Fluoride Dosage – McCarron WTP, 1999

Chemical	Avg	Min	Max
Hydrofluorosilicic acid (mg/L)	1.2	0.9	1.4
Chlorine (mg/L)	5.0	–	6.0

Table 9-24 Post-filtration Water Qualilty – McCarron WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	0.04	0.02	0.29
Colour (TCU)	10	5	12
pH	8.8	8.6	9.0

Filtered water is stored in finished-water reservoirs from which two 2-m-diameter suction lines deliver it to the distribution system. Before water enters the distribution system, its pH is adjusted to 8.5, using phosphate-based inhibitors, for corrosion control.

9.5.2 Plant Operations

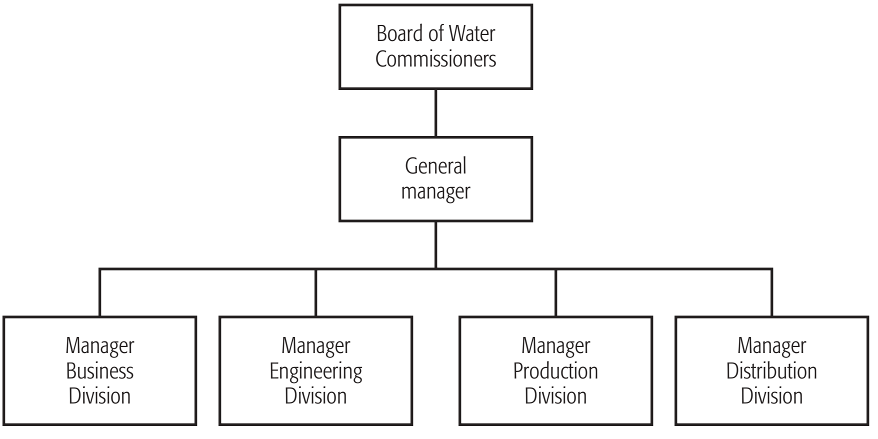
Management Structure

The plant is operated by Saint Paul Regional Water Services. The utility is governed by the Board of Water Commissioners, consisting of three members of the Saint Paul City Council, two Saint Paul residents representing the public, and one public member from Maplewood. The day-to-day operation of the utility is under the direction of a general manager. Figure 9-7 gives an overview of the management structure for Saint Paul Regional Water Services.

Operating Staff

In total, 43 staff are assigned primarily to the operation of the facility, including the plant manager, who maintains full authority for plant and process shutdown, five supervisors, and 10 operators.

Figure 9-7 Saint Paul Regional Water Services Management



Quality Management

Continuous monitoring of treated water turbidity, pH, temperature, and disinfectant residual concentration, combined with daily microbiological sampling, ensures compliance with the federal Surface Water Treatment Rule (see section 5.3.4). In addition, the utility's accredited laboratory frequently monitors samples for more than 160 regulated and non-regulated parameters.

Since 1994 the utility has also had a Flavour Profile Analysis Panel made up of utility employees who underwent extensive training to enhance their ability to identify tastes and odours that occur in water. The panel convenes once a week to examine the aesthetic quality of the water sampled at numerous locations throughout the distribution system. The members describe and quantify the intensity of flavour and odour, which provides the utility with reliable information on the aesthetic quality of the water.

9.5.3 Local Standards and Enforcement

As with all public water supply systems in the United States, the McCarron Water Treatment Plant must comply with the provisions of the federal *Safe Drinking Water Act*. Since 1974 the EPA has regulated the country's public water supply systems under the *SDWA*. As part of this act the EPA has established both maximum contaminant levels (MCLs) and required treatment procedures for contaminants that are known or suspected to pose significant health risks in drinking water.

Responsibility for enforcement of the *SDWA* lies with the individual states. The state of Minnesota was one of the first states, in 1977, to begin regulating public water supply systems.

9.5.4 Cost of Production

In 1999 the average cost of water production at the McCarron Water Treatment Plant was US$0.096/m^3. Based on the reported per capita consumption of

449 L/d, the per capita cost of water production in 1999 was \$0.043 per day, equivalent to US\$15.73 per year.

9.5.5 Funding

The utility is self-supporting – revenues come from the sale of water and payment for other services. Except for water used for firefighting, all water provided by the utility is metered. The utility owns and maintains more than 92,000 water meters, serving more than 395,000 customers. In addition to fixed charges for the billing period, customers are billed for water consumption. Table 9-25 provides a summary of water rates, effective January 1, 2000, for the City of Saint Paul and the surrounding communities whose water is supplied by Saint Paul Regional Water Services. The average income of the utility is \$32 million annually and, as of December 31, 1996, assets totalled \$130 million, including property and facilities.

Table 9-25 Water Rates – Saint Paul and Area, January 1, 2000 (US\$)

	First 100,000 ft^3/mo.		Excess
	winter (\$/m^3)	summer (\$/m^3)	year round (\$/m^3)
Saint Paul	0.49	0.52	0.45
Falcon Heights	0.58	0.62	0.54
Maplewood	0.55	0.60	0.52
Lauderdale	0.58	0.63	0.54
Lilydale	0.58	0.63	0.54
Mendota Heights	0.58	0.63	0.54
Mendota	0.58	0.63	0.54
Newport	0.58	0.63	0.54
Roseville	0.58	0.63	0.54
South Saint Paul	0.58	0.63	0.54
Sunfish Lake	0.58	0.63	0.54
West Saint Paul	0.58	0.63	0.54

9.6 Prescott (Ontario) Water Treatment Plant

9.6.1 Role of Technology

General Description

Prescott is a community of approximately 4,500 people located on the St. Lawrence River east of Brockville, Ontario. The population has remained essentially unchanged for the past two decades; if anything, there has been a slight decline.

Before the new treatment plant was commissioned in 1987, the town's drinking water was taken directly from the St. Lawrence River. After screening to remove algae, it was chlorinated and distributed to consumers. In the 1970s, fluoride, in the powder form of sodium silicofluoride, was added to promote the fight against tooth decay.

The fact that fluoridation in Prescott had received a higher priority than "chemically assisted filtration" demonstrates that as recently as the 1980s, there was a lack of understanding or acceptance of coagulation and filtration of surface water as necessities and not simply 'good practice.' Not until 2000 were they finally made mandatory, through the Ontario drinking water standards.

The Prescott plant has a firm rated capacity of 8,200 m^3/d. The high-lift pumping station constructed as part of the plant has a capacity of 12,100 m^3/d, or 140 L/s, to augment fire protection flows from the elevated storage tank.

The new facility brought many changes to the way in which the town, through its Public Utilities Commission, operated and managed its water system. As such, it is a good example of small plant operation and the role of technology in bringing about change.

The average daily flow through the plant in 1999 was 3,000 m^3. The reported per capita usage of 750 L/d is inflated by industrial consumption and does not reflect actual domestic use. The maximum one-day output, at 7,100 m^3, was 87% of the rated plant capacity (see table 9-26).

Because it has no sedimentation, the plant is classified as a direct filtration facility. In all other ways, however, the plant is conventional and applies the following processes: coagulation, flocculation, filtration, and disinfection (see figure 9-8). Hydrofluorosilicic acid is now used for fluoridation because of handling concerns associated with the powder form of the compound.

Raw-Water Supply

Raw water is drawn from the St. Lawrence River via a 600-mm-diameter gravity intake pipe approximately 125 m long and is monitored continuously for turbidity, temperature, and pH. Because of the relative stability of these parameters, neither automated responses nor alarm conditions are programmed. The information is used primarily for historical data records.

Data provided by the operating staff highlight the fact that raw-water turbidity is well below the 1 NTU standard set by the Ontario Drinking Water Standards for treated water (see table 9-27). This is a good example of why, historically, there has been confusion and a lack of understanding with respect to the treatment of surface water. If the raw-water turbidity is less than the required standard for treated water, why are filtration or coagulation necessary at all?

We now know, however, that chemically assisted filtration removes significant numbers of microbial pathogens and therefore provides an important barrier

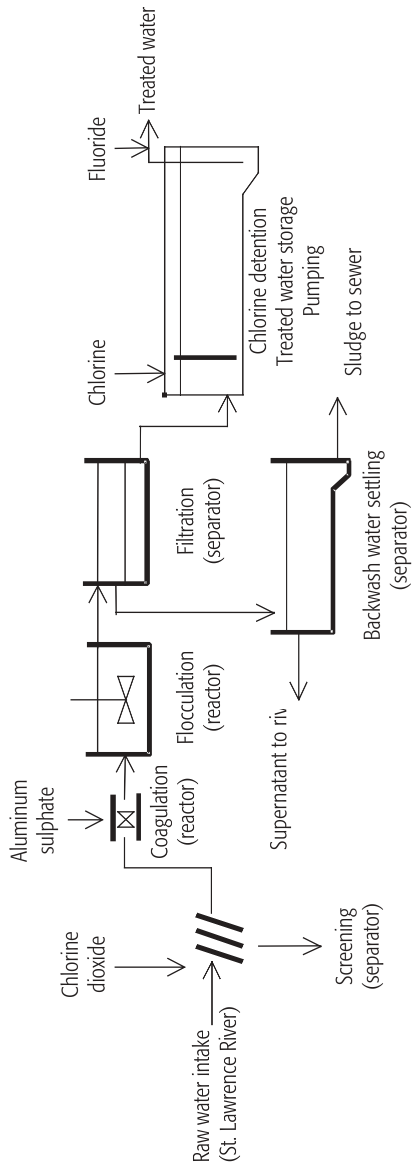
Table 9-26 Water Production – Prescott WTP, 1999

	Production
Firm capacity (m^3/d)	8,200
Daily average (m^3/d)	3,000
Maximum day (m^3/d)	7,100
Per capita average (L/d)	750

Table 9-27 Raw-water Quality – Prescott WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	0.30	0.19	0.59
Colour (TCU)	0.11	0.20	1.0
pH	7.4	6.0	8.0
Temperature (ºC)	10.7	0.4	20.2

Figure 9-8 Prescott Water Treatment Plant Process Layout



to contamination of treated water. It also reduces the dependence on disinfection as the only inactivation process for these pathogens. Ensuring that the disinfection system is not overburdened maintains its efficiency and promotes the overall safety of the water distributed to consumers. In requiring a minimum of chemically assisted filtration for treatment of surface water supplies, *Ontario Drinking Water Standards* acknowledges this approach.

Chemically assisted filtration was originally promoted by the Ministry of the Environment (MOE) using allocation of grant funds as the means to achieve what was, at the time, a loosely applied policy. Priorities for funding were established more by the willingness of the municipality to work toward the MOE's objective of filtration rather than by the quality of the raw-water source. In many instances, a phased program, limited initially to chlorination, was funded by the MOE without the application of tight deadlines to implement filtration.

The continuously monitored raw-water data should provide some indication of upstream spills through rapid changes in pH or turbidity. The primary mechanism for protection against spills, however, is the reporting system regulated under the provincial *Environmental Protection Act.* Using engineering judgement, the risk to the town's water supply was considered well below that necessary to warrant the installation of sophisticated, high cost, on-line toxicity monitoring instrumentation.

Pre-Disinfection

Adding free chlorine – even though the St. Lawrence River water at Prescott is low in organics – could increase trihalomethane (THM) concentrations. Although the levels were well below drinking water standards before the construction of the new plant (when chlorination was the only form of treatment), the town elected to pre-disinfect using chlorine dioxide, a compound that does not convert organic precursors to THM. Chlorine dioxide is also effective in controlling some of the compounds responsible for taste and odour. Prescott's water supply had occasionally experienced taste and odour difficulties, though at the time no testing had been carried out to determine chlorine dioxide's effectiveness. In 1999 chlorine dioxide was injected at the rates shown in table 9-28.

It is important to note that there is a fundamental difference in the way in which chlorine dioxide is used in Prescott and the way it has been used elsewhere in Ontario. The technology in Prescott achieves very high reaction efficiencies by combining precisely controlled stoichiometric ratios of sodium chlorite and hydrochloric acid in a reactor. This limits formation of disinfection by-products (DBPs) including chlorite (ClO_2^-) and chlorate (ClO_3^-) ions. Chlorine dioxide dosage rates are set by the operators and paced automatically proportional to plant flow so that by the time the water passes through the filters it has a zero residual. The design also incorporates alarms and automatic safe shutdown systems to protect against the loss of any constituent compound.

This system contrasts with the conventional method used in Ontario to produce chlorine dioxide for taste and odour control at the time the Prescott plant was designed. Normal practice had been to inject a sodium chlorite solution into the pre-chlorination stream, an approach that did little to limit THM formation because free chlorine was always present in the resultant chemical feed. It was also relatively inefficient and offered little control over the formation of DBPs.

The town recognized the operating cost premium associated with chlorine dioxide but considered it inconsequential when measured against the benefits of exceeding or surpassing drinking water quality objectives. In this respect, Prescott was ahead of its time.

Screening

Raw-water screens protect the plant against the effects of seasonal algal growths, which, if not removed, can rapidly blind or clog filters and reduce plant capacity. Although less significant, fish must be considered a 'contaminant' in terms of water plant operation. Intake velocities were selected to prevent fish from being drawn in, but the openings on the screens attached to the intake pipe are too big to prevent their unintentional migration. Fine screening later removes them from the raw water.

Table 9-28 Pre-disinfection Dosage Rates – Prescott WTP, 1999

	Avg	Min	Max
Chlorine Dioxide (mg/L)	0.32	0.30	0.34

Coagulation

Liquid aluminum sulphate (alum) is used for coagulation. It is injected into an in-line high-energy blender or mixer on the raw-water feed line to the flocculators at a rate proportional to plant flow. Standby chemical feed pumps provide redundancy, reducing the probability of process shutdowns. The energy input to the mixer is not varied. The dosage (12 mg/L) was set with the assistance of MOE water quality staff after the plant went into service and, because the raw-water quality is consistent, there has been no need to change it. The quality of the treated water demonstrates the success of this mode of operation.

