The State of MUNICIPAL WASTEWATER EFFLUENTS IN CANADA

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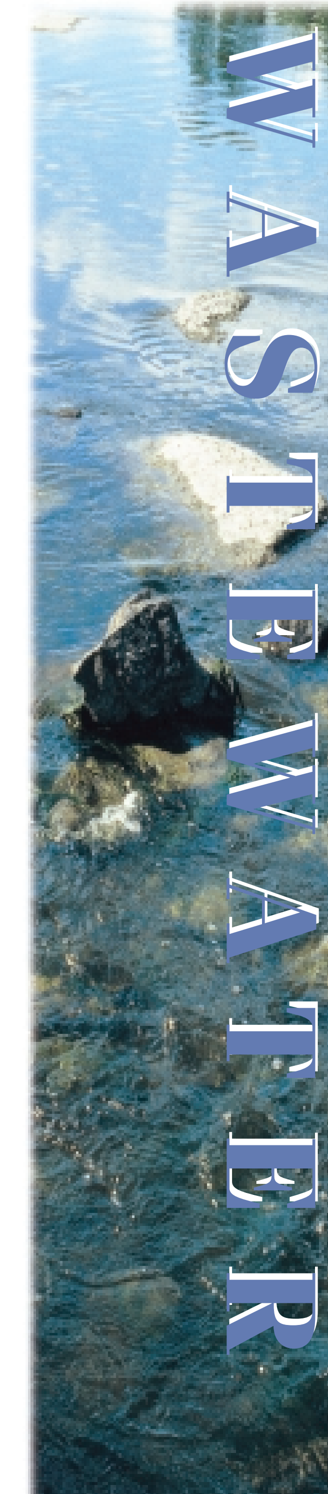

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The State of MUNICIPAL WASTEWATER EFFLUENTS IN CANADA

prepared by:

Indicators and Assessment Office
Ecosystem Science Directorate
Environmental Conservation Service
Environment Canada

National Library of Canada cataloguing in publication data

Main entry under title:
The state of municipal wastewater effluents in Canada (State of the environment report)

Issued also in French under title: État des effluents urbains au Canada.
Includes bibliographical references.
ISBN 0-662-29972-8
Cat. No. En1-11/96E

1. Sewage – Environmental aspects – Canada.
2. Sewage disposal – Canada.
3. Effluent quality – Canada.
4. Water quality management – Canada
I. Canada. Environment Canada.
II. Canada. Environmental Conservation Service
III. Series

TD526.C3S72 2001 363.72'8463'0971 C2001-980074-6

Copies of this publication may be obtained free of charge from:
Indicators and Assessment Office
Environmental Conservation Service
Environment Canada
Ottawa, Ontario K1A 0H3

For more information:
Call 1-800-668-6767
E-mail enviroinfo@ec.gc.ca

This document is also available on the Internet at The State of Canada's Environment Infobase www.ec.gc.ca/soer-ree

Photos:
Algae covered rocks: Vincent Mercier
Sewer grate: Vincent Mercier
Municipal wastewater treatment plant: City of Ottawa
Fishing boats in harbour: Corel CD photo #138003
Saskatoon: Corel CD photo #371046

Acknowledgements

This publication was prepared by the Indicators and Assessment Office of Environment Canada, under the direction of Wayne Bond. The research, writing, data analysis, and data interpretation were undertaken primarily by Vincent Mercier and Lara Cooper of the Indicators and Assessment Office. The report is partly based on the 1997 Environment Canada science assessment entitled "Review of the Impacts of Municipal Wastewater Effluents on Canadian Waters and Human Health", which was authored by Martine Allard, Judy Busnarda, Patricia Chambers, Catherine Jefferson, Robert Kent, John Lawrence, Jiri Marsalek, Steve Munger, Mark Servos, Sherry Walker, and Mike Wong. The technical writer for the present report was David Francis of Lanark Communications, and the technical editor was Marla Sheffer.

We would like to extend our appreciation to the following people, all Environment Canada representatives, for having provided their expert advice on the many drafts of the report: Martine Allard, Donald Bernard, Pierre-Yves Caux, Patricia Chambers, Murray Charlton, Maureen Copley, Richard Dalcourt, Connie Gaudet, Paul Gavrel, Peggy Hallward, Jim Haskill, Kathleen Hedley, Gary Ironside, Catherine Jefferson, Karen Keenleyside, Joseph Keller, Dave Lacelle, Nathalie Laroche, Liz Lefrançois, Kelly MacDonald, Jiri Marsalek, Elaine McKnight, Tom Tseng, Phil Wong, and Allan Wood.

We would also like to thank Dave Lacelle and Valerie Sexton of the Environmental Economics Branch of Environment Canada for providing expert advice and data from the Municipal Water Use Database surveys on wastewater treatment, municipal water use, and water metering in Canada; and Martha Guy, a consultant for the National Water Research Institute, for her contributions to the database manipulations and expertise in the analysis of contaminant loadings from wastewater treatment plants.

Translation was provided by the Translation Bureau of Public Works and Government Services Canada, and French editing was provided by Les Entreprises Hélène Bruyère. Page layout and graphical design services were provided by Crocodile Communications Inc. and Serge Bédard of the Indicators and Assessment Office.

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Acronyms

ASP	Amnesic shellfish poisoning
BMP	Best management practice
BOD	Biochemical oxygen demand
CBP	Chlorination by-product
CSO	Combined sewer overflow
DSP	Diarrhetic shellfish poisoning
MUD	Municipal Water Use Database
MWTP	Municipal wastewater treatment plant
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PSP	Paralytic shellfish poisoning
SOE	State of the Environment
THM	Trihalomethane
TSS	Total suspended solids

Preface

Environment Canada issues state of the environment (SOE) reports for two key purposes: to provide Canadians with timely and accurate information, in a non-technical manner, about current environmental issues, and to foster the use of science in policy- and decision-making. In examining important environmental issues, the reports attempt to answer four key questions:

- **What is happening to the environment** (i.e., how are environmental conditions and trends changing?)**?**
- **Why is it happening** (i.e., how are human activities causing the environmental changes?)**?**
- **Why is it significant** (i.e., what are the resulting implications for ecosystems, economic and social well-being, and human health?)**?**
- **What is being done about it** (i.e., how is society responding to these concerns through government action, changes by industry, and voluntary initiatives to ultimately make progress towards environmental sustainability?)**?**

By serving these purposes and satisfying the content and presentation guidelines of the federal government's SOE reporting program, as approved by the five natural resource departments (5NR),[1] this report, *The State of Municipal Wastewater Effluents in Canada*, carries the SOE reporting symbol.

The report is intended primarily for policy- and decision-makers at all levels of government and private industry, including municipal councillors, water and wastewater managers, and urban planners, to help them in making informed decisions about municipal water and wastewater management. It also serves to inform concerned Canadians, such as members of non-government organizations and community groups, educators and students, and the media, about the status and trends of one of Canada's top environmental problems — the release of municipal wastewater effluents. These releases, which include both sanitary sewage and stormwater discharges, are one of the largest sources of human-related pollution, by volume, in Canadian waters.

[1] The 5NR departments are Agriculture and Agri-Food Canada, Environment Canada, Fisheries and Oceans Canada, Natural Resources Canada, and Health Canada.

The State of Municipal Wastewater Effluents in Canada is partly based on an extensive scientific review conducted by Environment Canada to identify the causes, nature, and extent of the impacts of municipal wastewater effluents in Canada (Environment Canada 1997).[2] This review was undertaken in association with the Canadian Council of Ministers of the Environment to assess the impact of municipal wastewater effluents on the environment. A version of the science assessment was published in 1997 (Chambers et al. 1997). This scientific review was subsequently updated in an executive summary prepared for senior Environment Canada management in October 1999 (Environment Canada 1999a).

[2] Environment Canada. 1997. Review of the Impacts of Municipal Wastewater Effluents on Canadian Waters and Human Health. Ecosystem Science Directorate, Environmental Conservation Service. Prepared for the Canadian Council of Ministers of the Environment.

