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FRESHWATER MANAGEMENT IN CANADA: II. RESOURCES, USE AND TREATMENT

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INTRODUCTION

Canada faces an emerging water crisis, which is manifesting itself by an increasing number of water-related disease outbreaks, endangered watersheds and aquatic ecosystems, and problems with an aging water infrastructure. Canada's ability to respond successfully to this crisis will depend partly on water managers' and policy makers' ability to resolve difficulties related to the current distribution of responsibilities pertaining to water. These responsibilities are often either shared or not well defined, leading to a patchwork approach in the management of water across the country. Canada has more renewable freshwater than most other countries. But how much of it is available for use? How well is Canada managing its water resources? Are we complacent about its stewardship?

This second paper in a series on Canada's freshwater management(1) provides facts about our freshwater resources and their use, examines the threats to water quality and availability, and describes the various wastewater and drinking water treatments in use across the country.

FRESHWATER RESOURCES IN CANADA(2)

The oceans hold 95% of the planet's water. The rest is freshwater, one-third of which is stored in ice caps and glaciers. The remaining two-thirds is primarily groundwater, and

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(1) The other two papers are *Freshwater Management in Canada: I. Jurisdiction*, PRB 04-48E, and *Freshwater Management in Canada: III. Issues and Challenges*, PRB 04-51E, both by François Côté, Parliamentary Information and Research Service, Library of Parliament, Ottawa, 2004.

(2) This section of the paper draws upon the following materials: Statistics Canada, Environment Accounts and Statistics Division, "Fresh water resources in Canada, Featured article," in *Human Activity and the Environment: Annual Statistics 2003*, Cat. No. 16-201-XPE, Ottawa, 2003; Environment Canada, *Freshwater Website*, http://www.ec.gc.ca/water/, accessed 20 August 2004; D. R. Coote and L. J. Gregorich, eds., *The Health of Our Water: Toward Sustainable Agriculture in Canada*, Research Planning and Coordination Directorate, Research Branch, Agriculture and Agri-Food Canada, Ottawa, 2000, http://res2.agr.gc.ca/publications/hw/PDF/water.pdf; and Organisation for Economic Co-operation and Development, *OECD Environmental Data*, Paris, 2002, http://www.oecd.org/document/21/0,2340,en_2825_495628_2516565_1_1_1_1,00.html.

only a small proportion (about 1/5 of 1%) is in the soil or on the surface (including lakes and rivers). This water represents 1/10,000th of all the water on the planet.

Canada is fortunate in terms of the quantity of freshwater within its borders; but that water is not evenly distributed across the country, and much of it is not available for use. Key facts are as follows:

- Canada has 7% of the world's renewable freshwater. (It actually has 20% of the world's freshwater, but only part of that reserve is readily available.)

- Canada's renewable reserve of freshwater consists of:
  - primarily groundwater, the volume of which is 37 times greater than the volume of water in lakes and rivers;
  - many lakes and watercourses, which cover almost 8% of Canadian territory;
  - wetlands, which account for 16% of Canadian territory; and
  - snow and ice.

- Sixty percent of Canada's freshwater flows north toward the Arctic, while 90% of its population lives less then 300 kilometres from the American border.

- Canada's climatic zones vary considerably in terms of their access to water: certain parts of British Columbia and the Prairies are very arid, whereas southern Ontario suffers few water shortages, and the east and west coasts of Canada receive abundant rainfall.

Water management in Canada must take all these conditions into consideration.

FRESHWATER USE

Canada overuses its water resources. For example, our residential water use is two to three times that of some European countries. Our overuse costs billions of dollars in supply and wastewater infrastructure.

Canada's gross water use totalled 65.7 billion cubic metres in 1996.(3) Of this volume:

- 44.9 billion cubic metres were withdrawn, of which 20.8 billion cubic metres were recirculated in various industrial sectors;

- 40.1 billion cubic metres returned to the environment after use and thus remained available; and

- 4.7 billion cubic metres were removed from circulation, and thus consumed.

(3) Statistics Canada (2003).