Flocculation

The flocculation zone comprises four tanks that can be operated either as two-in-series, to provide tapered flocculation, or as four-in-parallel. Total retention time at the design plant flow of 8,200 m^3/d is 20 minutes. Vertical mechanical flocculators, or mixers, in each tank can vary the energy input to achieve a range of G-values from 20 s^{-1} to 70 s^{-1}.

Filtration

The plant operates three dual-media (anthracite and sand) filters, designed for a filtration rate of 10 m/h at the design flow. The filters work in a constant-rate mode, in which each filter shares the plant throughput equally. When a filter is taken off-line for backwashing the plant flow automatically reduces to maintain a constant flow through the remaining filters and thereby minimizes the potential for turbidity breakthrough.

Each filter is equipped with a dedicated turbidimeter. Alarm settings, together with measurements of head loss, or filter plugging, can be used to initiate the backwash cycle automatically. However, the operators elect to initiate backwashing at times when they are present to witness the sequence. To minimize media loss during backwashing, the wash water flow rate automatically reduces with lower water temperature (viscosity and particle drag increase in colder water). The filters are not equipped with filter-to-waste valving, which would waste filtered water for the first few minutes after a filter returns to service, when water quality is typically poorer.

Although the post-filtration water quality data reported in table 9-29 show a slight inconsistency (average turbidity is higher than the maximum), it is reasonable to state that filtered water turbidity is consistently 20 times better than that required by the Ontario drinking water standards. On this basis, plant performance is exemplary.

Disinfection

Liquid sodium hypochlorite is stored on site and fed by metering pump into the clearwell and reservoir after filtration, at a rate proportional to plant flow rate. The reservoir has a capacity of 1,600 m^3, equal to 20% of the rated plant capacity, and provides balancing storage for the distribution system and backwash water. At current average flows of 3,000 m^3/d, detention time is approximately 13 hours. See table 9-30 for dosage and residual concentrations for 1999.

A second dosing point is provided at the inlet to the high-lift pumping well. Dosing is controlled by a compound loop instrumentation system designed to achieve tight residual control before water enters the distribution system. Chlorine residual is monitored continuously. The CT concept is not used by the operators as a measure of disinfection performance, but CT is in the order of 500 mg·min/L at average flows (the requirement is 30 to 50 mg·min/L).

Table 9-29 Post-Filtration Water Quality – Prescott WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	0.06	0.03	0.05
Colour (TCU)	0.53	0.2	1.0
pH	7.0	6.8	7.1

Table 9-30 Disinfection Dosage – Prescott WTP, 1999

	Avg	Min	Max
Sodium hypochlorite (mg/L)	1.0	0.8	1.2
Chlorine residual (mg/L)	1.0	0.82	1.1

Fluoridation

Hydrofluorosilicic acid is added to the plant discharge line before water enters the distribution system. Dosage is controlled automatically, and acid consumption rates are monitored by the plant control system to calculate dosage on a daily basis (see table 9-31). Grab samples are taken periodically to check the actual rate.

Treated Water Monitoring

Chlorine residual and turbidity are recorded continuously on the plant discharge line before water enters the distribution system. Microbiological grab samples are taken in accordance with MOE regulations and analyzed by an outside laboratory.

Solids Handling and Disposal

Backwash water discharges to a tank where it settles under static conditions. The underflow, or sludge, is withdrawn and pumped to a sanitary sewer. The supernatant, with suspended solids concentrations less than 25 mg/L, returns to the low-lift pumping station where it either re-enters the treatment process or discharges back to the St. Lawrence River via a submerged outfall pipe. The practice since the plant went into operation has been to discharge it to the river. Chlorine residual in the supernatant discharge to the river is not monitored. The certificate of approval does not require de-chlorination, although it could become necessary in the future should the MOE demand non-toxic conditions at the point of discharge instead of at the edge of the mixing zone.

Table 9-31 Fluoridation Dosage – Prescott WTP, 1999

Source of fluoride	Avg	Min	Max
Hydrofluorosilicic acid (mg/L)	1.0	0.8	1.2

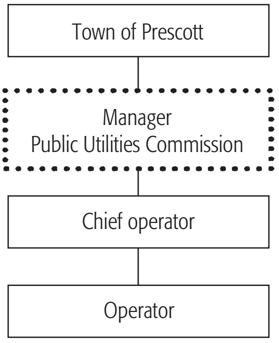
9.6.2 Plant Operations

Management Structure

Until recently the Prescott Public Utilities Commission (PUC) managed both electrical and water supply to the town. The Ontario Clean Water Agency operates wastewater treatment. With the current moves toward municipal amalgamation throughout the province, and deregulation of the electrical industry, the town became a 35% shareholder in a newly formed entity, Rideau St. Lawrence Utilities, which now operates the electrical system. The town retains ownership of the water system, including the treatment plant, and is debating the merits of entering a services contract with Rideau St. Lawrence. Although the PUC still exists, responsibility for water plant operations has been effectively transferred back to the town until such time as council decides whether water plant operations should be privatized. Although change is likely, the organization should not differ significantly from its current structure as shown in figure 9-9.

The key point to note is that operation of the Prescott water supply is managed locally by a very small organization. The only source of technical support was the Ministry of the Environment. One example of this in practice was the involvement of the MOE water quality staff in optimizing coagulant dosage, an important factor in producing high quality drinking water. As the MOE's focus progressively moved toward regulation and enforcement, the town's operators had to seek advice on an ad hoc basis from other sources. The PUC has not perceived a need, nor has it been directed by regulatory agencies, to engage the services of outside specialists to provide ongoing support.

Figure 9-9 Prescott Water Treatment Plant Organization



Operating Staff

The plant is operated by two level III operators who gained their certification through waterworks experience augmented by MOE training courses. The PUC continues to make some commitment to training. In the past year training accounted for 1.2% of the operators' time, a total of 40 hours.

Role of Technology in Plant Operations

Technology, introduced when the plant was constructed in 1987, has reduced plant supervision to a single eight-hour, two-operator daytime shift during the week (reduced to one operator on weekends). The original pumping station was staffed 24 hours a day to ensure rapid control responses to emergencies such as loss of power and fires. The new plant handles these situations automatically.

The plant control system incorporates an automated synthesized-voice alarm dialer. It characterizes alarm conditions into various categories from "critical" to "informational" and transmits them to a privately operated and staffed alarm centre that, in turn, relays critical alarms to the operator on call.

Emergency Response Plans

The plant systems and equipment have all the usual electrical safety devices required by code, and alarm conditions are automatically signalled and recorded. All process information is alarmed, but the alarms do not initiate any automated process shutdowns. Engineering judgement determined that alarms rather than automated shutdowns provide an adequate level of safety.

The Operating Manual describes all procedures required to operate the plant under abnormal conditions, but no specific emergency procedures were considered necessary for process or plant shutdown.

The two level III operators have full authority, by virtue of their role at the plant, to shut down individual processes or the whole plant, based on their assessment of the need to do so. Such action would be reported as a matter of course to the PUC manager. Formalized and structured reporting systems are considered unnecessary due, in part, to the size of the organization.

Plant Security

Most doors into the treatment plant are secured during the daytime shift and alarmed during unsupervised periods. In general, however, anyone visiting the plant is given free access to all areas. The plant is designed to limit access to the reservoir and prevent surface water from flooding the structure.

Quality Management and Best Practices

No formal quality plans are used by the PUC in the operation of the water system other than those relating to the reporting requirements defined through regulation. ISO registration is not being considered. Quality practices are measured only by the quality of the end product.

9.6.3 Local Standards and Enforcement

As at all other water systems in Ontario, drinking water produced by the Prescott plant must meet the January 2001 Ontario drinking water standards. Operation of the plant, its management, and its staff are regulated under Ontario Drinking Water Protection Regulation 459/00 of the *Ontario Water Resources Act.*

Through the reporting requirements of the regulation, the town must make performance information fully and freely available.

9.6.4 Cost of Production

When the new treatment plant was built in 1987, the total project cost was \$4.75 million, of which approximately \$4.5 million was for the plant. The remaining \$0.25 million was required for distribution system rehabilitation. The plant was one of the last facilities constructed in Ontario under the MOE's Direct Grant program. The town contributed \$1.18 million (25%) and MOE contributed the remaining \$3.57 million. With a firm capacity of 8,200 m^3/d, the 1987 unit capital cost for the plant was \$550 per m^3/d. Table 9-32 shows the total and per capita capital cost for construction of the plant.

The debt has been effectively retired in the intervening years and the PUC must now only generate revenues to cover the cost of operation. No annual charges are made against plant operations for depreciation or future capital works. The annual cost of water production is \$0.20/m^3, equivalent to a per capita cost of \$0.0147 a day, or \$54 a year. See table 9-33 for contributing factors to the overall cost of production.

9.7 Camptonville (California) Water Treatment Plant

The following case study was developed through review of a 1995 article in the *Journal of the American Water Works Association.*[204]

Table 9-32 Capital Cost Breakdown – Prescott WTP (\$)

	Total	Borne by municipality	Borne by province
Capital cost	4,750,000	1,180,000	3,570,000
Per capita cost	1,055	264	791

Table 9-33 Water Production Costs – Prescott WTP, 1999

	Cost (\$)	Unit cost (\$/m^3)
Electrical power	33,494	0.031
Other energy sources	–	–
Chemicals	21,838	0.020
Sampling & analysis	6,500	0.006
Direct labour	115,405	0.105
Corporate charges	–	–
Contracted services	11,200	0.010
Debt repayment	–	–
Other	26,284	0.024
Total	**214,721**	**0.196**

[204] F. Riesenberg et al., 1995, "Slow sand filters for a small water system," *Journal of American Water Works Association,* vol. 87, no. 11, pp. 48–56.

9.7.1 Role of Technology

General Description

Camptonville is a small community located approximately 185 km northeast of Sacramento, California, in eastern Yuba County. A new water treatment facility to serve the community began operation in December 1991, serving a population of approximately 260 via 70 connections. The Camptonville Water Treatment Plant is a slow-sand-filtration facility designed with a maximum plant capacity of 547 m^3/d. Over the first three years of operation, the average flow rate through the facility was approximately 216 m^3/d, which is equivalent to a per capita consumption of 831 litres per day. The maximum daily output observed over this time was 432 m^3 (see table 9-34). The new facility was designed to bring the Camptonville water supply system into compliance with the U.S. Environmental Protection Association (EPA) Surface Water Treatment Rule (SWTR).

Before construction of the new facility, the community used a crude water supply and treatment system. Water was diverted from Campbell Gulch, a perennial stream, and moved by gravity through a hydraulically driven hypochlorite feed system directly to an undersized distribution system that was more than 40 years old. On numerous occasions, between 1973 and 1991, boil water orders were issued for the community. During periods of heavy rain the system was unable to remove suspended sediment, resulting in high-turbidity water. That there was a lack of understanding of proper drinking water supply – particularly from surface water sources – as recently as the 1990s, is emphasized by the fact that the community's water treatment consisted solely of chlorination in a system that was in poor repair.

Table 9-34 Treated Water Production – Camptonville WTP, 1991–1994

	Production
Firm capacity (m^3/d)	547
Daily average (m^3/d)	216
Maximum day (m^3/d)	432
Per capita average (L/d)	831

In 1988 the Camptonville Community Services District (CCSD) was formed. It purchased the community's existing private system and contracted an engineering consultant to conduct a water supply study. It applied for funds through the state Safe Drinking Water Bond Law of 1986. In 1989 the preliminary engineering report was submitted to the California Department of Health Services (DHS). The complete project comprised construction of a new Campbell Gulch water diversion, a slow-sand-filtration facility, a storage tank, and a completely new distribution system (see figure 9-10). An interesting feature of the plant is that it is located on a hillside at an elevation – above the first service connection – such as to make it a full gravity system.

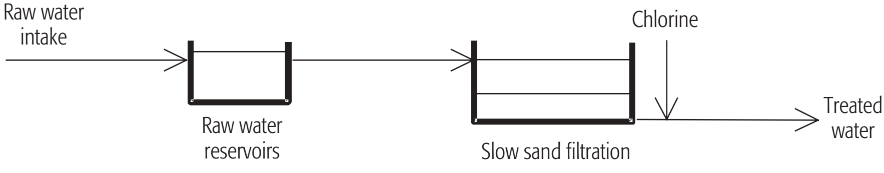
Raw-Water Supply

Campbell Gulch, the closest surface water body, supplies raw water to the Camptonville Water Treatment Plant. The perennial stream has been the community's primary source of water since 1850. Water flows to the treatment plant by gravity from the new Campbell Gulch diversion into two 1.2-m-diameter, 2.4-m-deep polyethylene raw-water reservoirs connected in series. A pilot float-control valve hydraulically controls the water flow into the raw-water basins.

During periods of low creek flow, two previously existing wells provide additional source water to the plant via a pipeline. When necessary, water from the wells is pumped directly into the raw-water reservoirs, although manual control is required. It was not feasible to use groundwater as the primary source because of the cost of removing iron and manganese, which exceeded maximum contaminant levels (MCLs).