Executive summary

Comprehensive in scope, this report, *The State of Municipal Wastewater Effluents in Canada*, outlines the sources and the nature of contaminants entering municipal sewer systems, the degree of municipal wastewater treatment across Canada, the wide variety of impacts that municipal wastewater effluents can have on water quality and on plant and animal life, and the implications of these impacts for human health and beneficial water uses, such as shellfish harvesting and recreation. The report concludes by examining how municipal wastewater is managed in Canada and what our society is doing to improve the quality of the effluents to mitigate harmful effects. It also examines important emerging issues, such as the potential endocrine-disrupting hazards associated with toxic substances present in municipal wastewater. It should be noted, however, that the report deals only with wastewater effluents and does not discuss related issues surrounding the handling and disposal of sewage sludge from wastewater treatment plants.

Municipal wastewater effluents represent one of the largest sources of pollution, by volume, in Canadian waters. They are made up of both sanitary sewage and stormwater and can contain grit, debris, suspended solids, disease-causing pathogens, decaying organic wastes, nutrients, and about 200 identified chemicals.

In 1999, of the Canadian population on sewer systems, 97% were served by some level of sewage treatment, while the remaining 3% discharged raw sewage directly to Canadian waters. More untreated sewage was released to coastal waters than to inland waters. Canada has improved its sewage treatment capacity over the past 15 years. The degree of treatment is increasing, with secondary and tertiary treatment provided to 78% of the sewered population in 1999, up from 56% in 1983.

Municipal wastewaters contribute to a number of impacts on Canada's aquatic environment:

- increases in nutrient levels, often leading to algal blooms;
- depletion of dissolved oxygen, sometimes resulting in fish kills;

- the destruction of habitat from sedimentation, debris, and increased water flow; and
- acute and chronic toxicity from chemical contaminants, along with bioaccumulation and biomagnification of chemicals at higher levels of the food chain.

Health problems related to water pollution in general are estimated to cost Canadians $300 million per year. The release of untreated or inadequately treated municipal wastewater effluents may put Canadians at risk from drinking water contaminated with bacteria, protozoans (such as *Giardia* and *Cryptosporidium*), and several other toxic substances. Canadians are also put at risk from consuming contaminated fish and shellfish and engaging in recreational activities in contaminated waters.

Economic impacts related to water pollution can be partly attributed to water pollution from sewage. The marine coasts of Canada support a shellfish industry that had a total landed value of over $1 billion in 1997. However, in British Columbia, Quebec, and the Atlantic provinces, the full potential of this industry may not be achieved because of large areas that are closed to harvesting, partly as a result of sewage contamination. Municipal wastewater effluents are also partly responsible for millions of dollars in lost tourism revenue from lost recreational opportunities as a result of beach closures and restrictions on other beneficial water uses.

Excessive water use in Canada increases the need for water and wastewater treatment capacity and reduces wastewater treatment efficiency. Full water pricing by volume used is an effective means of achieving reduced water use. In Canada, metered households used about 288 litres per capita per day in 1999, compared with 433 litres per capita per day for households that paid a flat rate. The percentage of the municipal population with water meters increased from 52.6% to 57.0% between 1991 and 1999.

Many communities have also made improvements over the last 10 years in recognizing and addressing pollution problems resulting from stormwater runoff and combined sewer overflows. In general, the standard of municipal wastewater management that now exists in Canada compares well with that of any other country. However, there are still communities without municipal wastewater treatment, and existing infrastructure is faltering in many parts of the country. Even in areas with a high degree of municipal wastewater treatment, toxic substances, many with unknown ecological consequences, may be released to the environment. As an example, endocrine-disrupting substances can pass through wastewater treatment systems. These substances are known to disrupt or mimic naturally occurring hormones and may have an impact on the growth, reproduction, and development of many species of wildlife.

1 Municipal wastewater effluents: What they are and what they contain

What are municipal wastewater effluents?

Simply put, municipal wastewater effluents are the liquid wastes that come out of a community's sewer system and municipal wastewater treatment plants (MWTPs). These wastes are of two types: *sanitary sewage*, which comes from homes, businesses, institutions, and industries, and *stormwater*, which comes from rain or melting snow that drains off rooftops, lawns, roads, and other urban surfaces. Sanitary sewage usually receives some level of treatment before being discharged into a receiving body of water. Stormwater, on the other hand, is usually discharged without treatment, although stormwater treatment capabilities have improved in many communities over the past decade.

Since the mid-1950s, most communities in Canada have built separate sewer systems for sanitary sewage and stormwater, but in older neighbourhoods both sanitary sewage and stormwater are often carried together in a combined sewer system. If the combined sewer is connected to a sewage treatment plant, as it usually is, the stormwater can be treated along with the sanitary sewage. However, heavy storms can overload the treatment facilities, causing raw sewage to overflow from the system directly into the receiving water body before it reaches the treatment plant.

Why are municipal wastewater effluents of concern?

Municipal wastewater effluents are of concern not only because of the many pollutants that they normally contain, but also because of their sheer volume. In fact, municipal wastewater discharges represent one of the largest single effluent discharges, by volume, in the country — some 14.4 million cubic metres per day of treated wastewater alone from 1118 municipalities, according to estimates made in 1999 (Environment Canada 1999b).

Municipal wastewater effluents can contain:

- *grit, debris, and suspended solids*, which can discolour the water, make it unfit for recreational, domestic, and industrial use, and eventually smother and contaminate plant and animal life on the bottom of the receiving water body;

- *disease-causing pathogens (e.g., bacteria and viruses)*, which can make the water unfit for drinking, swimming, and other recreational uses and can contaminate shellfish;
- *decaying organic wastes*, which use up the water's dissolved oxygen and threaten the survival of fish and other aquatic life;
- *nutrients*, which overstimulate the growth of algae and other aquatic plants, giving rise to odours and other aesthetic problems, diminished biodiversity, and, in some cases, toxic contamination of shellfish; and
- *about 200 different identified chemicals*, many of which may be either acutely or chronically toxic to aquatic organisms and may pose a health risk to humans. Many of these chemicals may have long-term environmental effects, as they are not easily broken down and tend to accumulate in aquatic or terrestrial organisms through the food chain.

Quantities of these contaminants can be high in untreated sewage, stormwater, and combined sewer overflows (CSOs), but even treated sewage may still contain some harmful substances, albeit in smaller quantities than in raw sewage.

Social and economic costs associated with municipal wastewater effluents, resulting from the closure of fisheries and beaches, the loss of tourism revenue, or the need to adopt extra treatment measures before water can be used for domestic or industrial purposes, can be considerable.