Canada’s water withdrawal in 1996 (44.9 billion cubic metres) was used as follows:

- electric power and other utilities (64%);
- manufacturing (14%);
- personal and governmental sectors (9%);
- agriculture (9%);
- mining (1%); and
- other primary resource and manufacturing industries (3%).

The amount of water required for these uses varied considerably among regions and provinces. For example, the thermal power generation sector in Ontario accounted for 82% of the national withdrawal for this purpose.

Most of the water withdrawn was in fact “recycled.” Consumed water represented 10% of what was withdrawn. Consumed water is that part of the water withdrawal that is evaporated, incorporated into products or crops, consumed by people or livestock, or otherwise removed from the local hydrologic environment. The agriculture sector was the largest consumer of water at 64%, followed by manufacturing industries at 13%.

Not accounted for in the data above is the instream use of water. Unlike withdrawal uses, instream uses cannot be measured quantitatively because the water is not removed from its natural environment. However, instream uses of water can be important and affect the quality and the availability of water for other resource users. The main instream uses are:

- hydroelectric power generation;
- water transport;
- freshwater fisheries;
- wildlife;
- recreation; and
- waste disposal.

Per capita, Canadians are among the world's greatest users of water. Each Canadian used, on average, 343 litres of water a day in 1998 for domestic purposes. Domestic use of water comprises: baths and showers (35%); toilets (30%); laundry (20%); cooking and drinking (10%); and cleaning (5%). Table 1 compares water usage in a variety of countries.

Table 1: Comparison of Freshwater Withdrawals for Public Water Supply and Domestic Use, for Canada and Selected OECD Countries

Country	Total Freshwater Withdrawals[a]		Withdrawals for Public Water Supply per Capita[a,b]	Domestic Use per Capita[c]
	Per Capita	As Proportion of Total Available Renewable Freshwater Resources[d]		
	litres/day	%	litres/day	litres/day
U.S.A.	5,123	19.9	584	382
Canada	4,411	1.7	499	343
Australia	3,562	6.8	439	
Italy	2,685	32.1	483	250
Mexico	2,192	16.2	276	
Japan	1,945	21.2	360	
Norway	1,644	0.7	494	
Russia	1,534	1.9	287	
France	1,425	15.9	277	150
Germany	1,342	22.3	184	
Sweden	822	1.5	288	200
U.K.	575	17.4	306	
Israel				135

a Data refer to 1999 or latest available year.

b "Public water supply" refers to water supply by waterworks, and may include other uses besides the domestic sector.

c 1998 data.

d Renewable freshwater resources: net result of precipitation minus evapotranspiration (i.e., total amount of water that is transferred from the earth's surface to the atmosphere) plus inflow.

People in developed countries use more water than those in developing countries. The International Food Policy Research Institute estimated that, in 1995, daily consumption per capita averaged 131 litres in developed countries and 70 litres in developing countries. The Institute estimated that this consumption could reach 149 and 93 litres a day per capita by 2025.

Regional disparities in water use also exist. The South Saskatchewan, Missouri, and Assiniboine-Red drainage area, which includes the southern portions of Alberta, Saskatchewan and Manitoba, has a surface freshwater withdrawal to streamflow ratio above 40%.[(4)] The majority of Canada's other drainage areas have ratios below 10%. Alberta alone accounts for 60% of the irrigated agricultural land in Canada. Given that the agricultural sector returns very little of its water withdrawal to the local hydrologic environment, these figures are significant.

THREATS TO WATER QUALITY AND AVAILABILITY

Human activity is the biggest threat to freshwater, especially its quality and quantity. Human activity has had profound effects on the aquatic environment, including:

- overexploitation of resources as a result of increased consumption and population growth;
- alteration of natural riverbanks and lakeshores by urban and agricultural development;
- destruction of peat bogs and other wetlands as a result of the regulation of water levels;
- acidification of lakes caused by the emission of acid-producing substances into the atmosphere;
- abnormal changes in the levels of water bodies as a result of increased greenhouse gas emissions and climatic changes;
- organic and chemical contamination of water caused by industrial, agricultural and urban activities; and
- diminished aquatic biodiversity through the introduction of exotic species.