The facility was designed to pre-chlorinate at the wellheads and upstream of the filters. When necessary, pre-chlorination with hypochlorite may be used to oxidize

Figure 9-10 Camptonville Water Treatment Plant Process Layout



iron and manganese present in the groundwater source. If pre-chlorination is used, the water is de-chlorinated with sodium bisulphate before it enters the slow sand filters. This protects the biological layer, or *schmutzdecke,* of the filter. During the first three years of operation, pre-chlorination has not been necessary, since effluent iron and manganese levels have been below the maximum contaminant level. This is due in part to partial oxidation of the iron and manganese by aeration as the water splashes into the raw-water tanks and as the surface and groundwater supplies are blended.

At the time the plant was under construction, the EPA was reviewing the Lead and Copper Rule, and provisions were made to comply with future lead and copper regulations. A chemical feed pump and orthophosphate corrosion inhibitor were included in the design, although they were not used in the plant's first three years of operation. The fact that the design accounted for possible future compliance problems with iron, manganese, lead, and copper indicates the utility's sustainability and flexibility in dealing with increased regulation and possible changes in source water quality.

Slow Sand Filtration

Slow sand filtration is one of the oldest treatment technologies still used in water supply systems. Its advantages include efficient operation without chemical addition, reliability, low operating costs, and simple operation that requires only relatively unskilled personnel. The main disadvantage of slow sand filtration is the greater area required over conventional filter designs. The larger size of the filters may not be as serious a problem for small-scale systems in less developed regions than it would be for larger systems in highly developed areas where space is limited.

Water enters the filter, passes through a layer of sand, and is collected by the underdrain system for further treatment and distribution. Following initial start-up or after cleaning, a maturing period is required during which the sand provides physical removal of particulate matter and the *schmutzdecke* that forms on the topmost layer of the bed. As the filter matures, the *schmutzdecke* provides both physical removal of particulates and biological breakdown of organic matter. Over time, head loss across the filter increases due to clogging of the biological layer. When the head loss reaches a predetermined limit, the filter bed is drained and the upper layer of sand is removed.

At the Camptonville treatment plant, water flows by gravity from the reservoirs into the slow sand filters. The filter inlets are located below the operating water surface to minimize turbulence in the supernatant. The water flows through the filter beds and is collected by a perforated polyvinyl chloride pipe underdrain system, which is supported by a gravel bed.

The filter facility consists of five precast concrete cells having a total filter area of 93 m^2, with an initial sand depth of 1.1 m. The sand has an effective size of 0.30 mm and a uniformity coefficient of 2.0. It is supported by four layers of graded gravel with a combined depth of 0.5 m. The inside dimensions of the filter cells are 5.5 m x 3.7 m x 3.0 m. One of the cells is divided into two, with one part housing the raw-water reservoirs and the other being a smaller 3.5 m x 3.7 m x 3.0 m filter cell.

The filter units are covered to protect them from debris falling from nearby trees. Average filtration rates during winter and summer are 0.024 m/h and 0.10 m/h, respectively. The Camptonville slow sand facility is outlet controlled. Therefore, as the head loss across the filters increases, the height of water above the sand also increases and maintains the desired flow. Cleaning is required when the water level approaches the overflow pipe elevation at 1.4 m above the sand. In the first three years of operation the filters have only required cleaning twice – less than was anticipated. Cleaning takes two people approximately two hours per filter to shovel out the dirty sand.

Disinfection

Filtered water is disinfected with sodium hypochlorite, in the form of 12.5 % chlorine solution, and discharged to a 24 m^3 bolted steel treated-water storage reservoir. A valve downstream of the filters controls flow into the tank and is adjusted manually by the operator in response to water demand.

9.7.2 Plant Operations

On a typical day it takes operators only 15 minutes to check the facility, including monitoring of the treated-water storage tank level, filter inflow, and discharge turbidity, chlorine residual, chlorine level in the solution tank, and total plant throughput since the previous visit. Weekly duties for the operators include preparation of the chlorine solution (once or twice a week), removal of debris, monitoring of flow at the raw-water intake, calibration of the turbidimeter, plant cleaning and record keeping, and well-testing and monitoring. Filter cleaning and other duties occasionally require more operator time, but overall operation duties require approximately 15 hours per month.

The only automated controls are for the chemical feed system, which is paced by a signal from the flowmeter, and for the emergency power system, which starts up automatically during power outages.

Quality Management

Slow sand filtration is credited with 2-log *Giardia* and 1-log virus reductions, according to the California Department of Health Services. Disinfection provides the remaining reduction required to meet the overall SWTR requirements for 3-log *Giardia* and 4-log virus reductions.

For the most part, removals of turbidity and coliform bacteria have been the measures applied to monitor the success of the Camptonville Water Treatment Plant. Monitoring of coliform bacteria in the plant discharge and within the distribution system is performed monthly. No positive test results for coliform bacteria occurred in the plant's first three years of operation.

Turbidity measurements of the filter influent and effluent are taken daily using a bench-top turbidimeter. The SWTR requires that effluent turbidity from a slow sand filter never exceed 5 NTU and that 95% of daily samples in a month have turbidity less than 1 NTU. During initial plant start-up, turbidity levels exceeded the SWTR limits because of excess fines in the fresh filter sand and slow development of the biological layer. Turbidity levels in the filter discharge were not a problem after the first few months of plant operation.

During winter storms, source water turbidity may increase dramatically. When raw-water turbidity exceeds 10 NTU, the plant is often shut down. Since water demand in winter is low, the plant can remain shut down for several days, after which the well supply may be used if the high turbidity levels persist.

9.7.3 Local Standards and Enforcement

As with all public water supply systems in the United States, the Camptonville Water Treatment Plant must comply with the provisions of the federal *Safe Drinking Water Act*, enforced by the EPA.

With the exception of microbiological criteria, small systems can apply for a variance to the regulations. To obtain a variance a utility must show that it cannot afford to comply with a particular regulation, having exhausted all options. A variance results in a prescribed treatment technology that need not meet the regulatory requirements, but provides the maximum protection affordable. There is no evidence that the Camptonville facility received a variance.

9.7.4 Cost of Production

Gravity flow, which limits power consumption, together with careful design of the facility, has minimized operation and maintenance costs. Nevertheless, even with gravity flow of the surface source water, power costs account for almost half of the plant operating expenses, mainly due to use of the well water supply during periods of low creek flow. When wells are in use, power costs exceed US$1,000 per month. Fortunately, the wells are operated for an average of only three months a year, although they were not run at all in 1993. The use of the gravity flow system for source water delivery saves the facility approximately $9,000 annually in power costs based on the figure of $1,000 per month for nine months.

Water consumption by the residents of Camptonville is very high. For instance, measured water use during the summer often exceeds 3,800 L/d per household. Water consumption of residents is metered, but water rates were not available for this report. The plant supplies water to 70 customers, representing a population of approximately 260. The operating costs for this period are equivalent to approximately $8 per month per customer or $0.07 per capita per day. Based on the average flow rate of 216 m^3/d,the approximate water production cost is $0.085 per cubic metre, which is quite low for a small facility.

Funding

The total project cost in 1991, for the entire water system, was approximately US$532,000. See table 9-35 for a breakdown of costs between the various project components.

9.8 Serpentine Pipehead Dam Water Treatment Plant – Western Australia

9.8.1 Role of Technology

General Description

The Serpentine Pipehead Dam Water Treatment Plant is situated almost 50 km from the city of Perth, the capital of Western Australia. Perth receives treated water from a combination of surface water and groundwater sources. The Serpentine Pipehead plant is operated by the Water Corporation and has a firm capacity of 500 ML/d. In 1999 the plant treated an average of 220 ML/d, which is approximately equivalent to a population of 0.56 million, based on an overall per capita consumption of 390 L/d. Its maximum day production in 1999 was 450 ML, which is within the firm capacity of the plant (see table 9-36).

The plant provides no treatment other than chlorine disinfection and fluoride addition. It takes raw water from the Serpentine Pipehead Dam, which has a catchment area of 690 km^2 and a storage capacity of 140,000 ML.

Table 9-35 Camptonville Project Construction Costs (US$)

Project Component	Cost
Diversion structure	46,500
Equipping of wells	23,000
Slow sand filter facility	226,000
Treated-water storage tank	36,000
Distribution system	200,500
Total	**532,000**

Raw-water Supply

Water quality is monitored continuously for turbidity. Grab samples are taken for pH, temperature, and microbiological parameters. Data provided by the Water Corporation highlight the fact that raw-water turbidity was generally below the Australian Drinking Water Guideline (ADWG) standard of 5 NTU for treated water. Colour was also well below the ADWG standard of 15 colour units. The Australian guideline for pH – 6.5 to 8.5 – is the same as Ontario's. Serpentine raw water fell well within this range (see table 9-37).

Disinfection

Chlorine gas (Cl_2) is used to disinfect the water before it is transferred almost 50 km to Perth. It is injected into the discharge water stream at a rate proportional to plant flow rate. Because of the long distance travelled, contact time is well beyond that required to meet the CT levels that ensure good micro-organism kill. Chlorine residual is monitored continuously on-line (see table 9-38).

Table 9-36 Water Production – Serpentine WTP, 1999

	Production
Firm capacity (ML/d)	500
Daily average (ML/d)	220
Maximum day (ML/d)	450
Per capita average (L/d)	390

Table 9-37 Raw-water Quality – Serpentine WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	0.8	0.6	2.4
Colour (TCU)	1.3	1.0	3.0
pH	6.9	6.7	7.4
Temperature (ºC)	–	–	–

Table 9-38 Chlorine Dosage – Serpentine WTP, 1999

	Avg	Min	Max
Chlorine dosage (mg/L)	2.0	1.5	2.5
Chlorine residual (mg/L)	1.1	0.9	1.5

Fluoridation

To help prevent tooth decay, fluoride is added at a dosage proportional to plant flow (see table 9-39).

Treated Water Monitoring

Chlorine residual and turbidity are monitored continuously. Microbiological grab samples for *E. coli,* total coliforms (TC), and heterotrophic plate count are taken, as are a limited number of samples for *Giardia* and *Cryptosporidium.*

Treated Water Quality

Treated water quality from the plant meets Australian drinking water guidelines for the parameters reported (see table 9-40). However, the relatively high turbidity values, compared with major Ontario plants, could undoubtedly be reduced by applying chemically assisted filtration, which is the minimum treatment accepted for surface water in Ontario. Distribution of unfiltered surface water, though, is relatively common in Australia. Physical parameters in the raw water are often, as in this case, within the guideline values. Long detention times in raw-water reservoirs, with considerable exposure to natural ultraviolet light, are often found sufficient to reduce micro-organism concentrations to a manageable range prior to disinfection.

Table 9-39 Fluoride Dosage – Serpentine WTP, 1999

Source of fluoride	Avg	Min	Max
Hydrofluorosilicic acid (mg/L)	0.85	0.7	1.0

Table 9-40 Treated Water Quality – Serpentine WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	0.8	0.6	2.4
Colour (TCU)	1.3	<1.0	6.0
pH	6.5	6.3	6.8

9.8.2 Plant Operations

Management Structure

Figure 9-11 shows the organizational structure for surface water treatment in the Bulk Water and Wastewater Division of the Western Australian Water Corporation. These personnel are responsible for operation of five surface water treatment plants. Groundwater plants are managed according to a different structure.

Plant Operations

The plant is fully automated and mostly unattended. One supervisor, who shares duties across five treatment plants, spends approximately one day each week at the plant. Three operators are available approximately 40% of the week. Maintenance and laboratory duties are contracted out. Operators hold a level II designation, based on in-house training. Approximately 32 hours of in-house training were completed in 1999. Table 9-41 shows the normal weekday operator shift schedule. It also shows the total person-days required to operate the plant daily.

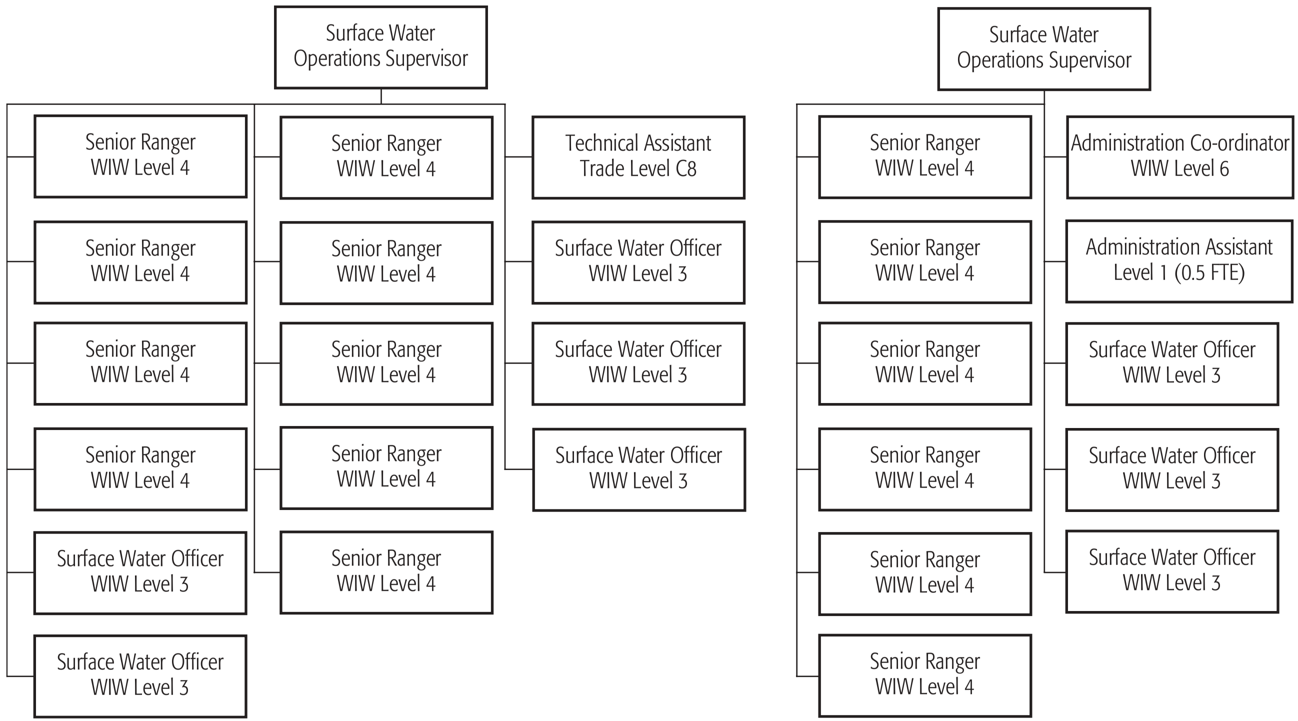
Role of Technology in Plant Operations

The major use of technology in the plant is automated plant operation. The plant also uses computerized maintenance management and geographic information systems. Operational data storage and water quality management systems are also in place.