Municipal wastewater: What goes into the system and what comes out

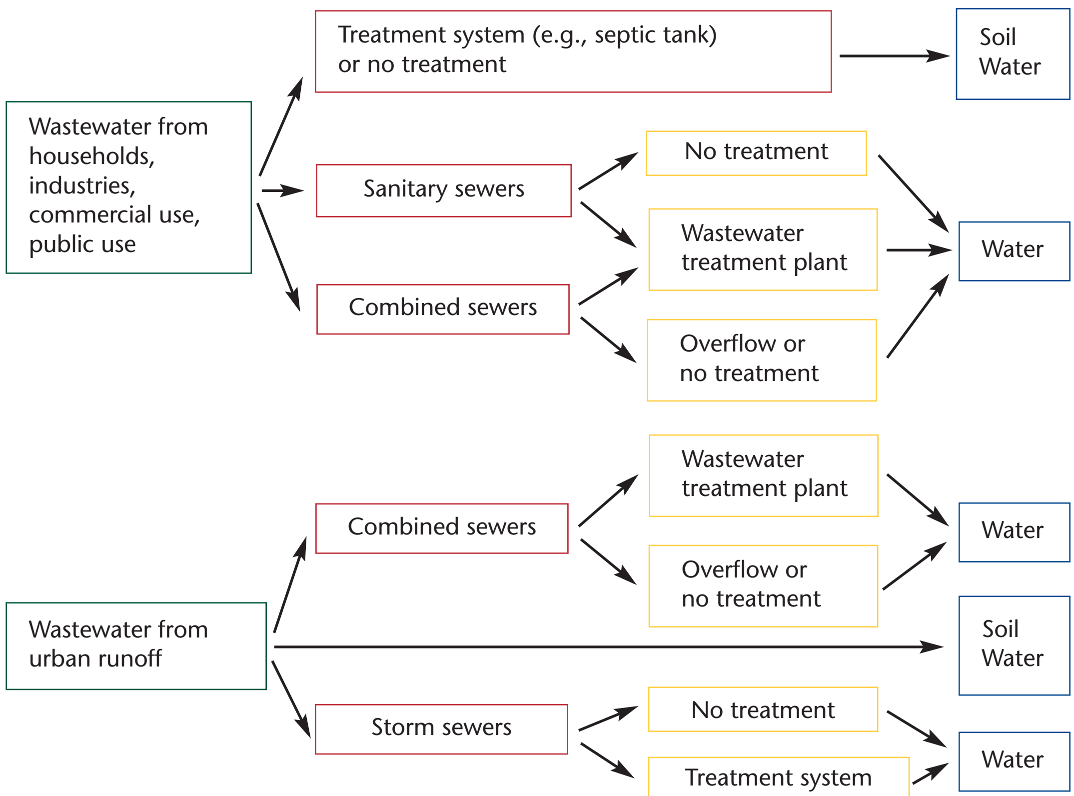
Figure 1 shows the various paths that can be taken by municipal wastewater, from its origins as sanitary sewage or stormwater to its final discharge into surface waters or the ground. What goes into the wastewater stream and the treatment it receives before discharge have an important influence on the type and magnitude of the stresses that these effluents will place on the environment.

Sanitary sewage

Sanitary sewers receive everything that is flushed down the toilets or rinsed down the drains of households, commercial establishments, institutional facilities, and factories. Raw sewage contains a variety of substances in addition to human wastes — dirt particles, food fragments, oil and grease, soaps, detergents, bleaches, other cleaning agents, solvents, paint, pharmaceuticals, and cosmetics. Even human wastes can contain surprising amounts of trace metals, such as copper, zinc, iron, cobalt, manganese, and molybdenum, because they are essential elements in human nutrition. Although most metals and chemicals in municipal wastewater come from industries, businesses, and institutions, the contribution from domestic sources is also important. Regardless of its origins, the largest single constituent of raw sewage is water, which comprises about 99.9%.

In many communities, wastewater from industries, businesses, and institutions has a significant effect on the volume and composition of the sewage stream. Process wastes from these sources can include silver from photo-finishing outlets, solvents from dry-cleaning services, and inks and dyes from printing plants, to name a few examples. Many municipalities have sewer use by-laws that either prohibit the discharge of certain hazardous substances in sewer systems or establish allowable limits for the levels that can be discharged. Many large industries have wastewater management systems to collect, treat, and reuse (where feasible) their own process or cooling waters, while using public sewers to discharge the human component of their wastewater.

Figure 1: Sources and fate of municipal wastewater

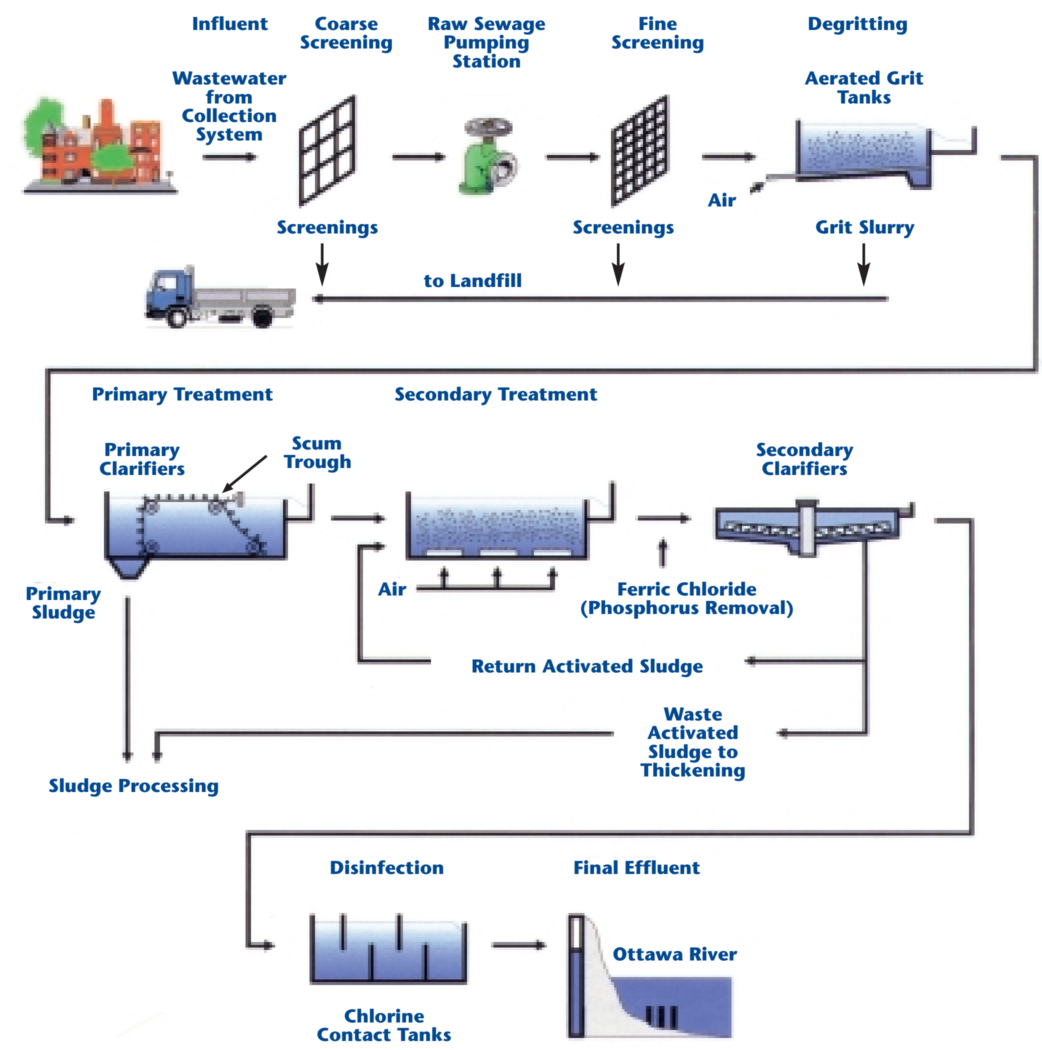


Municipal wastewater effluents are typically a mix of biological, chemical, and physical constituents (Appendix 1). The specific composition of these effluents will vary from one municipality to another, however, depending on the level of treatment they receive and the number and type of households, businesses, industries, and public facilities discharging into the system. The presence of combined sewers conveying stormwater is also an important determinant of sewage quality.

Raw sewage can be either treated in a septic tank or a MWTP or discharged directly into a body of water. About 26% of Canadians, mostly living in rural areas, rely on septic tanks with tile fields for sewage treatment, according to 1999 figures. The remaining 74%, living in some 1200 municipalities, are serviced by municipal sewers. In 1999, 97% of the Canadian population on sewers was served by some level of sewage treatment (Environment Canada 1999b). This coverage compares favourably with that of other developed countries, such as the United Kingdom (96%), Denmark (94%), and the Netherlands (92%).

MWTPs in Canada, especially those in larger municipalities, each have unique engineering designs with various combinations of treatment processes. The design and volume capacity of treatment systems depend on such things as the specific needs or objectives of municipalities, the source and quantity of the wastewater, and financial constraints. Treatment plants can be roughly categorized as having up to three levels of treatment, depending on their particular design — primary, secondary, and advanced or tertiary treatment (see Box 1 for detailed descriptions).

Box 1: How does sewage treatment work?



Although the type and sequence of wastewater treatment may vary from one treatment plant to another, the process shown above for the Regional Municipality of Ottawa-Carleton's wastewater treatment plant is fairly typical. This plant provides secondary biological treatment with advanced phosphorus removal.