These factors not only lead to habitat loss and a decrease in biodiversity, but also contribute to a build-up of toxins in the food chain and a decline in the quality of water prior to treatment. Even though approximately 90% of the water used in Canada finds its way back into the water supply, the loss of the remaining amount – mainly attributable to evaporation during use – has an impact on aquatic ecosystems, especially in areas that are susceptible to drought.

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(4) According to the Organisation for Economic Co-operation and Development (OECD), a watershed can be considered in a situation of stress when greater than 40% of the available renewable water within the watershed is used for industrial, agricultural, or personal uses.

The National Water Research Institute (NWRI), part of Environment Canada's Environmental Conservation Service, is Canada's largest freshwater research facility. In recent years, the Institute has held two key symposia, the first to discuss water-quality related threats to sources of drinking water and aquatic ecosystem health, and the second to discuss threats to the availability of freshwater in Canada. Two reports were issued following these symposia.

The NWRI has described the threats to sources of drinking water and aquatic ecosystem health as follows:(5)

- Waterborne pathogens: waterborne pathogens can pose a problem to drinking water supplies, recreational waters, and source waters for agriculture and aquaculture.

- Algal toxins and taste and odour: algal toxins in stock watering sources may affect animal health and even cause livestock mortality.

- Pesticides: synthetic chlorinated pesticides were introduced in the 1940s and 1950s, but serious environmental problems began to be noticed only in the 1960s and 1970s.

- Persistent organic pollutants (POPs) and mercury: POPs comprise a group of chemicals that degrade slowly in the environment, bioaccumulate and have toxic properties.

- Endocrine-disrupting substances (EDS): EDS can exert an array of effects on growth, development and reproduction in biota at extremely low concentrations, and these effects can be expressed in future generations.

- Nutrients – nitrogen and phosphorus: the amount of nitrogen and phosphorus available for plant uptake has increased dramatically. Available nitrogen has doubled since the 1940s, and human sources of phosphorus greatly exceed natural sources.

- Aquatic acidification: scientific consensus justified controls on emission of both sulphur dioxide (SO_2) and nitrogen oxides (NO_x) in Canada and internationally, and both Canada and the United States have significantly reduced SO_2 (but not NO_x) emissions. However, given present sulphate deposition levels, critical loads(6) will still be exceeded for most of Canada's monitored lakes.

- Ecosystem effects of genetically modified organisms (GMOs): the use of GMOs, specifically genetically modified crops, began in the 1990s in Canada, has grown significantly, and is projected to continue to do so.

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(5) Environment Canada, *Threats to Sources of Drinking Water and Aquatic Ecosystem Health in Canada*, NWRI Scientific Assessment Report Series No. 1, National Water Research Institute, Burlington, Ontario, 2001, http://www.nwri.ca/threats/threats-eprint.pdf.

(6) The maximum amount of deposition that a defined environment can withstand, without suffering long-term damage.

- Municipal wastewater effluents (MWWE): MWWE are a complex mixture of human waste, suspended solids, debris and a variety of chemicals derived from residential, commercial and industrial sources.

- Industrial point-source discharges, including:
  - pulp and paper;
  - mining;
  - petrochemical.

- Urban runoff: urban runoff is a mixture of storm water, raw sewage and scoured sewage transported by sewers, drainage channels and streams, and ultimately discharged to receiving waters.

- Landfills and waste disposal: Canada ranks among the highest producers of solid waste in the industrial world. These wastes are produced from domestic, commercial, industrial and agricultural activities.