Table 9-41 Weekday Personnel Complement – Serpentine WTP

Plant staff	Total	Scheduled		Estimated
	(no. staff day)	(no. staff day)	(no. staff night)	(person-days per day)
Supervisor	1	0.2	0	0.2
Operators	3	0.4	0	1.2
Total	**4**	**0.6**	**0**	**1.4**

Figure 9-11 Water Production Organization – Western Australia Water Corporation



Emergency Response Plans

Warning alarms shut down chemical feed systems rather than the complete water supply. High fluoride-ion level, chlorine leaks, and fluorosilicic acid leaks initiate alarms that close down the chemical feeds. Chlorine alarms relating to supply cause changeover to the standby chlorinator. If the standby chlorinator fails to operate at any time before the normal operating chlorinator returns to service, the dosing system shuts down.

Manual shutdown in response to alarms is available for the chlorination and fluoridation systems. The plant operating manual contains chlorine emergency response procedures, fluorosilicic acid emergency response procedures, and procedures for other high-risk conditions such as fires. Plant supervisors and operators have full authority – through liaison with the Water Distribution Control Centre – to close down either a specific process or the complete plant.

Plant Security

Sign-in procedures control general plant access. Access to the process areas is limited to visitors accompanied by a staff member.

Quality Management and Best Management Practices

The Serpentine Pipehead treatment plant is operated according to the procedures documented in the divisional water quality management system, which addresses water quality management and procedures for treatment. A designated quality manager reports to the general manager of the Bulk Water and Wastewater Division.

The plant uses in-house and contracted laboratory services. In-house facilities are not accredited, but those used by contract are. The plant does not yet have ISO designation, but it is an objective for 2001. Through formal workshops, the Water Corporation has undertaken risk assessments on factors that could affect water quality and safety:

- review of all schemes from catchment to tap
- sanitary survey of catchments

- asset condition survey
- operational practices
- operator training and awareness
- review of sample results

Consumer interaction includes surveys of customer satisfaction, particularly with aesthetic water quality. The corporation also sponsors a conservation program and a water quality program.

Historical water quality data are used through systematic reviews to plot result trends, investigate causes of non-compliance, generate "risk reports," and revise sampling programs. Plant benchmarking was completed between 1996 and 1999.

9.8.3 Local Standards and Enforcement

A licence issued through the Office of Water Regulation governs the Water Corporation. This licence contains standards for, among other things, drinking water quality (the 1987 Australian Drinking Water Guidelines), pressure and flow of water, response standards, complaints handling, and response to customer calls. All connections are metered, and water losses total 11%.

9.8.4 Cost of Production

The annual cost of water production in 1999 was A\$0.014/m^3 (C\$0.012) for a total production of 30,807,000 m^3 (see table 9-42).

9.9 Wanneroo Water Treatment Plant – Western Australia

9.9.1 Role of Technology

General Description

The Wanneroo Water Treatment Plant is one of several plants that supply treated water to Perth, the capital of Western Australia. The city receives treated water from a combination of surface water and groundwater sources. The Wanneroo plant is operated by the Water Corporation. In 1999 it delivered an average of 130 ML/d, which is approximately equivalent to a population of 330,000 million based on an overall per capita consumption of 390 L/d. Its maximum day production in 1999 was 230 ML.

The plant provides rapid chemical mixing, combined flocculation and clarification, filtration, chlorine disinfection, and fluoride addition (see figure 9-12).

Raw-Water Supply

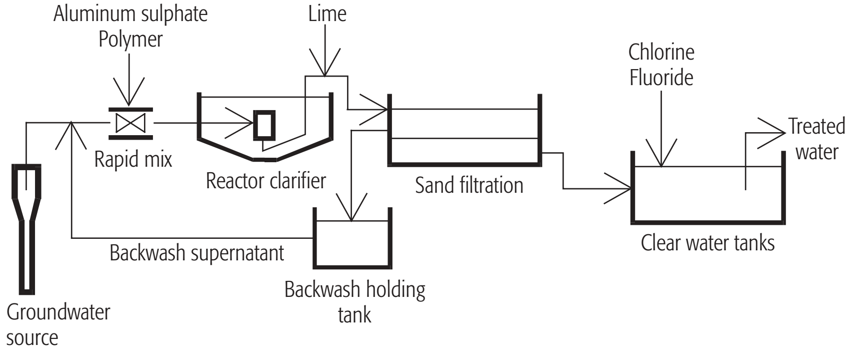
The Wanneroo plant uses groundwater wells for its source water. The raw water is monitored continuously for turbidity and pH. Grab samples provide

Table 9-42 Water Production Costs – Serpentine WTP, 1999

	Total cost (A$)	Unit cost (A$/m³)
Electrical power	12,000	0.00039
Chemicals	110,840	0.00360
Sampling & analysis	10,000	0.00032
Direct labour	100,000	0.00325
Corporate charges	30,000	0.00097
Contracted services	130,000	0.00422
Debt repayment		
Other	50,000	0.00162
Total	**442,840**	**0.01437**

Note: A$1 = C$0.833

Figure 9-12 Wanneroo Water Treatment Plant Process Layout



microbiological data, and a streaming current meter is used continuously on the incoming plant flow. Raw-water turbidity ranged from 10 to 22 NTU in 1999, averaging 16 NTU. This level is unusual for groundwater; however, the source is located in a relatively shallow water table close to a pine-treed area. The source is also reflected in the higher-than-expected colour in the raw water, which measured up to 121 colour units (see table 9-43). In fact, these parameter levels are more typical of surface water quality; consequently, the plant must apply treatments not normally necessary for a groundwater source.

Coagulation/Flocculation/Sedimentation

The Wanneroo plant uses three reactor-type clarifiers to combine the processes of coagulation, flocculation, and sedimentation (see table 9-44). This is normally achieved by contacting the water, after addition of coagulant, with a suspended solids blanket in the clarifier to promote flocculation and settling. In addition to the aluminum sulphate (alum) coagulant, a polymer is added to enhance coagulation. To combat the effects of the relatively high dosages of alum (which reduces pH considerably), lime is added to adjust pH. The applied alum dosage

Table 9-43 Raw-Water Quality – Wanneroo WTP, 1999

Parameter	Avg	Min	Max
Turbidity (NTU)	16	10	22
Colour (TCU)	97	77	121

Table 9-44 Sedimentation Facility – Wanneroo WTP

Type	conventional reactor clarifiers
Number of tanks	3
Rise rate	3.5 m/hr. average
Total surface area	900 m^2
Retention time	120 minutes
Sludge removal	mechanical automated on time
Sludge disposal	to drying lagoons
Settled water sampling	grab
Sludge sampling	grab

ranged as high as 110 mg/L in 1999, exceptionally high for a groundwater source. Operators determine the required alum feed rate based on jar tests conducted on an as-required basis. See table 9-45 for 1999 dosages of these three chemicals.

Filtration

The plant uses 12 declining-rate filters for final particle removal. The filters are multi-media and operate within the loading rates normally expected for rapid sand filtration. Turbidimeters measure filtered water turbidity continuously on each filter discharge. Filter head loss is also measured continuously. See table 9-46 for details of the filters.

A 3 m head loss through the media initiates backwashing on a filter. The backwash pump supplies cleaning water at 388 L/s for (typically) six minutes to dislodge retained debris from the media. Waste backwash water discharges to a backwash holding tank and returns, after settling, to the plant headworks. Filters do not have a filter-to-waste period. See table 9-47 for a summary.

Table 9-45 Raw-water Chemical Dosage – Wanneroo WTP, 1999

Chemical (mg/l)	Avg.	Min.	Max.
Alum	65	50	110
Polymer	0.6	0.4	0.9
Lime (for pH adjustment)	17	15	25

Table 9-46 Filtration Facility – Wanneroo WTP

Type	declining-rate rapid sand		
Number of filters	12		
Filtration rate	12.5 m/hr.		
Total surface area	750 m^2		
Water depth over media	2 m		
Layer	1	2	3
Type	other	sand	gravel
Depth	650 mm	300 mm	150 mm
Effective size	1.3 mm	0.6–0.8 mm	9.0 mm

Disinfection

Chlorine gas (Cl_2) is used to disinfect the water before transfer to Perth. It is injected into the discharge water stream at a rate proportional to plant flow rate. Because the treated water has one to two days' residence in a service reservoir before consumption, contact time is well beyond that required to meet CT levels that ensure good micro-organism kill. Chlorine residual is monitored continuously on line. See table 9-48 for chlorine addition and residual.

Fluoridation

Hydrofluorosilicic acid is added at a dosage proportional to flow rate (see table 9-49).

Treated Water Monitoring

Chlorine residual, pH, and turbidity are monitored continuously. Microbiological grab samples for *E. coli* and total coliforms (TC) are taken from the treated water.

Table 9-47 Filter Backwash Operation – Wanneroo WTP

Initiation	head loss >3 m
Rate	388 L/s
Termination	auto elapsed time
Duration	6 min
Disposal	to recovery tank

Table 9-48 Disinfection Dosage and Residuals – Wanneroo WTP, 1999

	Avg.	Min.	Max.
Chlorine addition (mg/L)	0.70	5.5	9.0
Chlorine Residual (mg/L)	5.5	3.5	7.0

Table 9-49 Fluoride Dosage – Wanneroo WTP, 1999

Source of fluoride	Avg.	Min.	Max.
Hydrofluorosilicic acid (mg/L)	0.85	0.7	0.90

Treated Water Quality

Treated water quality from the plant meets Australian drinking water guidelines for the parameters reported, except for chlorine residual, which at the average reported value of 5.5 mg/L exceeds the health-related 1996 guideline value of 5 mg/L (the aesthetic guideline value is 0.6 mg/L). However, the plant treats a difficult groundwater that frequently exerts a significant chlorine demand. Table 9-50 shows treated water quality.

9.9.2 Plant Operations

Plant Coverage

Full plant coverage is provided 24 hours a day. One plant manager, one supervisor, and one operator are always on duty, and shifts change after 12 hours. Maintenance duties are contracted out, and laboratory testing is shared between the plant and an outside laboratory. Operational testing is done at the plant, but accredited tests must be performed at the commercial laboratory. The plant is fully automated and is unattended most of the time. One supervisor who shares duties across five treatment plants spends approximately one day per week at the plant. Approximately 300 hours of in-house training were completed in 1999. See table 9-51 for details of the weekday shift coverage at the plant.

Table 9-50 Treated Water Quality – Wanneroo WTP, 1999

Parameter	Avg.	Min.	Max.
Turbidity (NTU)	1.1	0.79	1.8
Colour (TCU)	6	1	–
pH	6.6	6.2	6.8
Chlorine residual (mg/L)	5.5	3.5	7.0

Table 9-51 Weekday Personnel Complement – Wanneroo WTP

Plant Staff	Total	Scheduled		Estimated
		(no. staff day)	(no. staff night)	(person-days per day)
Plant Manager	1	1	1	2
Supervisor	1	1	1	2
Operators	1	1	1	2
Total	**3**	**3**	**3**	**6**

Role of Technology in Plant Operations

Although the plant has limited automation, a computerized maintenance management system and a geographical information system are in place.

Emergency Response Plans

Chlorination alarms cause plant or process shutdown. Emergency response procedures are also in place for chlorine leaks, fluorosilicic acid spills, quantity and quality problems, and environmental incidents. No one on site can shut down the plant without approval.

Plant Security

Sign-in procedures control general plant access, and doors to the process and administration areas are alarmed.

Quality Management and Best Management Practices

The Wanneroo treatment plant is operated according to the procedures contained in the divisional water quality management system, which addresses water quality management and procedures for treatment. A designated quality manager reports to the general manager of the Bulk Water and Wastewater Division.

The plant uses in-house and contracted laboratory services. In-house facilities are not accredited, but those used by contract are. The plant does not yet have ISO designation. Through formal workshops, the Water Corporation has undertaken risk assessments of factors that could affect water quality and safety:

- review of all schemes from catchment to tap
- sanitary survey of catchments
- asset condition survey
- operational practices
- operator training and awareness
- review of sample results

Consumer interaction includes surveys of customer satisfaction with respect to the aesthetic quality of the water. The corporation also sponsors a conservation program and a water quality program.

Historical water quality data are used through systematic reviews to plot result trends, investigate causes of non-compliance, generate "risk reports," and revise sampling programs. Plant benchmarking was completed within the last three years.

9.9.3 Local Standards and Enforcement

A licence issued through the Office of Water Regulation governs the Water Corporation. This licence contains standards for, among other things, drinking water quality (the 1987 Australian Drinking Water Guidelines), pressure and flow of water, response standards, complaints handling, and response to customer calls. All connections are metered. Water losses total 11%.