Primary treatment

To prevent damage to pumps and clogging of pipes, raw wastewater passes through mechanically raked bar screens to remove large debris, such as rags, plastics, sticks, and cans. Smaller inorganic material, such as sand and gravel, is removed by a grit removal system. The lighter organic solids remain suspended in the water and flow into large tanks, called primary clarifiers. Here, the heavier organic solids settle by gravity. These settled solids, called primary sludge, are removed along with floating scum and grease and pumped to anaerobic digesters for further treatment.

(continued on next page)

Secondary treatment

The primary effluent is then transferred to the biological or secondary stage. Here, the wastewater is mixed with a controlled population of bacteria and an ample supply of oxygen. The microorganisms digest the fine suspended and soluble organic materials, thereby removing them from the wastewater. The effluent is then transferred to secondary clarifiers, where the biological solids or sludges are settled by gravity. As with the primary clarifier, these sludges are pumped to anaerobic digesters, and the clear secondary effluent may flow directly to the receiving environment or to a disinfection facility prior to release.

Advanced treatment (tertiary treatment)

Advanced wastewater treatment is the term applied to additional treatment that is needed to remove suspended and dissolved substances remaining after conventional secondary treatment. This may be accomplished using a variety of physical, chemical, or biological treatment processes to remove the targeted pollutants. Advanced treatment may be used to remove such things as colour, metals, organic chemicals, and nutrients (phosphorus and nitrogen).

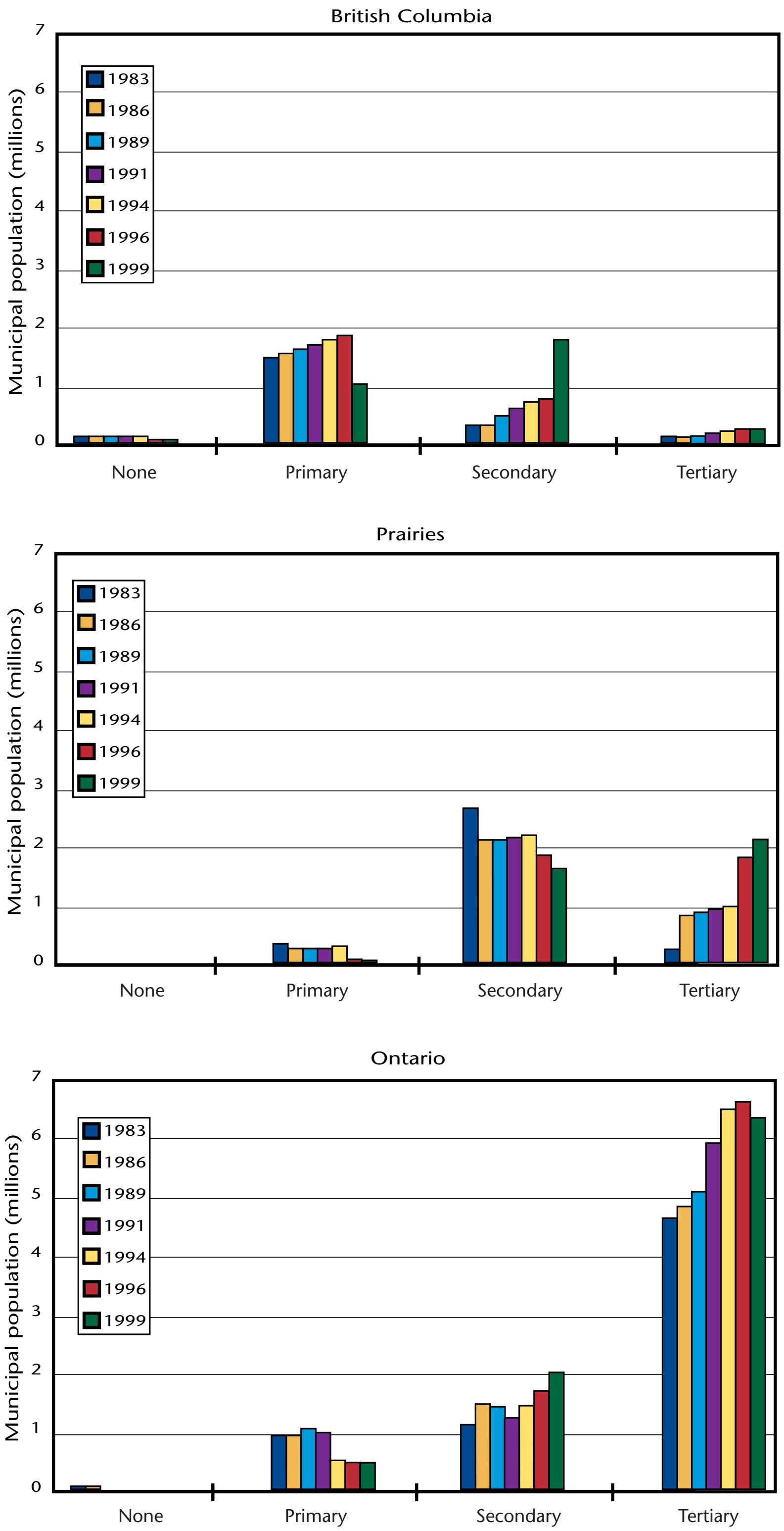
Disinfection

Before the final effluent is released into the receiving waters, it may be disinfected to reduce the disease-causing microorganisms that remain in it. The most common processes use chlorine gas or a chlorine-based disinfectant such as sodium hypochlorite. To avoid excess chlorine escaping to the environment, the effluent may be dechlorinated prior to discharge. Other disinfection options include ultraviolet light and ozone.

The degree of wastewater treatment varies greatly across Canada, according to data collected by the Municipal Water Use Database (MUD) survey.[3] In British Columbia, about 1.9 million people or 63% of the population served by sewers had secondary or advanced treatment in 1999, up significantly from 1996 (Figure 2). In both Ontario and the Prairie provinces, over 94% of the sewered populations had secondary or advanced treatment in 1999. Quebec had an even mix in 1999, with about 43% of the sewered population with primary treatment and 49% with secondary and advanced treatment. In the Atlantic provinces, nearly half of the population served by sewer systems released untreated wastewater directly into inland and coastal waters, unfortunately relying on the dilution capability of the receiving waters to reduce environmental impacts. Insufficient data exist to adequately assess the degree of wastewater treatment in the Northwest Territories, Yukon, or Nunavut.

[3] The MUD survey collects water- and wastewater-related information from Canadian municipalities having populations of 1000 or more, every two or three years. Municipalities self-report their wastewater treatment levels based on the definitions provided in the MUD survey. Therefore, some municipalities may report treatment levels that are different from those reported by other agencies (i.e., provinces/territories, regions, and non-governmental organizations) based on differences in treatment level definitions (see Fig. 2 for MUD definitions). Furthermore, MUD occasionally amalgamates several different treatment facilities for a municipality into one overall level of treatment, when more than one facility exists in a municipality.