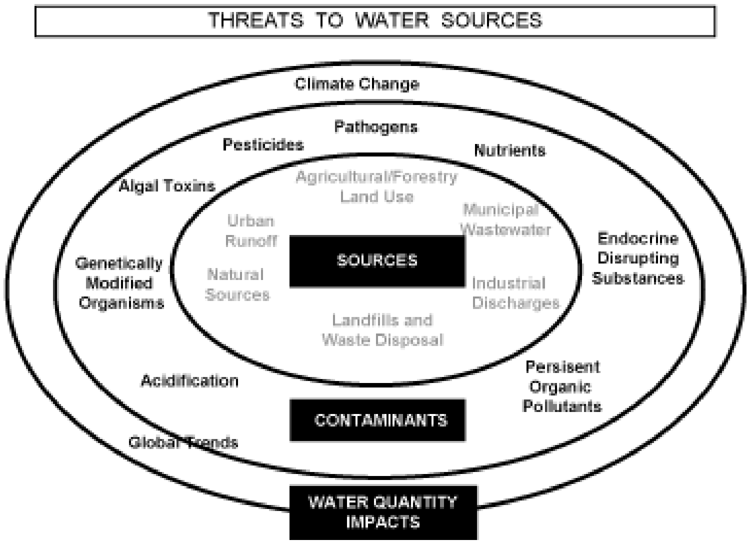
- Agricultural and forestry land use: in Canada, approximately 12% of the total land base is currently managed for timber harvest, another 7% is used for farming and an additional 1% is in urban/industrial development. Timber harvest can: increase water yield (due to increased runoff), suspended solids and temperature in streams; disrupt the cycle of nutrients between the soil and trees; and increase concentrations of dissolved nitrogen, organic carbon, base cations (positively charged elements such calcium, magnesium and potassium) and phosphorus in streams and lakes.

- Natural sources of trace element contaminants: natural geologic sources of trace element contaminants exist in many regions of Canada.

- Dams, diversions and climate change: impacts of water quantity changes on water quality are based largely on studies of the effects of Canada's 600 dams and 60 large interbasin diversions. Changes to water quantity affect water quality in the reservoir and downstream, and flow diversions also produce major changes in water quality.

Figure 1 summarizes the threats to water, whether these threats affect the source of freshwater, are a potential for contamination, or affect the availability and the quantity of water.

Figure 1



Source: Environment Canada (2001), p. x.

The NWRI has also produced a document that discusses specifically the threats to water availability[7] in Canada. These threats are:

- water allocations, diversion and export;
- dams, reservoirs and flow regulation;
- droughts;
- floods;
- municipal water supply and urban development;
- manufacturing and thermal energy demands;
- land-use practices and changes related to agriculture, forestry, mining and petroleum production;
- climate variability and change in groundwater resources, rivers, streams, lakes and reservoirs, wetlands and water in its frozen state; and
- integrated and cumulative threats to water availability.

(7) Environment Canada, *Threats to Water Availability in Canada*, NWRI Scientific Assessment Report Series No. 3, National Water Research Institute, Burlington, Ontario, 2004, http://www.nwri.ca/threats2full/intro-e.html.

TREATING WASTEWATER

Most of the wastewater from municipalities is treated to varying degrees in a sewage plant before being discharged. The quality of the returning water depends on the level of treatment. Primary treatment involves the physical removal of solids by screening and settling; secondary treatment involves the biological removal of residual organics; tertiary treatment involves chemical treatment to remove additional contaminants. The effect on the receiving water depends on the municipal treatment facility. The organic compounds discharged in wastewater are consumed by bacteria in the receiving water – a process that depletes the dissolved oxygen which is essential to most aquatic life. The term used to quantify the organic concentration of wastewater is biological oxygen demand (BOD). The higher the level of treatment, the lower the wastewater BOD. When only primary treatment is used, the probability of contamination by disease-carrying bacteria increases. Regardless of treatment, a large amount of chlorine and ammonia enter the receiving water. Chlorine is sometimes used for disinfection in the last stage of wastewater treatment, just before the water is discharged into the aquatic environment.[(8)]

In 1998, the proportion of Canadians living in municipalities that were not serviced by sewage treatment was 3%, as compared to 28% in 1983. Only 40% of the population, however, was serviced by sewage systems involving tertiary treatment. It is estimated that close to 7 million people, or almost a quarter of the Canadian population, relied on septic or alternative wastewater treatment systems.[(9)] Primary treatment is used in British Columbia, while the Prairie provinces favour secondary treatment. Ontario has opted for tertiary treatment. All three types are used in Quebec to varying degrees, although tertiary treatment is less common. In the Atlantic provinces, half the population is serviced by sewer systems that discharge untreated wastewater directly into estuary or coastal waters that are considered unable to properly dilute the wastes.

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(8) Chlorinated wastewater effluent and associated chlorine by-products are highly toxic to aquatic organisms, even in small amounts.