9.9.4 Cost of Production

The annual cost of water production in 1999 was A$0.117/m^3 (C$0.097) (see table 9-52).

Table 9-52 Production Costs – Wanneroo WTP, 1999

	Production cost (A$/m^3)
Electrical power	0.0548
Chemicals	0.0368
Sampling & analysis	
Direct labour	0.0056
Corporate charges	
Contracted services	0.0158
Debt repayment	
Other	0.0044
Total	**0.1174**

Note: A$1 = C$0.833

9.10 Implications of Case Studies

9.10.1 Role of Technology

Large-Scale Water Treatment Facilities

Except for the Serpentine Pipehead Dam WTP, all the large-scale treatment plants examined in this chapter need well-operated treatment technology to produce high quality drinking water.

The best performing plants continue to rely on processes that have been established for many years. What is new, however, is the improved level of treatment made possible by enhanced operations procedures and improved monitoring and control instrumentation. In this regard, the E.L. Smith plant in Edmonton is particularly noteworthy. Although raw-water turbidity reached a maximum of 500 NTU and averaged 54 NTU in 1999, the plant discharged treated water with turbidity no greater than 0.11 NTU and an average of 0.04 NTU. The Canadian drinking water quality guideline for maximum acceptable turbidity concentration is 1 NTU.[205] Similarly, colour removal at the plant is impressive: from a maximum raw-water value of 100 TCU and an average of 13 TCU to a maximum treated value of 2 TCU and an average of 1 TCU. The Canadian aesthetic objective for treated water colour is ≤15 TCU.[206] To achieve this level of treatment, the E.L. Smith WTP incorporates an innovative coagulant feed system, adds powdered activated carbon, exercises relatively low filter loading rates, and uses a dedicated particle counter on each of 12 filters. Clarification and lower filtration rates also promote removal of *Giardia* cysts and *Cryptosporidium* oocysts, forming part of a multiple-barrier control. *Cryptosporidium* in particular is recognized as a potential problem for Edmonton drinking water, as the North Saskatchewan River shows very high concentrations of the parasite. Chlorine disinfection completes the CT disinfection requirements of the Alberta Standards and Guidelines for Municipal Waterworks.

Although the source water is not as challenging as Edmonton's, treatment achieved by Toronto's F.J. Horgan WTP is also outstanding. In 1999 the plant reduced raw-water turbidity from a maximum of 30 NTU and an average of 0.4 NTU to a maximum treated value of 0.18 NTU and an average of 0.05 NTU. Colour,

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[205] Canada, Health Canada, 1996, *Guidelines for Canadian Drinking Water,* 6th ed. (Ottawa: Supply & Services Canada).
[206] Ibid.

though also less of a problem, was reduced from 2 NTU (maximum and average) to 1 NTU. With its more stable raw-water quality, the F.J. Horgan WTP does not include sedimentation in its treatment sequence, relying on chemically aided filtration for turbidity and colour control and partial micro-organism removal. The operations staff maintain good filtration control and have also incorporated innovative technology such as particle counters and multi-port head loss indicators on two filters. The plant does not use filter-to-waste after backwashing to control potential initial turbidity spiking or elevated pathogen concentration in the treated water, but based on the treatment achieved it may not be necessary.

The McCarron WTP in Minnesota depends on several less common treatment technologies to combat high taste, odour, and colour in its raw-water source. They include addition of ferric chloride at several raw-water pumping stations, installation of aerators on two of the lakes, and addition of potassium permanganate at the treatment plant. The plant discharges very low turbidity drinking water (maximum 0.29 NTU, average 0.04 NTU). Treatment of colour achieves the required standard although both the average and maximum values (10 TCU and 12 TCU) are close to the EPA secondary maximum contaminant level of 15 TCU.

The Australian case studies provide an interesting contrast. The raw surface water source for the Serpentine plant exhibits characteristics normally expected of a groundwater source, whereas the groundwater source for the Wanneroo plant shows a quality similar to surface water. Consequently, the Serpentine plant does not rely on treatment technology other than chlorination and fluoridation. The raw – and final – turbidity of 2.4 NTU maximum and 0.8 NTU average is higher than that that in water discharged from the other case-study plants, but it is within the 5 NTU limit of the Australian drinking water guidelines. Similarly, colour in the raw and treated water readily falls within the guideline values. The most immediate difference between the treatment approach at the Serpentine plant and an equivalent in Ontario is that an Ontario plant would be required to provide a minimum of chemically aided filtration to treat a surface water. However, Australian experience has shown that long residence times in raw-water reservoirs, coupled with prolonged exposure to sunlight, allows natural ultraviolet radiation to reduce pathogen concentration significantly.

The Wanneroo plant treats a groundwater source that in Ontario would likely be abandoned. However, water resources are considerably scarcer in Western Australia. Turbidity in the raw water ranges between 10 NTU and 22 NTU, and colour ranges between 77 TCU and 121 TCU. Consequently, the plant incorporates treatment processes normally reserved for surface waters. Coagulation, flocculation, clarification, and filtration reduce turbidity to an average of 1.8 NTU and colour to an average of 6 TCU. Thus, technology plays a strong role in treatment at this plant.

Small-Scale Water Treatment Facilities

The town of Prescott's completely automated treatment plant relies exclusively on technology to provide high quality drinking water. This includes a feedback control system for chlorine and fluoride addition (the alum coagulant feeds at a constant rate). Plant throughput, which responds to both the level in the reservoir and the variation in demand rate, is also automated. Although the St. Lawrence River raw water is of high quality, the treatment plant further reduces turbidity level from 0.59 NTU maximum and 0.3 NTU average to an average of 0.06 NTU. Colour in the raw water, at less than 1 TCU, is low and remains essentially unchanged after treatment. The plant's emergency control system is also automated, incorporating direct phone contact with the operators whenever required.

The Camptonville WTP in California is significantly smaller than the Prescott WTP and, while much of its operation is automated, plant operation is considerably less sophisticated. This seems an appropriate response to the raw-water quality and the low water demand. Plant throughput is controlled hydraulically in response to demand, and disinfection dose is adjusted manually by the operators.

Commentary

The case studies show that technology plays a crucial role in providing high quality treated water. Most of this technology is not new – coagulation, flocculation, and filtration have been used for many years in conventional water treatment plants. Adding powdered activated carbon for taste and odour control is also a frequently used strategy. The success of the high-performance plants is more a reflection of how modern methods of process control have optimized performance of technology. Installation of dedicated particle counters as a control device on each filter in the E.L. Smith plant, for example, has moved turbidity removal to levels that are at least 25 times better than required standards. The control strategy at the F.J. Horgan plant in Toronto produces similar results. It should also be recognized that these plants have set themselves performance objectives much stricter than guideline parameter values.

This level of physical and chemical treatment not only produces aesthetically pleasing water, but also provides a significant level of protection against microbial contamination. In fact, the latest US regulations rely on turbidity removal as the only effective control method for *Cryptosporidium* oocysts. The performance of the Prescott WTP shows that this level of treatment is also available for smaller systems, with the additional advantage of complete automation.

9.10.2 Plant Operations

Large-Scale Water Treatment Facilities

Each of the large plants examined provides 24-hour operator coverage, and each of the parent utilities is dedicated to operator certification. The F.J. Horgan WTP, operated by the city of Toronto, has a total of 16 managers, supervisors, and operators, of whom13 hold operator certification. All except one gained certification through examination, and this operator was scheduled to take the exam in 2001. This suggests a strong commitment to having the plant operated by personnel trained in both the practice and theory of water treatment. The plant has well-established procedures in place for plant shutdowns in response to water-quality or other emergencies. Except for the automated shutdown procedure on the chlorination system used to control zebra mussels in the incoming raw water, a plant operator must initiate all shutdowns. The city prefers not to rely on automated plant shutdowns, but rather to depend on the operators' judgment. Plant process shutdown and emergency procedures are defined in the plant's operating manuals.

The E.L. Smith plant is operated by EPCOR Water Services Inc., which is a division of EPCOR Utilities Inc., a corporation of which the City of Edmonton is the sole shareholder. The plant has a total of 16 operators, all of whom are certified. Edmonton's philosophy on shutdowns is the opposite of Toronto's. EPCOR depends on a plant control system to shut the plant down automatically if predetermined set-point values are exceeded for particle counts, turbidity, pH, fluoride, or chlorine. Personnel have a detailed emergency procedures manual available at the plant. They have also developed, with Alberta Environment, a comprehensive boil order emergency protocol to respond to potential microbial contamination of treated water. All levels of treatment plant operators have the authority to shut the plant down in the event of water-quality or other emergencies.

Saint Paul Regional Water Services operates the McCarron WTP in Minnesota. It is interesting to note that the Board of Water Commissioners, which governs the utility, includes two Saint Paul residents to represent the public interest. The plant maintains a total compliment of 43 staff, including one plant manager, five supervisors, and ten operators.

The Serpentine Pipehead Dam WTP, which treats surface water for Perth, Western Australia, is fully automated and mostly unattended – the only treatments applied are chlorine and fluoride addition. Plant programming will shut down chemical feed systems in response to high fluoride levels, chlorine leaks, or fluorosilicic acid leaks. Plant operation is the responsibility of a supervisor who divides his duties among five surface water treatment plants. Three additional operators are available for approximately 40% of the week. The operators hold level II certification, obtained through in-house training.

The Wanneroo WTP, which treats a challenging groundwater source, is attended 24 hours a day. A plant manager, a supervisor, and an operator are on duty at all times; each works a 12-hour shift. Maintenance duties are contracted out, and the plant shares testing duties with a private laboratory. Alarms for chlorine leaks cause dosing shutdown. Emergency response procedures are in place for chlorine leaks, fluorosilicic acid spills, quantity and quality problems, and environmental incidents.

Small-Scale Water Treatment Facilities

As noted previously, operation of the Prescott WTP is almost completely automated. The operation is overseen by two level III operators, who received their certification through a combination of experience and MOE training courses. Automation at the plant has reduced full-time coverage to a two-operator, eight-hour shift during weekdays. This reduces to a one-operator, eight-hour shift at the weekends. The town relies on the automated control system to notify the operators of any emergency conditions. The operators then decide on the most appropriate response, including plant shutdown if necessary.

Operational requirements are minimal at the Camptonville WTP in California. Typically, it takes no more than 15 minutes to complete normal daily checks at the plant.

Commentary

Each of the case-study plants is overseen by certified operators. The F.J. Horgan, E.L. Smith, and Wanneroo plants all provide 24-hour operator coverage. The smaller plants provide less coverage because plant operation is constant, raw-water quality is predictable, or automation is sufficiently developed to respond to exceptional circumstances.

Overall automation of treatment plant operations is becoming more significant as instrumentation and computerization improve. Both the E.L. Smith and the Prescott treatment plants rely on automated shutdowns in cases of emergency. The F.J. Horgan plant, on the other hand, relies primarily on direct operator intervention to shut down unit process or complete production in cases of emergency.

9.10.3 Local Standards and Enforcement

Large Scale Water Treatment Facilities

The F.J. Horgan WTP meets all the requirements of the Ontario drinking water standards (revised Jan. 2001). In accordance with regulatory requirements, quarterly reports of Toronto water quality are posted on the city's Web site.[207] These results indicate that the treatment level provided by the F.J Horgan plant is exemplary. Similarly, E.L. Smith water met all regulatory requirements as outlined in Potable Water Regulation of Alberta's *Environmental Protection and Enhancement Act.* EPCOR posts annual water quality data for Edmonton on its Web site.[208] Monthly updates are also provided.

The McCarron WTP in Saint Paul meets or exceeds the requirements of the U.S. federal *Safe Drinking Water Act.* In the past, lead concentration occasionally failed to meet the required standard, but changes to the corrosion control strategy and replacement of lead services have brought the utility into compliance.

Both of the Australian treatment facilities examined are governed by on operating license issued to the Water Corporation by the Office of Water Regulation. This licence covers water quality through adoption and enforcement of the 1987 Australian drinking water guidelines. It also stipulates, among

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[207] <www.city.toronto.on.ca/water/>.
[208] Alberta, Alberta Environment, 1997.

others, minimum requirements for pressure, water flow, response standards, complaints handling, and response to customer calls. The Serpentine Pipehead Dam WTP and the Wanneroo WTP meet all of the licence provisions.

Small-Scale Water Treatment Facilities

The Town of Prescott is obliged to meet the Ontario drinking water standards (revised January 2001). To date, treatment at the plant meets all stipulated requirements. Similarly, the Camptonville WTP in California meets the stipulated requirements of the *Safe Drinking Water Act.*

Commentary

Although water supply standards worldwide are continually improving, it is apparent that well-equipped and well-operated treatment facilities usually have little difficulty in meeting their provisions. In fact, the ability of normal operating processes to meet mandated parameter values is a factor considered explicitly by the EPA when setting standards in the United States. The large Canadian plants in particular have set, and meet, operational objectives that are well in excess of those required by their operating licences.

9.10.4 Costs

Table 9-53 summarizes the cost of water production at each of the facilities examined. Costs are in Canadian dollars.

Table 9-53 Summary of Water Production Costs at Case-Study Facilities

Facility	Production cost ($/m^3)
F.J. Horgan WTP	0.10
E.L. Smith WTP	0.509
McCarron WTP	0.15
Prescott WTP	0.196
Comptonville WTP	0.13
Serpentine Pipehead Dam WTP	0.012
Wanneroo WTP	0.097

Of the North American facilities, production cost was lowest at the F.J. Horgan plant. E.L. Smith showed the highest production cost, which reflects increased costs associated with treatment of a more difficult source water. A similar relationship was evident with the Australian plants where the Serpentine plant had very low production cost and the Wanneroo plant, which treats a difficult water, had significantly higher production costs.