Figure 2: Municipal population served by wastewater treatment in British Columbia, the Prairie provinces, Ontario, Quebec, and the Atlantic provinces, 1983–1999 (based on municipal populations serviced by municipal sewer systems)



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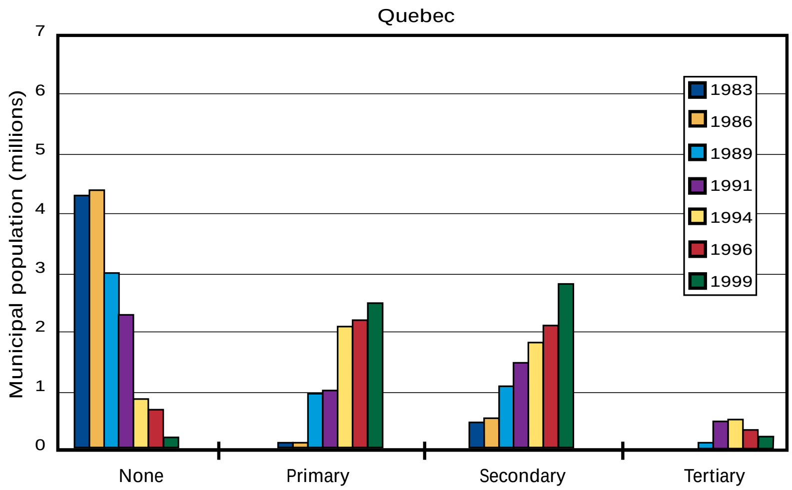
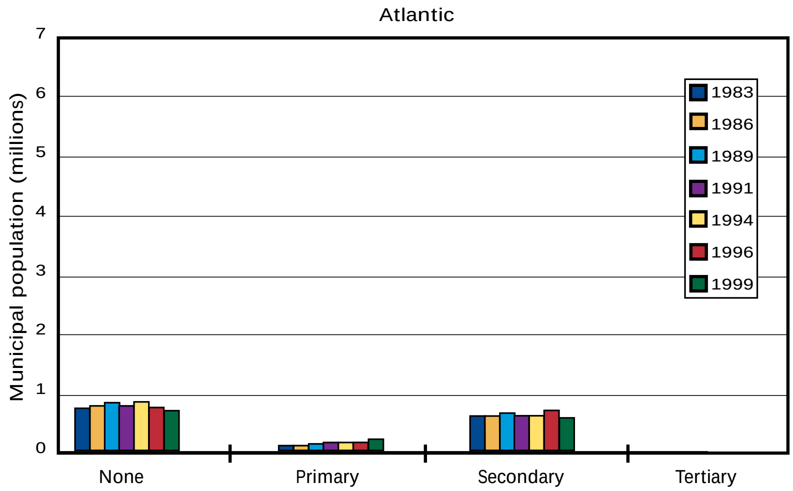




Notes:

(i) The slight decrease in tertiary treatment in Ontario and Quebec between 1996 and 1999 likely results from the change in reported data verification procedures for the MUD survey starting in 1996.

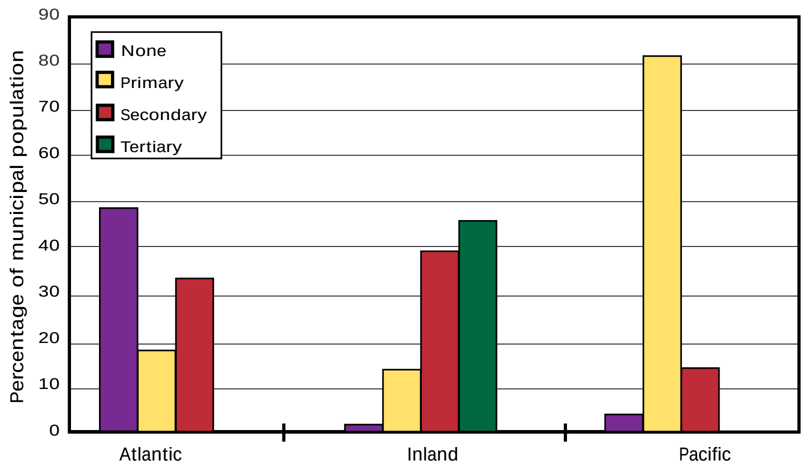
(ii) The MUD survey defines primary treatment as any form of mechanical sewage treatment, secondary treatment as biological sewage treatment or waste stabilization ponds, and tertiary treatment as some form of sewage treatment providing a higher level of treatment than secondary treatment.

(iii) Readers should be aware that use of definitions of wastewater treatment levels (e.g., in Box 1) that are different from those used in the MUD survey would yield different results from those represented in Figure 2. Under the MUD survey definitions, mechanical screening could be considered as primary treatment.

(Source: Adapted from Environment Canada 1999b)

The level of wastewater treatment in Canada also differs greatly between municipalities discharging to coastal versus inland (fresh) waters (Figure 3). In 1999, about 84% of the inland municipal population served by sewers received secondary or advanced wastewater treatment, while 15% received primary treatment. By contrast, many coastal municipalities served by sewers had only primary or secondary treatment, while some had no treatment at all. Of the municipalities discharging directly into Pacific coastal waters, about 80% of the population served by sewers received primary treatment and 15% received secondary treatment. Among municipalities discharging to Atlantic coastal waters and the St. Lawrence estuary, about 18% of the population served by sewers received primary treatment, about 34% received secondary treatment, while 48% had no treatment (adapted from Environment Canada 1999b).

Figure 3: Level of treatment of municipal wastewaters in Canadian coastal and inland receiving waters, 1999 (based on municipalities serviced by municipal sewer systems)



Note: Discharge into coastal versus inland (fresh) waters is largely self-reported. The Atlantic coastal waters include municipalities discharging into the St. Lawrence estuary.

(Source: Adapted from Environment Canada 1999b)

Municipal wastewater treatment plant effluents

After treatment, the concentrations of many pollutants that were present in the raw sewage are reduced, but smaller amounts of most of these pollutants still remain in the effluent. In many cases, the concentrations of the remaining pollutants may still be high enough to cause serious environmental damage.

Certain constituents, mostly associated with human waste, are present in all sewage effluent. These include:

- biodegradable oxygen-consuming organic matter (measured as biochemical oxygen demand or BOD);
- suspended solids (measured as total suspended solids or TSS);
- nutrients, such as phosphorus (measured as total phosphorus and/or ortho-phosphates) and nitrogen-based compounds (nitrate, nitrite, ammonia, and ammonium, which are measured either separately or in combination as total nitrogen);
- microorganisms (which are usually measured in terms of the quantity of representative groups of bacteria, such as fecal coliforms or fecal streptococci, found in human wastes); and
- sulphides.

BOD and TSS[4] are the single largest constituents of municipal wastewater effluents. A litre of effluent that has received primary treatment typically contains between 100 and 200 milligrams of each of these effluent components, although these amounts drop off sharply with higher levels of treatment. Nevertheless, even with advanced treatment, the amounts discharged to the environment by large treatment plants can be substantial. For example, a sewage treatment plant in Montreal that uses primary treatment enhanced by additional physical and chemical processes produces TSS and BOD concentrations of about 20 and 40 milligrams per litre, respectively, and discharged an average of nearly 23 tonnes of TSS and 43 tonnes of BOD per day into the St. Lawrence River in 1993 (CUM 1994). In 1999, releases of BOD and TSS from all Canadian MWTPs were estimated at 101 950 tonnes and 121 619 tonnes, respectively (OMOE 1993; Environment Canada 1999b).

Nitrogen and phosphorus[5] concentrations are an order of magnitude lower, with typical nitrogen concentrations in the 20–40 milligrams per litre range and phosphorus concentrations in the 7–15 milligrams per litre range for primary treatment. In inland areas where eutrophication problems from phosphorus discharges have been widespread, tertiary treatment is often needed to reduce phosphorus concentrations to more benign levels (typically 3 milligrams per litre or less, depending on the characteristics of the ecosystem that is exposed to the discharges).

Although microorganisms[6] are found in huge numbers in raw sewage (e.g., anywhere from 1 million to 1 billion fecal coliforms per 100 millilitres), wastewater treatment is effective at reducing their numbers in the effluent. Septic tanks typically remove 25–75% of all microorganisms, primary treatment removes 5–40%, and more advanced treatments remove over 90% of microorganisms (Droste 1997). Beyond the removal efficiency of standard wastewater treatment, facilities with well-functioning disinfection processes can achieve a nearly 100% reduction in the number of microorganisms present in the final effluent. However, even with a 99% removal rate, 10 000 – 100 000 organisms may still remain in the treated effluent. This causes problems when the receiving water is used for an activity, such as swimming or shellfish harvesting, that requires a very low number of microorganisms per 100 millilitres in order for the activity to be safe. Microorganisms are of even greater concern in stormwater and CSOs, where effluent is generally released untreated.