(9) Statistics Canada (2003), p. 17.

In September 2004, the Sierra Legal Defence Fund (SLDF) published its *National Sewage Report Card*.[10] This report, the third in a series that began in 1994,[11] described how 22 cities across Canada treat and manage their sewage. The report graded cities based on the quality of their sewage treatment as determined by various criteria including level of treatment, volume of raw sewage discharged and their progress since the previous report in 1999. Cities such as Victoria and St. John's ranked badly, while Calgary and Edmonton were praised for their performance.

Wastewater-related toxic pollutants can originate not only from the discharge of raw and inadequately treated sewage, but also from sewer overflows and bypasses, storm sewer systems, and disposal of sewage sludge. Bypasses are used when a treatment facility is overloaded, and occur most often in combined sewer systems which carry sewage, stormwater and urban runoff in the same pipe. When bypasses occur, raw sewage is discharged into the receiving waters without treatment. According to the SLDF, at least 20% of the sewers in Winnipeg, Hamilton, Montréal and Saint John are combined systems.[12] Sewage sludge is the solid waste resulting from the treatment of sewage. It often contains a variety of toxic chemicals. There are various methods of disposal of sewage sludge; not all of them are safe.

A. Primary Treatment

After undergoing preliminary treatment to remove grit and solid material, wastewater goes through a physical process that separates solid matter from liquid. Floating, oily and greasy material is removed from the effluent, and the resulting sludge can be disposed of in a number of ways. If the effluent is not treated further, it is simply returned to the environment. Primary treatment alone usually results in effluent of a lower quality than is achieved by complete treatment. Generally, primary treatment without chemicals reduces BOD by 25% to 40% and removes between 40% and 60% of solid matter in suspension.[13]

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(10) Sierra Legal Defence Fund, *The National Sewage Report Card (Number Three): Grading the Sewage Treatment of 22 Canadian Cities*, Vancouver, 2004, http://www.sierralegal.org/reports/sewage_report_card_III.pdf.

(11) Miranda Holmes and Karen G. Wristen, *The National Sewage Report Card (Number Two): Rating the Treatment Methods and Discharges of 21 Canadian Cities,* Sierra Legal Defence Fund, Vancouver, 1999, http://www.sierralegal.org/reports/Sewage.pdf; and Sierra Legal Defence Fund, *The National Sewage Report Card – Rating the Treatment Methods and Discharges of 20 Canadian Cities*, Vancouver, June 1994.

(12) Sierra Legal Defence Fund (2004).

(13) Holmes and Wristen (1999).

B. Secondary Treatment

Secondary treatment, also known as biological treatment, may follow primary treatment. Secondary treatment reduces the amount of suspended solids and BOD by breaking down the organic material present in the sewage. This is achieved by adding oxygen through mechanical aeration or using biological filters and layers of stones, gravel and sand. The microorganisms present in the sewage are activated by the added oxygen and then feed on the organic matter. Secondary treatment considerably reduces the quantity of solid matter in wastewater, reduces BOD by 85% to 95% and eliminates up to 99% of coliforms.[14] Enhanced secondary treatment refers to secondary treatment with phosphorus and/or nitrogen removal.

Biological processing is the most efficient way of removing organic matter from municipal wastewaters. The various processes available all rely on mixed microbial cultures to decompose and remove colloidal and dissolved organic substances from solutions. The treatment chamber holding the microorganisms provides the controlled environment, and the wastewater provides the biological food, growth nutrients and added microorganisms. One example of biological processing is the trickling filter process. The filter is constructed of a bed of crushed rock or other supporting material which provides a large surface area for the development and growth of colonies of microorganisms. Aerobic bacteria build up on the support media and oxidize the organic materials in the wastewater as it is fed through the filter. An underdrain tile system supports the filter media and carries off the effluent, which can be recirculated for improved treatment. High-rate trickling filters are used in treating certain types of industrial wastes.