Production costs at the smaller treatment facilities were between 50% and 100% greater than at the F.J. Horgan WTP. This shows an expected economy of scale, since larger operations can often obtain reduced costs for chemicals, etc., based on greater consumption.

10 Considerations for the Ontario Drinking Water Supply

10.1 Standards

10.1.1 Standards in General

The public depends on water suppliers to provide drinking water that is of high quality and safe to consume. Because most people are unfamiliar with water treatment and have no basis on which to judge its quality, government regulators issue standards that define and regulate drinking water quality. Water that meets these standards is considered safe for consumption. Drinking water standards define not only what can be tolerated in water, but also the frequency with which it must be sampled, the quality of its source, the treatments that must be applied, and the steps that must be taken to ensure that it remains safe after it leaves the treatment plant. Standards may also define minimum levels of service (flow, pressure, etc.) that must be provided.

A distinction should be made between standards and their implementation. Often, an early reaction to adverse water supply incidents is a call for tougher standards and more regulation. Implicit in such demands is an assumption that existing standards are deficient. Generally, they are not. Most water supply incidents result from a lack of knowledge of correct procedure or ignorance of the consequences of incorrect procedure. Thus, the problem more often lies in compliance with the standards than in the standards themselves. Conversely, no matter how high standards of water quality, treatment, or training are set, they do not guarantee that supply will be error-free unless they are followed rigorously at all times.

As noted in chapter 4 of this paper, natural water is never pure. As a result of contact with its natural surroundings, water contains a variety of compounds and microbial life, some of which are harmful and must be removed. Water quality standards generally address drinking water impurities under the headings of physical and chemical parameters, radiological quality, and microbiological quality.

10.1.2 Ontario Drinking Water Standards

In August 2000 the Government of Ontario adopted *Ontario Drinking Water Standards,* which replaced the previous guidelines used by the Ministry of the Environment. The standards, which are legally enforceable throughout the province, were revised in January 2001. In many respects Ontario is in the forefront of drinking water regulation. The provincial drinking water standards not only deal with the quality of drinking water in the province but also regulate water utility infrastructure, testing and analysis, and provision of information to the public.

10.1.3 Contrast with Standards and Regulations in Other Jurisdictions

Microbiological Standards

Examination of standards worldwide reveals little difference in what is considered acceptable for physical and chemical contaminants. Neither do the acceptable radiological concentrations vary greatly. However, the approach to guaranteeing microbiologically safe water does differ significantly between jurisdictions. In all cases, treatment for microbiological safety involves removing or inactivating pathogens. Conventional water treatment procedures, particularly disinfection, are highly effective in protecting against bacteriological contamination. But they must be applied correctly. A much greater challenge to safe water is presented by microbial pathogens – including viruses and protozoa such as *Giardia* and *Cryptosporidium* – that are considerably more resistant to common disinfectants. These pathogens have been responsible for many outbreaks of illness worldwide and are considered a health threat, particularly to immuno-compromised populations. Ontario has adopted the CT approach (see section 4.3.4) and some of the EPA Surface Water Treatment Rule provisions for inactivation of *Giardia* and viruses. Standards have not been included for inactivation of *Cryptosporidium.*

Viruses and Giardia *Ontario Drinking Water Standards* (ODWS) includes tables of CT values for inactivation of *Giardia* cysts and viruses under various conditions of temperature, pH, and disinfectant residual. These tables, which are reproduced from the EPA Surface Water Treatment Rule, are applicable only for chlorine disinfection.[209] Even though OWDS notes that “the use of disinfectants such as ozone, chloramines, chlorine dioxide, and ultraviolet radiation is increasing in Ontario,” it does not provide CT tables for these disinfectants. Such tables are available and form part of the Surface Water Treatment Rule.[210] Given that ozone and chlorine dioxide are effective in the

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[209] United States, Environmental Protection Agency, 1989, *National Primary Drinking Water Regulations: Filtration, Disinfection, Turbidity,* Giardia lamblia, *Viruses, Legionella, and Heterotrophic Bacteria; Final Rule,* Federal Register 54(124):27485-27541.

[210] American Water Works Association, 1991a, *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (Denver: AWWA).

control of *Giardia* and viruses, and have also shown promise for inactivation of *Cryptosporidium*, these powerful disinfectants will likely receive greater attention in the province. It is therefore surprising that OWDS did not provide greater guidance for their application to control at least *Giardia* and viruses.

Cryptosporidium New Zealand has adopted CT values for *Cryptosporidium* inactivation, but only with chlorine dioxide or ozone disinfection.[211] The U.S. approach to *Cryptosporidium* control has been to limit drinking water turbidity. The draft Enhanced Surface Water Treatment Rule notes that rapid sand filtration that reduces turbidity to 0.3 NTU or less in at least 95% of samples each month, and to at most 1 NTU in the remaining 5%, would achieve at least a 2-log removal of *Cryptosporidium*.[212]

Perhaps the strictest approach to *Cryptosoridium* regulation is that adopted in England and Wales (see section 7.3). The Water Supply (Water Quality) (Amendment) Regulations 1999 require water providers to examine their supply systems to determine whether a significant risk of distributing waterborne oocysts exists. If such a risk is deemed to exist, the supplier must install treatment that ensures the average concentration of oocysts in the treated water is no more than 1 per 10 litres. It must also install on-line sampling equipment to sample a representative flow of no less than 40 litres per hour. Samples must be analyzed daily, and the results must show that the average oocyst concentration remains at less than 1 oocyst per 10 litres. The regulations note that, to meet the requirements, a treatment must be able to remove particles with a diameter greater than 1 micron, be continuously monitored, and be able to be taken off-line in the event of an emergency. Failure to meet these provisions can lead to a fine.

Directives of the European Union do not deal specifically with removal of either *Giardia* or *Cryptosporidium*. However, the Drinking Water Directive (98/83/EC) does require member states to address parameters not specifically listed if required to protect human health.

The approaches of New Zealand, the United States, Britain, and the European Union, while different, acknowledge that control of *Cryptosporidium* is necessary

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[211] New Zealand, Ministry of Health, 2000, *Drinking Water Standards for New Zealand 2000* [online], [cited December 2000], <www.moh.govt.nz/moh.nsf>.
[212] United States, Environmental Protection Agency, 1998b, *National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment; Final Rule* [online], 40 CFR Parts 9, 141, and 142 [cited December 2000], <www.epa.gov/OGWDW/mdbp/ieswtrfr.pdf>.

and that such control should be included in the national drinking water standards of these countries.

ODWS does note that "it is desirable that no virus or protozoa (e.g., *Giardia, Cryptosporidium*) be present in drinking water." Nevertheless, it does not specifically address *Cryptosporidium* removal. Because control of *Cryptosporidium* is probably the most challenging task that faces water treatment facilities in the province it, will be necessary to follow the lead of other jurisdictions and consider methods for its inactivation. Ontario will likely have to implement strict standards to minimize the potential for disease caused by this parasite and ensure that the safest possible drinking water is available to the public.

Groundwater under the Influence of Surface Water

The EPA Surface Water Treatment Rule subjects groundwater sources under the direct influence of surface water to the same provisions as surface water sources. Such sources must meet surface water treatment requirements and have the same level of disinfection control. In the past there has been some uncertainty as to what constituted groundwater under the influence of surface water. The EPA outlined a number of conditions to be examined in determining whether a particular source should be considered a groundwater under the influence of surface water.[213] These conditions relate to well depth, well construction, distance from surface water, water quality records, and particulate matter in the well. They enable a provider to predict, independently of the regulator, what treatments will be necessary for the water.

ODWS also states: "Ground water under the direct influence of surface water is considered to be surface water." It stipulates that treatment of such water must achieve a minimum 3-log removal of *Giardia* and a minimum 4-log removal of viruses. However, unlike the Surface Water Treatment Rule, ODWS does not outline the conditions under which groundwater should be considered groundwater under the influence of surface water.

Although this is a relatively minor issue that would likely be considered during approval, allowing the water supplier to make this determination beforehand and avoid the work and cost associated with the application process would

[213] American Water Works Association, 1991a.

be useful. Suppliers from existing sources should also be able to determine whether their sources require treatment equivalent to the minimum specified for surface water.

Water Resource Management

Watershed management is a broad topic that must be considered in relation to many activities, only one of which is drinking water abstraction. Effective management of watersheds also requires the cooperation of the various stakeholders. Nevertheless, the principle of source protection becomes crucial as science discovers new contaminants that represent a danger to health at ever decreasing concentrations. Such contaminants are often difficult to remove from water, and the treatments required to guarantee protection are expensive, challenging to operate, and not in widespread use. Eventually, the difficulty and costs required to remove contaminants become greater than those required to limit initial contamination of the source. In recognition of this fact, both the United States and the European Union have incorporated watershed protection requirements directly into their drinking water regulations and standards.

Modern water treatment has embraced the concept of multiple-barrier protection of drinking water. This concept relies on sequential application of barriers against contamination, particularly by microbial pathogens. Source management is the first of these barriers, yet it has not been sufficiently emphasized or incorporated into standards. Most of the other barriers – including chemically assisted filtration, disinfection, and continuing protection of water in the distribution system – have been stipulated by regulation.

Although a number of watershed management projects are currently underway in Ontario, ODWS does not formalize any requirements for a watershed management plan beyond noting that "water supply should be obtained from a source that is most likely to produce drinking water of a quality meeting the Ontario Drinking Water Standards and Policies." It does state that the "owner of the water works should conduct frequent surveys of impacts of pollution on the water source," but it does not specify the frequency or extent of these surveys. Ontario practice contrasts with the approach taken by the European Union, which has made river basin management and generation of a "programme of measures" central to its integrated water quality management (see chapter 6). Similarly, the EPA's Surface Water Treatment Rule outlines watershed protection provisions that are mandatory for supplies that do not filter and are recommended for those that do. The focus of these provisions is to control "detrimental activities" that can lead to increased concentrations of contaminants, particularly microbial, in water abstracted for drinking.[214]

As population, agriculture, and industrial growth continue to pressure water sources, the need to apply direct control over watersheds will become more apparent.

Conclusion

Ontario Drinking Water Standards is comprehensive and represents a significant improvement to provincial regulation. It is also well written and easy to understand. The limitations noted in this section are not insurmountable and, in the interest of providing clear direction to Ontario water suppliers, they should be addressed.

10.2 Operations and Quality Management

10.2.1 General

Chapter 3 presents the elements and practices that constitute a best-in-class utility or define best-management practice. They are the targets for which all Ontario water suppliers must aim. This section looks at those targets in the context of Ontario water supply. However, in considering how Ontario water supply can be elevated to the status of world leader, we must be careful not to discount Ontario water supply as it stands. An examination of data recently made available through quarterly reports reveals that many elements of Ontario's supply are definitely at the forefront and can meet the most exacting of quality standards.

A true definition of what constitutes a world leader is difficult to capture. It depends greatly on the criteria applied. For example, which is a world leader: a facility that produces drinking water whose characteristics are orders of magnitude better than the required standards, but at an exorbitant price, or a plant whose water just meets the standards but also minimizes consumer cost?

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[214] Ibid.

10.2.2 Large-scale Water Supply Facilities

Water Resource Management

The ultimate goal of water supply is to provide customers with as much clean and safe drinking water as they need, and at a reasonable cost. This can happen only if all elements of the supply train are well managed and well operated. Good supply begins with management of the water resource. As noted in the previous section, Ontario water utilities have not concentrated on source management to the same extent as those in other jurisdictions. This is not surprising, since 73% of Ontario consumers receive supply from the Great Lakes (see chapter 1), which offer a stable and plentiful source of high-quality water, and the International Joint Commission generally looks after their management.

Other sources can be less plentiful and often require more intense and more local source management. They also might supply several municipalities. Therefore, suppliers must plan water abstraction and its consequences. Their plans must consider both quantity and quality elements of supply. They must consider present and projected withdrawal rates and the subsequent effects on the source. They must protect source water from adverse effects of development in the catchment or recharge area, particularly industrial and agricultural expansion. They must also protect against contamination of the source, through a combination of buffer zones, controlled planning, and widespread education.

To establish the current status of the water source, water suppliers should also determine and report benchmark characteristics of the source, particularly its flow and its quality. (The new Ontario regulations require a characterization of the source water as part of the engineer's report). The supplier should then follow a defined schedule of follow-up examination and reporting of subsequent changes to the water resource. This examination should go beyond a simple chemical analysis of the raw water; it should at least include observations of flow changes, land use modifications, and industrial or agricultural development. The Ministry of the Environment should stipulate the frequency and extent of follow-up testing. Both the initial status report and subsequent examination reports should be made freely available to the public. This approach serves a two-fold purpose: protection of the source and protection of the abstractor, or supplier. The latter is important in cases where degradation of water supply does not result from the activity of the supplier.

The Ministry of the Environment, like the European Union, should then establish a registry of protected water sources in the province (see chapter 6).

Water Treatment

To achieve the status of world leader, Ontario must follow the highest standards of practice for water treatment and the operation of treatment facilities. Standards apply to design and construction of facilities, their management, their operation, and the budget required for each of them.

A well-managed water resource will deliver the best possible quality raw water to the treatment facilities. To be considered a world leader, treatment facilities must excel in

- treatment capability,
- treatment operation,
- maintenance of facilities, and
- staffing.

Treatment capability Each water treatment facility in the province must be able to meet the current needs of its community. Plant upgrades and expansions must be completed in time to meet future demands. These upgrades and expansions will include physical treatment capacity (intakes, clarifiers, filters, etc.), system storage (reservoirs), and delivery capability (pipe networks and pumping).