[4] Discharge guidelines for wastewater effluents of federal facilities for the protection of the environment recommend a maximum discharge of 5–30 milligrams per litre for BOD and for TSS, depending on whether effluents are discharged to lakes, streams, rivers, estuaries, or open coastline (FCEMS WWG 2000).

[5] Federal facilities discharge guidelines: 1 milligram per litre for ammonia, 10 milligrams per litre for nitrates, and 1 milligram per litre for phosphorus.

[6] Federal facilities discharge guidelines: 100 fecal coliforms per 100 millilitres and 1000 total coliforms per 100 millilitres.

In comparison, metals[7] are present only in very small quantities. Aluminum, strontium, and iron are the most abundant, as salts of these metals are often used in the sewage treatment process. Their concentrations are typically in the area of a few milligrams per litre. However, concentrations of other metals, such as cadmium, copper, lead, zinc, manganese, molybdenum, and nickel, are generally in the low microgram (i.e., billionths of a gram) per litre range. Mercury, which is a metal of considerable environmental concern, is usually present only in trace quantities, measured in nanograms (trillionths of a gram) per litre. A study of 37 Ontario treatment plants serving a total of 5.1 million people, published in 1988, gives some idea of the relative proportions of these substances that are being released into the environment. The study reported that the combined yearly discharges of metals from the 37 plants averaged as high as 450 tonnes for strontium and 284 tonnes for aluminum and as low as 48 kilograms for mercury. Zinc loadings from the 37 plants averaged 89 tonnes per year, while loadings of cadmium, copper, chromium, lead, nickel, and five other metals were each less than 150 kilograms per year (OMOE 1988).

Concentrations of organic chemicals[8] tend to be even lower than those of the metals, with most falling in the very low microgram per litre range. Concentrations of PCBs and of dioxins and furans are lower still and fall in the nanogram per litre range. Together, the 37 Ontario treatment plants in the 1988 study discharged an average of 30 kilograms of PCBs per year, 1.2 kilograms of dioxins and furans per year, and 1.6 and 2.5 tonnes of the solvents tetrachloroethylene and trichloroethylene, respectively, per year (OMOE 1988).

In spite of their very low concentrations in wastewater effluent, organic chemicals and metals do not have to be discharged in large quantities to result in environmental degradation. That is because many of these chemicals can be toxic at low levels and can remain in the environment for very long periods. Consequently, large amounts of these substances can build up in sediments over time or be transported by water and air currents to other environments far from the original point of discharge. Some of these substances also tend to accumulate in living tissue and be passed up the food chain. As a result, concentrations in top predators such as fish-eating birds can reach very high levels, even though ambient concentrations in the water are very low.

Stormwater and combined sewer overflows

Since urban lands are covered largely by deforested areas and impervious surfaces such as asphalt or concrete, they absorb much less water than natural landscapes. As a result, about 30–50% of stormwater or snowmelt in urban areas is converted into surface runoff, and in downtown areas the amount may be 90% or higher. Urban runoff flushes debris and contaminants from roads, parking lots, sidewalks, rooftops, lawns, and other surfaces into the sewer system as well as into other drainage channels, such as ditches and creeks.

[7] Federal facilities discharge guidelines (milligrams per litre): 1 for aluminum, 0.3 for iron, 0.005 for cadmium, 0.2 for copper, 0 (limit of detection) for lead, 0.5 for zinc, 0.5 for manganese, 0.2 for molybdenum, 0.3 for nickel, and 0 (limit of detection) for mercury.

[8] Federal facilities discharge guidelines: 0 (limit of detection) milligrams per litre for PCBs and for dioxins and furans.

Stormwater contains suspended solids, nutrients, bacteria and other microorganisms, and most of the other constituents found in sanitary sewage; however, because much of it comes from road surfaces, it also contains substantial amounts of oil and grease, chlorides from road salting, toxic metals, and organic chemicals, such as PAHs (a group of combustion by-products, some of which are carcinogenic). In addition, runoff from lawns and gardens is likely to contain residues of fertilizers, insecticides, and herbicides. Other common constituents of stormwater include debris, sand and eroded soil, and air pollutants that have settled on the ground or been washed out of the atmosphere by rain.

If stormwater is carried in a combined sewer system, it is usually treated in a MWTP, unless flows are too high, in which case the system is commonly allowed to overflow into receiving waters at various points upstream of the treatment plant. In most municipalities, though, stormwater is carried in separate storm sewers and discharged directly into a receiving water body without treatment. That situation has been changing gradually over the past 10–20 years, however, as communities have begun to realize that stormwater is an important pollution source.

Loadings of stormwater and CSO contaminants are difficult to measure because of the episodic and highly variable nature of wet weather events. In addition, contaminant concentrations in CSOs are much greater in the early phases of these events (known as the first flush) and drop off considerably during their later stages. Stormwater and CSO discharges, unlike those from sewage treatment plants, also occur at many points within an urban area. The Greater Vancouver Regional District, for example, has 50 CSO outfalls within the region's boundaries. In general, however, loadings to the environment depend on the extent and type of urban development in the watershed, the level of treatment (if any) that the stormwater might receive, and, in the case of CSOs, the source of the sewage that overflows (e.g., the amount and type of industries discharging to the sewer system). Consequently, the mix of discharged contaminants can vary considerably between watersheds and even between different locations within watersheds. There is also often considerable variability from one season to another and from one runoff event to another.

The approximate quantity and quality of stormwater entering aquatic ecosystems in Canada have not been very well documented. However, a recent review of 140 studies from the United States, Europe, and Canada (Makepeace et al. 1995) provides a useful indication of the contaminants that are commonly present. The review identified 28 pollutants with the potential to affect aquatic life and human health (mainly through the drinking water supply). The list included total solids, TSS, chloride, oxygen-depleting substances, 3 types of microorganisms, 12 heavy metals, and 9 organic chemicals.

CSO constituents have been studied even less than those of stormwater, in part because the design of combined sewers makes them more difficult to monitor than storm sewers. During the first flush, however, the CSO constituent levels resemble or even exceed those of raw sanitary sewage (especially if sewage sludge is scoured from the sewer bottom by high flows). The main pollutants of concern in CSOs are suspended solids, oxygen-depleting substances, nutrients (nitrogen and phosphorus), fecal bacteria, and toxic chemicals originating from local municipal and industrial sources (Environment Canada 1997).

Municipalities with combined sewer systems usually experience tens of CSO events in the course of a year. In the Greater Vancouver area, which experiences more CSOs than any other Canadian city, some of the major outfalls have 100–150 discharge events annually, with most of them occurring in the winter months (Hall et al. 1998a). Surface runoff volumes during an average stormwater discharge in the Great Lakes basin have been estimated at about 760 litres per capita per day (Marsalek and Schroeter 1988). If the average is taken for wet weather days only, however, the discharges are in the range of 2000–3000 litres per capita per day — considerably higher than the average municipal sewage flow of 300 litres per capita per day.

Estimates of annual stormwater and CSO pollutant loadings for the whole country are not available. However, loadings for the Canadian Great Lakes basin, an area that is home to over 9.2 million Canadians, have been calculated. For stormwater runoff, loadings were highest for TSS (91 000 tonnes per year), followed by oil and grease (100–1000 tonnes per year), metals (420 tonnes per year), PAHs (0.73 tonnes per year), PCBs (0.08 tonnes per year), chlorinated benzenes (0.06 tonnes per year), and organochlorine pesticides (0.03 tonnes per year) (Marsalek and Schroeter 1988; Marsalek, unpublished data). Typical concentrations of fecal coliforms and *E. coli* in Ontario stormwater have been measured at 1200–5100 cells per 100 millilitres and 800–6100 cells per 100 millilitres, respectively (Marsalek et al. 1992). For CSOs, estimated loadings of conventional pollutants were 17 400 tonnes per year for TSS, 3700 tonnes per year for BOD, 760 tonnes per year for total nitrogen, and 130 tonnes per year for total phosphorus (Waller and Novak 1981). Fecal coliforms measured in Ontario CSOs have measured as high as 1 million cells per 100 millilitres, probably during the first flush of contaminants (Waller and Novak 1981).