Another example of biological processing is the waste stabilization pond, which uses natural purification effected by microorganisms in the soil and water. The pond’s loading and depth, the soil conditions and liquid losses are all controlled, together with wind action, sunlight, algae growth and oxygen. These factors provide the environment that fosters the aerobic bacterial action and photosynthetic oxidation required to stabilize the wastes. In the process, microorganisms convert much of the carbon content into carbon dioxide, which, together with sunlight and the dissolved nutrients, provides conditions for growth of algae, which in turn provide a plentiful supply of oxygen for the microorganisms. In light of the growing

(14) Coliforms are a specific class of bacteria found in the intestines of warm-blooded animals. The presence of coliforms in water indicates that the water is polluted and may contain disease-causing (pathogenic) microorganisms (Source: Health Canada).

advantages and efficiency of such natural systems for reducing waste's impact on the environment, the biological processing of waste, or "bioremediation,"[15] is being widely studied.

C. Tertiary Treatment

Tertiary treatment involves the use of technologies that supplement other treatments; the choice of supplementary technologies depends on the characteristics of the wastewater being treated. Examples include precipitation, oxidation, micro-screening, reverse osmosis and coagulation-sedimentation. Carbon filters or other specialized filters may be used to remove heavy metals, chemicals and other types of contaminants. In addition to further reducing the amount of suspended matter and BOD, tertiary treatment helps eliminate such substances as phosphorus, nitrogen and ammonia.

PURIFICATION OF DRINKING WATER

In addition to treating wastewater, municipalities must also treat the water drawn from main sources to prevent diseases caused by waterborne pathogens. Drinking water is disinfected in one of three ways: chlorination (or chloramination), ozonization, or irradiation with ultraviolet light. It may also be purified by methods that include coagulation, flocculation, sedimentation and waste filtration.

The treatment of public drinking water to remove pathogenic microorganisms began more than a century ago, using methods such as sand filtration as well as adding chlorine for disinfection. Chlorination remains the most commonly used technique because it is effective in killing fecal coliforms and other bacteria and microorganisms, and it continues to disinfect water as it moves through the distribution system. There are nevertheless disadvantages to using chlorine, since it can interact with residual organic matter and generate toxic by-products. Chloramination has been used instead of chlorine in Ottawa water purification plants since 1992. Chloramine is effective and tends to lead to lower levels of trihalomethanes (which are carcinogens) due to its lower reactivity with organic material. However, it poses a risk to aquatic life and produces its own harmful by-products.

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(15) Bioremediation is the use of a natural system or living organisms to remove the polluting components of waste streams. Bioremediation is used in the treatment of municipal and industrial wastewaters to remove organic materials and other dissolved compounds. It is widely used in treated contaminated soils. It is highly efficient and may reduce the costs of pollution mitigation.

Ozonation is used in many places in Quebec. Although effective, ozone quickly breaks down, and so chlorine is still added to the water to continue disinfection along the distribution system. Ozone also produces by-products such as formaldehyde and bromate, which are known to be toxins. Ultraviolet disinfection, in which light energy is used to destroy pathogens, is another alternative to chlorination. Like ozone, ultraviolet light is effective, but both treatments disinfect water only temporarily.

CONCLUSION

Water is ubiquitous; water is the most common solvent; water is the universal carrier; water is a basic necessity of life. Proverbs about water are commonplace around the world, emphasizing the fundamental importance of water to humankind and our planet. Understandably, the ongoing global water crisis has had, and will continue to have, repercussions everywhere and for everyone, on every aspect of our lives. Millions of people lack access to safe water supplies. The urgent need to ensure universal access to water is reflected in the Millennium Development Goals to which the United Nations agreed in 2000; in events marking 2003 as the International Year of Freshwater; and now in a UN recommendation to proclaim 2005-2015 the International Decade of Action, “Water for Life.”

Water is also of vital importance to Canada’s environment, economy and population. We are fortunate to have more renewable freshwater than most other countries; however, this good fortune is less than it appears, as a large part of that water is not accessible. In addition, our poor management and over-use of the resource are threatening both its quantity and quality. Canada now faces its own water crisis, as demonstrated by an increasing number of water-related disease outbreaks, endangered watersheds and aquatic ecosystems, and a crumbling water infrastructure. It is essential that the country adopt effective conservation and management strategies to protect this vital resource.