Treatment operation Treatment facilities must be controlled by operators properly trained with respect to the equipment and processes in use. Ontario Regulation 435/93 classifies facilities by a points system that acknowledges, among other things, the size and complexity of the operation, the quality of the raw water, and the extent of laboratory control. Facilities are rated class I, II, III, or IV. Operator licences are also rated class I to IV. The regulation demands that for any given classification of facility, the operator in charge must hold a licence of the same class or higher. However, in addition to holding the appropriate licence, operators must also undergo continual training, especially on new or upgraded equipment. Managers of the facility must also understand and accept the importance of highly trained operators to the success of treatment. These operators must be given the time and the resources necessary to ensure that they can complete their duties satisfactorily.

Facilities maintenance Water treatment utilities must adopt defined maintenance programs appropriate to specific equipment. Preventive maintenance programs are applicable to specific equipment operating time or periodic inspection; predictive programs consider major rotating equipment; and run-to-failure programs cover equipment that could be more economically run to failure than subjected to continuing maintenance.

Maintenance of equipment should be computerized and tracked, and the information made readily available.

Staffing Staff throughout a utility should be adequately trained for their duties. Training programs should be made available to help operators obtain required certification. As an ongoing policy, education must be encouraged and supported by management. Staff must also be compensated appropriately at all levels, and both management and staff should be extended the opportunity, through performance reviews, to express and deal with concerns or difficulties.

A best-in-class utility will ensure good retention and recruitment of staff by pursuing equal opportunity and equal treatment policies. It will also take steps to ensure that staff are aware of these policies, and it will extend opportunities for open discussion with management.

Water Distribution

To achieve world-leader status, Ontario water distribution systems must provide a continuous supply at adequate pressure. Fire-flow capacity should be sufficient to allow preferred fire insurance rates for local homeowners and businesses. To reduce customer inconvenience and traffic interruption, maintenance, repair, and upgrading of distribution system elements should be well coordinated with other utilities that have buried services in the area.

Distribution systems in the province should have sufficient storage provision for pressure balancing, peak demands, fire protection, and other emergency needs. Maintaining quality of water in the distribution system is critical. Steps to ensure this will include the provision of adequate disinfectant residual (as required by the Ontario drinking water standards), comprehensive sampling and analysis, and monitoring of flows and pressures. Inadequate disinfectant residual in the distribution system can result in contamination of treated water by pathogens resident on the pipe walls or through infiltration of poorly sealed joints.

Other Recommended Practices

Chapter 3 gives a comprehensive examination of other best practices that should be adopted in Ontario water supply. Achieving the aim of being a world leader will require adoption of as many as possible of those practices.

10.2.3 Small-scale Water Supply Facilities

Many of the best-in-class and best management practices discussed in relation to large-scale water facilities also apply to smaller water supplies. Smaller facilities tend to use groundwater as their raw-water source. In Ontario almost 250 supply facilities out of a total of approximately 600 supply groundwater to populations of fewer than 1,000 people. Groundwater tends to be of better initial quality, and is generally less prone to microbial contamination than surface water sources.

The majority of small-scale systems in Ontario are municipally owned and operated, partially the result of downloading of the responsibility and ownership of water supply systems from the province to municipalities in the 1990s. This situation could change with the increasing trend toward privatization of public services.

Problems Facing Small-scale Systems

Perhaps the main problem that smaller facilities have to deal with is funding. Small communities, particularly those in non-metropolitan areas, often have lower per capita incomes, higher unemployment, and less access to capital for loans. Combined with the obviously smaller ratepayer base, the cost of water production per capita can be significantly higher than in larger centres. Although some funding is available from the province for facility improvement, smaller communities often do not have the financial freedom to invest in extensive process testing to improve plant performance, or to pay for ongoing professional advice.

Even with higher water rates, small facilities will have difficulty complying with more exacting regulations for microbial and chemical contaminants. In the United States between 1992 and 1994, systems serving fewer than 500 people exceeded maximum contaminant levels more than twice as often as those serving populations greater than 10,000.

Finding and maintaining qualified operations and management personnel is also a challenge, both financially and otherwise, for small facilities. Adequate operator training is often unavailable or inaccessible due to expense of travel from remote areas and a lack of back-up personnel. Existing training programs quite often focus in detail on treatment and distribution only, and therefore might not meet the specific needs of small-system operators. A small-scale plant operator could be only one of a small number of employees at a utility and consequently might need to be skilled in numerous areas, including treatment, distribution, supply sources, metering, customer service, financing, and human resources.

Recommendations

Any effort to solve the problems facing small systems should focus on ensuring sustainable high-quality service. An effective system must have the technical, financial, and managerial capabilities to satisfy long-term public health and safety requirements.

Depending on a small system's proximity to other systems, physical interconnection with a larger system could be a restructuring alternative. This could involve the wholesale purchase of water from another facility or ownership consolidation. Another alternative, often referred to as satellite management, involves the cooperation of two or more systems with respect to sharing of some services. This could involve such arrangements as joint purchasing and sharing of operations and management services to provide the individual small systems with cost effective access to management, financial, and engineering expertise.

An important aspect of improving the operation of many small-scale systems is adequate operator training, which will require improvements in current training and certification methods for small-system operators. Training and certification programs must be made accessible to operators in remote areas and must focus on the skills that are important for these individuals to properly manage their facility. Programs should concentrate on processes employed by the operator's particular system rather than the technical aspects of numerous unrelated treatment technologies.

10.2.4 Private Drinking Water Supply Systems

Private, very small, or institutional suppliers that provide less than 50,000 litres per day, that do not have the capacity to supply 250,000 litres per day, and that serve five or fewer residences do not have to meet the provisions of the *Ontario Water Resources Act* or the Ontario drinking water standards (see section 2.3.1). The Ministry of the Environment is currently considering whether these facilities should be subject to licensing or whether they should have to meet specific sampling and analysis requirements for their water. Because they range from gas stations to campgrounds, and include stores, churches, motels, and restaurants, the total number that would fall under such regulations is unknown. The number of people who receive drinking water from such facilities is also unknown.

The ministry outlined a number of questions about regulating these facilities and elicited public input in a discussion paper released in August 2000.[215] The paper notes that local public health units throughout the province inspect restaurants, hospitals, daycares, and nursing homes. It also notes that service stations, boarding houses, churches, rental cottages, and stores without food service are not currently subject to inspection.

10.3 Training

Chapter 3 outlines many of the general goals and requirements for training of water supply personnel. It is not possible to make specific recommendations based on the number and classification of operators currently working in Ontario facilities. Although this information was requested, the Ministry of the Environment did not provide it. Therefore, the following deals with the general principles of treatment plant personnel training and its significance to provision of safe drinking water.

Along with demands for higher water quality standards, the initial reaction to adverse water supply incidents is often a call for better training, particularly of treatment plant operators. Yet operators produce millions of cubic metres of safe drinking water daily in the province without incident. This raises the questions, To what extent will adverse incidents occur as a result of chance alone? and How can training minimize the number of such incidents?

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[215] Ontario, Ministry of the Environment, 2000e, *Protecting Drinking Water for Small Waterworks in Ontario* [online], (discussion paper) [cited February 2001], <www.ene.gov.on.ca/envision/waterreg/Pibs4070.pdf>.

Some of the answers come from considering how a modern water treatment plant operates. The life of aircraft pilots has been described as 95% boredom interspersed with 5% sheer terror. Similar percentages might well be assigned to water treatment plant operation. The treatment technologies applied in most Ontario plants, both large and small, are capable of providing safe and clean drinking water consistently. When the quality of the source water is stable and the treatment process is working as designed, operation of a plant is relatively uneventful. Under these conditions plant automation is also relatively straightforward.

Any rapid change in the quality of raw water or in the operation of the treatment equipment, however, should be followed by a rapid and knowledgeable response from plant operators or from automated control, if installed. It is during circumstances of unexpected or unnoticed change that many treatment failures occur and during which it is crucial to have well-trained personnel in charge. These personnel must have a thorough understanding of water treatment procedures in general and of the operation of the plant and its equipment in particular. An operator must have the knowledge to apply corrective measures quickly and to recognize circumstances for which in-plant correction will be insufficient and for which it will be necessary to inform consumers and health authorities.

Thus, whether potentially dangerous situations are discovered by plant automation or by human operators, the response decision will require experience, judgment, and a thorough understanding of water treatment. It is a testament to modern water treatment that such incidents are relatively rare and that instances in which they remain uncorrected and cause harm are even rarer.

Unfortunately, it is also the rarity of harmful incidents that can lead to a false sense of security and the inference that ‘if it never happened before, it never *will* happen.’ The continuity of high-quality treatment in most treatment facilities also poses a challenge to administrators who oversee the appointment of operators. If treatment is easy and the intervention normally required is minimal, why is it necessary to have highly trained operators, especially if they cost more? This question can be particularly significant in small communities that require no more treatment than disinfection of groundwater.

In this regard the Ministry of the Environment has required that water facilities be operated by licensed operators. Unfortunately, some of the situations operators face can be beyond their training. This will become more apparent with the introduction of the updated Ontario drinking water standards, which require a good understanding of the CT approach to controlling micro-organisms – a relatively recent development. To ensure that operation of facilities, particularly those that lack scientific support, continues to produce safe water, operators must have a resource available from which they can readily obtain information and guidance.

This chapter later introduces the concept of a district water officer, who would be available to fulfil this role. If either this concept is pursued or the MOE returns to having field officers available to give advice, small communities will benefit greatly in reducing the risk of potentially dangerous process upsets.

10.4 Technology

Generally, two different kinds of demand drive development of water treatment technology. The first is the demand for methods to accomplish treatments or attain standards that were not previously required or considered possible. For example, the ability of membranes to remove *Giardia* cysts and *Cryptosporidium* oocysts physically from drinking water, by straining to the micron level, has greatly enhanced their application in the industry. Similarly, membrane or ion exchange processes can remove nitrates or very low level contaminants from groundwater. This ability has aided their development. Likewise, recent evidence that ultraviolet light is effective against *Cryptosporidium* has drawn attention to its application in drinking water treatment.

The second type of demand is for methods to improve on existing technology, in terms of performance, cost, or both. Particle counters for filter control, improved automation, and more sensitive instrumentation are examples of response to this demand.

The significance of technology development is determined to a large extent by the water resources available to suppliers. In situations where water is scarce, no choice exists but to purify poorer quality raw water and accept higher-cost premiums. The case study in chapter 9 from Wanneroo, Western Australia, demonstrates this situation, in which significant effort must go into purifying a lower quality groundwater. Extreme examples of this situation are seen in the countries of the Arabian Gulf in which reverse osmosis provides drinking water, at great cost, from seawater. Where water resources are plentiful, lower quality raw water is usually ignored in favour of alternative sources. In this case, treatment technology that can cope with exacting contaminants, present in the lower quality raw water, is not usually required.

Ontario, having some of the world's highest quality raw water, falls into the second of these categories. Although some areas of the province suffer from relatively poor water quality, they are few and usually have the option of alternative supplies. Consequently, the role of technology in Ontario is generally one of improvement of established treatments. The Ontario case studies examined in chapter 9 demonstrate that careful operation of established technologies produces very high quality drinking water. In the case of Prescott, a high level of automation in conjunction with good quality source water achieves treatment that well exceeds the Ontario drinking water standards. Similarly, plant operation, aided by individual turbidimeters and particle counters on the filters, helps the F.J. Horgan plant in Toronto achieve outstanding treatment. The E.L. Smith WTP in Edmonton demonstrates the concept very well. Although the plant uses treatment technology that was developed for the most part in the late 19th and early 20th centuries, it uses modern control and instrumentation technology to enhance performance and achieve a very good quality drinking water from a difficult source. It is therefore unlikely that treatment plants in Ontario that use conventional technology will undergo major change.

The only potential exception is in the area of microbial control. Concerns with disinfectant-resistant waterborne pathogens and potentially harmful disinfection by-products will promote more attention to physical removal methods or alternative disinfectants, and will likely bring attention to further development of membranes and ultraviolet disinfection, technologies in which Ontario is already considered a world leader.

The technologies that will help establish or maintain Ontario facilities as world leaders will likely include increased automation, improved control and data acquisition, and optimized process operation.

10.5 Research and Development

Research and development of drinking water technologies is becoming increasingly important for water utilities as they adapt to changing regulations. An example is the disinfection requirements of the new Ontario drinking water standards. They stipulate improved removal and inactivation of micro-organisms, while imposing a limit on formation of disinfection by-products (DBPs). Regulations in the United States stipulate a maximum total trihalomethane (TTHM) concentration of 80 μg/L, likely to drop to 40 μg/L over the next few years. Ontario regulations may follow, requiring a further decrease from the current 100 μg/L TTHM limit. Design and retrofit of plants to optimize pathogen reduction and meet DBP limits will depend on a combination of steps, including coagulation, flocculation, sedimentation, and filtration, as well as other processes such as membranes and adsorption. Disinfection will likely be achieved through a combination of chlorine, chlorine dioxide, ozone, and UV. Research efforts should therefore focus on problems experienced by plants throughout Ontario, especially those that rely on poorer-quality sources of raw water.

In the past, the Ontario Ministry of the Environment, and also to some degree Health Canada, funded research dedicated to specific treatment issues or to problems associated with raw-water sources. As a result of financial restraint both agencies now provide only minimal funding, if any, to applied research conducted by universities and other parties. Drinking water research in Canada, and specifically Ontario, has been supported in the last few years by the Natural Sciences and Engineering Research Council of Canada and organizations such as the Centre for Research in Earth and Space Technology or the Environmental Science and Technology Alliance Canada. These sources respond primarily to proposals from researchers at academic institutions, who must in turn cooperate with individual treatment facilities, as well as equipment and chemical suppliers to the water treatment industry.