How significant are municipal wastewater effluents as a source of pollution?

Municipal wastewater effluents are a leading source of the BOD, TSS, nutrients, organic chemicals, and metals that are discharged into Canadian waters. Table 1, for example, shows that loadings of phosphorus from stormwater and CSOs are roughly comparable to those from industries that do not use municipal sewer systems, while loadings from municipal treatment plants are between two and three times higher. In the case of nitrogen, loadings from municipal treatment plants may be seven times higher than those from industries that discharge directly to the environment. Unfortunately, there is insufficient information available for comparison of the loadings of nutrients through runoff or leaching from agricultural fields in Canada.

Table 1: Comparison of nutrient loadings to surface water and groundwater from various sources in Canada, 1996

Nutrient source	Phosphorus (10^3 tonnes per year)	Nitrogen (10^3 tonnes per year)
Municipal		
MWTPs	5.6	80.3
Sewers (stormwater and CSOs)	2.3	11.8
Septic systems	1.9	15.3
Industry	1.9	11.5
Agriculture (residual in the field after crop harvest)	55.0	293.0
Aquaculture	0.5	2.3
Atmospheric deposition	n/a	182 (NO_3^- and NH_4^+)

Notes:
(i) Industrial data are not available for Manitoba, New Brunswick, Nova Scotia, or Prince Edward Island, and therefore this value is underestimated. Data for septic systems represent the amount of nutrients that are released after retention by the septic tank and drain field has been taken into account.
(ii) There is no national information on how much residual phosphorus and nitrogen from agricultural sources moves to surface or groundwaters.

(Source: Chambers et al. 2001)

Municipal wastewater effluents also overshadow direct industrial discharges as the dominant source of waterborne PCBs and mercury entering lakes Superior and Ontario, according to estimates for 1991 and 1992 (Table 2). The significance of municipal wastewater effluents as a source of water pollution, especially in heavily populated areas, is underscored by the fact that municipal wastewater pollution was identified as a major problem in 10 of the 17 Canadian Great Lakes localities originally identified as Areas of Concern in 1985 by the International Joint Commission.

Table 2: Estimated loadings of PCBs and mercury to lakes Superior and Ontario, 1991–1992

Loadings	PCB loadings (kilograms/ year)		Mercury loadings (kilograms/ year)	
	Lake Superior	Lake Ontario	Lake Superior	Lake Ontario
Industry	10	4	39	12
Stormwater runoff	18	83	40	29
CSOs	2	4	3	2
MWTPs	8	15	34	89
Spills			2	

Note: Some data may refer to earlier years.

(Sources: *Lake Ontario*: Thompson 1992; *Lake Superior*: Dolan et al. 1993)

The relative contribution of MWTPs, storm sewers, and CSOs to total municipal wastewater discharges varies considerably from place to place and is very much influenced by the population and development patterns of each area. There is also considerable variability between seasons and, of course, between wet and dry weather. Some idea of the relative importance of the different types of discharges can be gleaned, however, from a recent study that compared the estimated contaminant loadings and discharge volumes of wastewater treatment plants, storm sewers, and CSOs for 17 Canadian Areas of Concern in the Great Lakes area (Schroeter 1997). The results showed that stormwater runoff contributed 17–65% of annual wastewater volume in these areas, CSOs 1–6%, and wastewater treatment plants 35–80%. The wide range in these numbers reflects factors such as population density and the extent and type of development in each of the 17 areas. During wet weather events, however, these relative contributions changed dramatically, as stormwater, CSOs, and treatment plants discharged about 80%, 7%, and 13% of total wastewater volume, respectively. Over half of the TSS was discharged by storm sewers. During wet weather, however, loadings of suspended solids came almost entirely from stormwater and CSOs. On the other hand, treatment plants contributed the highest annual loadings of toxic contaminants and CSOs the lowest.

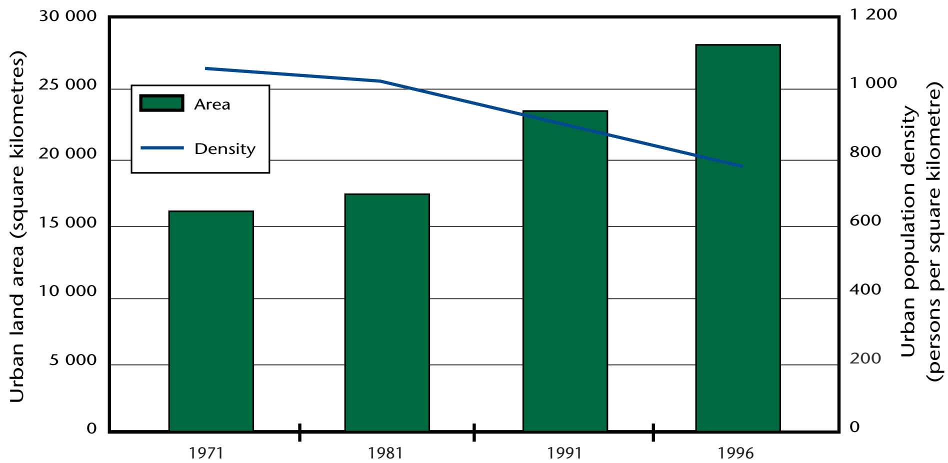
Factors influencing the effects of municipal wastewater effluents

The stresses that municipal wastewater effluents place on aquatic environments depend on several principal factors: the amount of effluent discharged, the quality of the effluent (i.e., the kinds and quantities of contaminants it contains), the characteristics of the receiving environment, the assimilative capacity of the receiving water, and climate and season.

Effluent volume

Other than precipitation, the amount of effluent discharged from a municipal sewage system depends mostly on the size of the population and the area served by the system, the nature of land use within the area, and the amount of water used by the population. Urban population growth has been a major factor in increasing the amount of municipal effluent discharged, through the increase in total water used and land development. In the quarter century since 1971, Canada’s urban population grew by 37% to a total of 22.5 million people, or 76% of the total population. Because this growth has been accommodated mostly by the development of low-density suburbs, urban land area has actually increased at a much greater rate than urban population. Between 1971 and 1996, Canada’s urban land area grew by 77%, or an additional 12 250 square kilometres, an amount equivalent to twice the area of Prince Edward Island (Statistics Canada 1997) (Figure 4). This growth is occurring within a relatively small area — the narrow band, no more than a few hundred kilometres wide, that runs adjacent to the border with the United States and contains 90% of the Canadian population. Many water bodies within this area are already stressed by human activities and competing land uses. The expansion of urban land use within this area only serves to intensify these pressures. The resulting increase in developed area has meant a corresponding increase in urban runoff and in the pollutants (such as oil and road salt) that it typically carries.

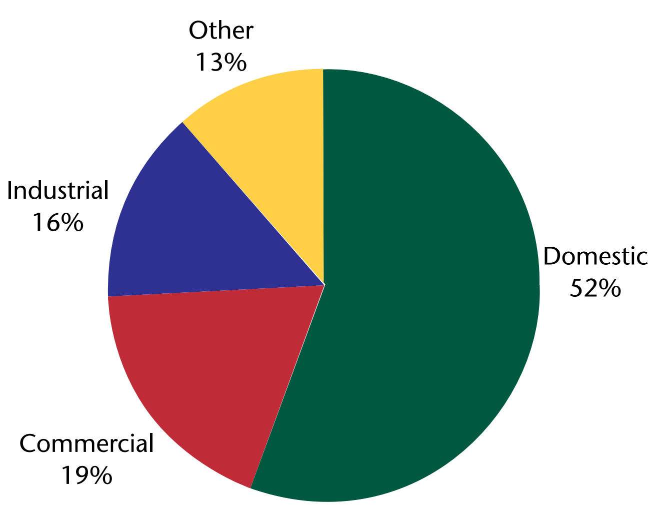
Figure 4: Urban land use and population density in Canada, 1971–1996



(Source: Statistics Canada 1997)

These stresses have been partially offset by an overall decline in municipal per capita water usage in the 1990s, reducing the per capita volume of sanitary sewage generated. However, total water usage in Canada is still increasing as a result of increasing urban populations. After peaking in 1989, municipal per capita water usage in Canada declined during the early 1990s by over 10%. Nevertheless, Canadian water usage is still exceptionally extravagant by international standards, and has recently increased slightly (2%) to an average municipal per capita consumption in 1999 of 638 litres per day — a level of usage second only to that of the United States. Slightly more than half of that water is used for household purposes such as cooking, cleaning, bathing, watering lawns, filling pools, and flushing toilets. The rest is used for commercial and industrial purposes and for other uses such as firefighting (Figure 5). Water lost through leaks in water mains can also account for a significant portion of municipal water use, ranging from 10 to 30% in some municipalities. This heavy water use, in combination with current land use patterns, is resulting in unnecessarily high volumes of municipal wastewater effluent.