In contrast, larger organizations such as the U.S. Environmental Protection Agency and the American Water Works Association Research Foundation (AwwaRF) fund drinking water research in the United States. They typically fund multi-year projects and teams of academics from various universities. In addition, many of these projects link directly to issues associated with specific water treatment facilities. It should be noted that, although AwwaRF is U.S.-based, Canadian researchers may also apply for research funds.

In summary, both the Ontario Ministry of the Environment and Health Canada should be re-established as funding sources for drinking water treatment research. MOE funding of projects would ensure that specific treatment issues are addressed when relevent to the needs of the province. It would also assist in the implementation of new drinking water standards and in the preparation of future standards. Health Canada funding would ensure a strong health focus in drinking water research, as well as allowing this information to be readily disseminated at both regional and national levels.

10.6 Utility Structure

10.6.1 Size

One of the obvious questions relating to water operations is, When is small too small? The case studies in chapter 9 highlight differences between small and large systems through the quality and depth of the responses to the questionnaires used to gather information. Operators of large systems seem to be well supported by knowledgeable scientific and engineering staff. Large utilities also support several levels of technically aware management, and thus decisions that affect water supply are in the hands of knowledgeable managers. Operators of small systems, by comparison, tend to answer directly to managerial or engineering staff who are not water or wastewater specialists.

Although there is little evidence to suggest that small systems are poorly operated, the MOE's move from technical and scientific support to a more regulatory role over the past ten to twenty years has brought about change. In simple terms, the result has been that advice and guidance once freely offered to small communities is no longer available. Although this service could in theory be obtained from the private sector, it is reasonable to suggest that much of the help provided by the MOE in the past was given in situations where operators were not even aware that advice was necessary.

Availability of funding is also a problem for smaller communities. While small municipalities might support a minor increase to water rates to spread costs over a year, they often cannot afford the cost of on-site consulting, especially when a consultant needs several days to become fully acquainted with the system. Lack of funding can also be a barrier to continued training of operators. As noted elsewhere in this paper, operating a modern water treatment facility is generally not difficult when raw water conditions are stable and equipment is functioning correctly. However, making decisions during emergency conditions usually requires an advanced understanding of water chemistry and water treatment processes. Small communities often cannot afford to invest in the training necessary to bring staff to this level of understanding. Small utilities might also question employing level IV operators, or an equivalent, when general water supply duties are minimal.

Although regionalization is sometimes presented as a solution to the problems of operating small systems, it can be costly because of administrative upheaval and having to integrate existing infrastructure. Furthermore, many communities resist the loss of independence that accompanies any form of merging. The cost analysis presented in section 1.10 also indicates that economies of scale are not often realized to the extent expected.

The best approach to water supply in small communities must therefore acknowledge the potential difficulties while ensuring that the appropriate level of help is available when required. One of the more successful positions in rural Ontario has been that of medical officer of health. These doctors are available as a resource within their districts, but they also fulfill a regulatory role. An equivalent structure related to water supply does not currently exist, but it should be considered. A specialized district water supply officer, supported by one or two technicians, could operate within a district that incorporates a number of small communities. The main function of the position would be to act as a resource to facility operators and small communities during normal water supply conditions, and especially during emergencies. Because the position would generate an annual rather than an immediate cost (such as is incurred every time an outside consultant is hired), it is likely that small communities would make more use of the resource.

Although the Ontario Drinking Water Protection Regulation now requires an engineer’s report of every water supply facility, the report is produced only once every three years. During the intervening period there will be less incentive to focus in detail on facility operation and equipment maintenance. Therefore, a second function of the water supply officer would be to perform ongoing inspections of water facilities in the district and to require corrections in the event that standards are not met. This would provide inspection continuity between updates to the engineers’ reports. The officer would also have the advantage of an ongoing familiarity with local systems and any shortcomings they might have. The position would therefore require a qualified specialist in water supply who could advise on treatment strategies, chemical dosing, regulatory requirements, general operating procedures, etc.

Whether such a position would be administered through the Ministry of the Environment or whether the provincial government would fund it wholly or partially is outside the scope of this paper. However, funding to support these staff would require only a minimal increase in existing water rates, as long as enough small communities were grouped together into each district. It can be shown that approximately 40 such districts could be supported in the province while keeping overall production cost increases to less than 5%.

Appendix 1 Drinking Water Treatment Questionnaire

Treatment Facility[1]

Information by:	Title:
Date:	

Production			**Specific Comments?**
Rating	Firm	ML/d	
Average day		ML/d	
Max day		ML/d	
Avg Per Capita		L/c/d	
Any other comments on water usage?			

Organization Structure - use following table to construct O&M org chart or attach separately

Any other comments on organization structure?

Plant Supervision - use following table to describe typical weekly shift

	Weekday 1	Weekday 1	Weekday 1	Weekday 1	Weekday 1	Weekday 1	Weekday 1	Weekday 1
Times								
Plant Manager								
No. Supervisors								
No. Operators								
No. Maintenance staff								
No. Laboratory staff								
No.								

Any other comments on plant coverage?

[1] As far as possible, select as your case study a single treatment plant or group of wells where there is a reasonably clear delineation between the operations of the system selected and any other plants or wells under the jurisdiction of the main operating authority. If the same operators are responsible for both a surface water and groundwater system, use as many versions of this form as necessary to explain their roles and describe technical operations.

Staff - assigned primarily to the operation of this facility	**Specific Comments?**
Number of staff	
Plant Manager	
Supervisors	
Operators	
Maintenance staff	
Laboratory staff	
Admin & Clerical	
Numbers of Staff by Certification	

Ontario Certification	Written Tests	Experience	**Other Jurisdictions**	Written Testing	Experience
Operators-in-training					
Operators Level I					
Operators Level II					
Operators Level III					
Operators Level IV					

Training – past year	Courses Attended	Staff Attendance	Total Time	**Specific Comments?**
In-house courses	No.	No.	Hours	
External courses	No.	No.	Hours	
Specialty conferences	No.	No.	Hours	
Occupational Health & Safety – past year				
Reported incidents	No.	Days lost		

Contracted Services - services contracted outside the operating authority	Contract Value

Plant Operations

Emergency Response Plans	**Specific Comments?**
Do you use any automated alarm-driven sequences for plant or process shutdown designed to specifically protect water quality?	
If 'Yes' - describe >	
Do your operating manuals define any manually controlled alarm-driven sequences for plant or process shutdown designed to specifically protect water quality?	
If 'Yes' - describe >	
Describe any other emergency response procedures contained in operating manuals or posted instructions	

Who has authority for plant or process shutdowns?	
Plant Manager	Full authority
Supervisors	Full authority
Operators-in-training	Full authority
Operators Level I	Full authority
Operators Level II	Full authority
Operators Level III	Full authority
Operators Level IV	Full authority
Maintenance staff	Full authority
Laboratory staff	Full authority

Non-Staff Plant Access	Unrestricted	Informal	Sign in/out	Escorted	Doors Alarmed
Doors Alarmed	☐	☐	☐	☐	☐
Site	☐	☐	☐	☐	☐
Process areas	☐	☐	☐	☐	☐
Maintenance & Storage	☐	☐	☐	☐	☐
Administration	☐	☐	☐	☐	☐

Role of Technology	
Which description bests fits the plant control system?	Fully automated plant computer interface
Do you use Computerized Maintenance Management Systems (CMMS)?	Yes
Do you use Geographical Information Systems (GIS)?	Yes
Any other comments on technology?	

Quality Management	
Do you have a written Quality Management plan?	**Specific Comments?**
If 'Yes' - name >	
Subjects covered >	
Do you have designated Quality Manager(s)?	
If 'Yes' - reports to > Director	
Does your plant or water supply have ISO designation?	
If 'Yes' - designation >	
Do you have in-house laboratory services?	
If 'Yes' - is it accredited > Accredited	
Do you undertake formal consumer satisfaction surveys?	
If 'Yes' - describe >	
Do you sponsor or invite community and consumer awareness and involvement programmes?	
If 'Yes' - describe >	

Best Management Practices		**Specific Comments?**
Risk Assessment		
Have you undertaken risk assessments on factors that may affect water quality and safety?		
Statistical definition	Describe	
How do you use historical water quality data?		
Systematic review to determine trends	Describe	
Benchmarking		
If 'Yes' - years >	years	
Water Efficiency		
Metered coverage - %		
Water losses - %		
Consumer incentives	Yes	
Other BMP initiatives		

Production Costs	Year	Per m^3	**Specific Comments?**
Electrical power			
Other energy sources			
Chemicals			
Sampling & analysis			
Direct labour			
Corporate charges			
Contracted services			
Debt repayment			
Other			
Total			

Plant Performance and Technical Data

Raw Water Quality	Avg	Min	Max	Data from past year
Turbidity – NTU				
Colour – TCU				
pH				
Temperature – ˚C				
Raw water monitoring				
Turbidity	Continuous on-line			
pH	Continuous on-line			
Temperature	Continuous on-line			
Alkalinity	Grab samples			
Microbiological	Grab samles			
Streaming Current	Continuous on-line			
Any other comments on monitoring?				

Is the data use for control?	Coagulation	Disinfection	**Specific Comments?**
Turbidity	Auto response	Auto response	
pH	Auto response	Auto response	
Temperature	Auto response	Auto response	
Alkalinity	Auto response	Auto response	
Streaming Current	Auto response		

Pre-Disinfection	Gaseous chlorine	Continuous on-line	Flowpaced	
dosage rate – mg/L	Avg	Max	Min	Data from past year
Any other comments on this subject?				

Rapid Mix			
Type	Mechanical in-line		
Number of units			
Velocity gradient	G	s^{-1}	estimate
G.t at plant rating			estimate
Any other comments on this subject?			

Chemical Feed - use data from past year				
pH adjustment	Soda Ash	Continuous	Flow paced	
dosage rate – mg/L	Avg	Max	Min	litres in past year
Coagulation	Aluminum Sulphate	Continuous	Flow paced	
dosage rate – mg/L	Avg	Max	Min	litres in past year
Enhanced coagulation	Polymer	Continuous	Flow paced	
dosage rate – mg/L	Avg	Max	Min	litres in past year
Taste & odour		Continuous	Flow paced	
dosage rate – mg/L	Avg	Max	Min	litres in past year
Other?		Continuous	Flow paced	
dosage rate – mg/L	Avg	Max	Min	litres in past year
How do you set coagulant dosage rates?		Jar tests		
Any other comments on this subject?				

Flocculation	Mechancial		
Number of tanks			
Number in series			
Velocity gradient	G	s^{-1}	estimate
G.t at plant rating			estimate
Any other comments on this subject?			

Sedimentation	Conventional	
Number of tanks		
Rise rate		m/hr at plant rating
Total surface area		m^2
Retention time		mins at plant rating
Sludge removal	Mechanical	Auto time schedule
Sludge disposal	Sanitary sewer	

Settled water sampling	Continuous on-line		
Sludge sampling	Continuous on-line		
Any other comments on this subject?			

Filtration			
Number of filters			
Filter rate		m/hr at plant rating	
Total surface area		m^2	
Nominal water depth over media		m	
Layer	No.1	No.1	No.1
Type	Sand	Sand	Sand
Bed depth	mm	mm	mm
Effective size	mm	mm	mm
Uniformity coefficient			
Underdrain system	Gravel support type - describe >		
Surface wash system	Rotary arm		
Filter to waste	Yes		
Control mode	Constant rate - flow controller		
Filtrate quality sampling	Continous on-line each filter		
Filter head loss	Continuous each filter		
Any other comments on this subject?			

Filter Backwashing				
Backwash initiation	Head loss - value >			
Initial low rate	Yes - value >		m/hr typical or	L/s
High rate	Manual fixed rate			
High rise rate @ 20˚C		m/hr		
Winter rise rate		m/hr typical or	L/s	
Summer rise rate		m/hr typical or	L/s	
Final low rate	Yes - value >		m/hr typical or	L/s
Backwash termination	Auto elapsed time			
Wash cycle duration		mins typical		
Filter to waste duration		mins typical		
Washwater disposal	Discharge to raw water service			
Any other comments on this subject?				

Post-Disinfection	Gaseous chlorine	Continuous on-line	Flow paced	
dosage rate – mg/L	Avg	Max	Min	litres in past year
Retention time		mins at rated capacity		
Summer C.t		at rated capacity		
Winter C.t		at rated capacity		
Any other comments on this subject?				

Fluoridation	Hydroflurosilicic acid	Continuous on-line	Flow paced	
dosage rate – mg/L	Avg	Max	Min	litres in past year
Any other comments on this subject?				

In-Plant Storage

Total volume			m³		
As percent of rating					
Any other comments on this subject?					

Treated Water Quality - use data from past year

Turbidity – NTU	Avg	Min	Max
Colour – TCU	Avg	Min	Max
pH	Avg	Min	Max
Chlorine residual	Avg	Min	Max

Treated Water Monitoring

Turbidity	Continuous on-line					
Particle counter	Continuous on-line					
pH	Continuous on-line					
Temperature	Continuous on-line					
Chlorine residual	Continuous on-line					
Microbiological	Grab samples	E-coli ☐	TC ☐	HPC ☐	Giardia ☐	Cryptosporidium ☐
	Sampling frequency	Daily	Daily	Daily	Daily	Daily

Any other comments on this subject?

Any comments on any other subject that may help describe your operations?

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