Figure 5: Municipal water use by sector in Canada, 1999



(Source: Adapted from Environment Canada 1999b)

Effluent quality

The kinds of contaminants in sanitary sewage depend initially on what is released into the sewer system. Industrial and commercial discharges, in particular, have an important impact on sewage characteristics, with the difference between one community's sewage and another's often being determined by the number and types of businesses and industries connected to each municipality's sewers. Household sewage is more consistent from place to place, but the extent to which households dump motor oil, oil-based paints, solvents, and other toxic substances down their drains may also affect a community's sewage quality.

The level of treatment that wastewater receives determines the final concentrations of the major constituents in the effluent that is discharged to the environment. However, plants providing the same level of treatment may vary considerably in the quality of their effluent, and even individual plants will show variations in their effluent quality. These differences can be due to a wide variety of factors, including the plant's design, the skill of its operators, fluctuations in the flow level, and the season of the year. Local water consumption is also a significant factor, because heavy water usage dilutes the raw sewage and makes it more difficult to process effectively. Treatment plants operate more efficiently when processing relatively undiluted sewage in which the contaminants are more concentrated.

About 3% of the Canadian population served by sewer systems lives in communities that provide no treatment whatsoever for their sanitary sewage. Even in communities that have treatment facilities, significant discharges of untreated sewage can also occur, sometimes frequently, as a result of CSOs and sanitary sewer overflows or bypasses.

In the case of stormwater, land use is the major factor determining effluent quality. Heavily developed areas with high traffic volume, for example, tend to contribute higher levels of suspended solids, metals, and PAHs to stormwater and CSOs than do residential areas. Since most stormwater in Canada is discharged without treatment, stormwater discharges can have a significant impact on local water pollution characteristics.

Receiving environment characteristics

The physical and chemical characteristics of the receiving waters are important factors influencing the impacts of municipal wastewater on aquatic environments. These characteristics include water hardness, temperature, acidity or alkalinity, background concentrations of nutrients and metals, and the physical nature of the receiving water body (e.g., whether it is a stream, lake, or estuary; whether it contains fresh water or salt water). The toxic effects of ammonia, for example, are related to the pH and temperature of the receiving waters. Un-ionized ammonia, which is highly toxic to fish, exists in equilibrium in water with its non-toxic counterpart, ammonium (or ionized ammonia). When the water becomes warmer and more alkaline, however, more ammonium is converted back to un-ionized ammonia, and the concentrations of un-ionized ammonia rise. Thus, quite significant amounts of ammonia can form merely as the result of a change in water temperature and pH.

The toxicity of many substances, in fact, tends to be affected by elevated temperatures, such as are common near municipal wastewater outfalls. For most chemicals, acute toxicity increases by an average of 3.1 times for every 10°C rise in temperature (Mayer and Ellersieck 1988). The effects of water hardness and pH, on the other hand, tend to vary with the type of substance involved. Water hardness, for instance, affects the toxicity of most inorganic chemicals, such as chlorides, but has little effect on the toxicity of organic chemicals (Pickering and Henderson 1964; Inglis and Davis 1972). The relative acidity or alkalinity of the water can also alter the toxicity of metals and weak organic and inorganic acids and bases (Mayer et al. 1994). As the water becomes more alkaline, the toxicity of bases, such as ammonia, increases, and the toxicity of acids, such as sulphuric acid, decreases.

In addition, in the case of organic chemicals, their bioavailability (i.e., the portion of the total amount of chemical that is available for uptake by an organism) can be reduced by the presence of particles of organic matter. This is because organic chemicals tend to form complexes with particulate matter, and these complexes are too large to pass through gill membranes, for example (Gobas and Zhang 1994). Since the amount of particulate matter can differ between aquatic ecosystems, the bioavailability and hence the toxicity of a given concentration of a contaminant can differ substantially from one ecosystem to another. Similarly, the bioavailability and toxicity of a substance can be different in marine and freshwater ecosystems, although these differences have not been widely studied.

Assimilative capacity of the receiving water

The volume and flow of receiving water will determine its ability to dilute or assimilate effluent discharges and, hence, the extent of toxic effects occurring in the vicinity of the discharge. Although a concentrated effluent may be highly lethal in laboratory tests, receiving systems with a large assimilative capacity may dilute the effluent to the point where it is no longer deadly. However, in small watercourses, intertidal areas, or receiving waters that are subject to periodically low seasonal flows, the water volume may be insufficient to dilute the effluent to non-toxic levels (OMOE 1990). In addition, a large assimilative capacity may have little effect on the long-term impact of persistent chemicals that tend to accumulate in sediments or the tissues of aquatic organisms over long periods of time.

The dilution capacity of a receiving water body also varies with time and depends on the volume of the discharge and the flow of the receiving water at the point of discharge. Receiving water flow is determined by precipitation, surface runoff, groundwater discharge, and the area, slope, soils, and vegetation of the drainage basin. Tidal patterns can also influence the dilution capacity of estuarine and marine receiving waters.

Climate and season

Climatic conditions and seasonal variations can act upon a number of factors that influence the toxicity of municipal wastewater and its effects in the receiving environment. The factors affected include dissolved oxygen concentrations in receiving waters, temperature of the wastewater and the receiving environment, water levels and assimilative capacity, the types of contaminants that accumulate on urban surfaces (e.g., road salt), and the efficiency of sewage treatment plants. In the Fraser River Valley, for example, a study of stormwater contaminants showed that concentrations were higher in the summer months. This was because summer rainfall events in the area were on average less frequent but more intense than winter rainfall events. Not only were the more intense summer rains more effective at flushing contaminants from the streets, but the longer intervals between rainstorms left more time for contaminants to accumulate (Hall et al. 1998b). In Ontario, on the other hand, stormwater runoff, especially from highways, showed the highest levels of toxicity during the winter, because of the use of road salt, the accumulation of contaminants in snow, and the higher mobility of metals in chlorine-laden runoff (Marsalek et al. 1999).

2 Municipal wastewater effluents: Their effects on the environment, the economy, and human health in Canada

Urban effluents, including discharges of treated and untreated wastewater, overflows of sanitary and storm sewers, and surface water runoff, affect both human and ecosystem health. The effluent components can be chemical, physical, or biological in nature, and their impacts include changes in aquatic habitats and species composition, decreases in biodiversity, impaired use of recreational waters and shellfish harvesting areas, and contaminated drinking water (Table 3). These impacts all lead to a less valuable environment, a less prosperous economy, and, ultimately, a diminished quality of life.

Credit: Vincent Mercier, Indicators and Assessment Office

Table 3: Ecological and socioeconomic effects of municipal wastewater effluents

Effluent component	Observed effects			
	Ecological effects			Socioeconomic effects
	Water quality, habitat	Plants	Animals	Health, economy, recreation
Chemical Nutrients (phosphorus and nitrogen)	• increase in nutrient concentrations • depletion of oxygen due to decay of plant material • reduced water clarity	• changes in algal species composition • increase in submerged weed growth • increase in algal biomass and possible formation of toxic blooms	• changes in species composition due to changes in food supplies for herbivores • reduced productivity and survival of invertebrates and fish due to oxygen depletion • concentration of biotoxins by shellfish	• health risk from contamination of drinking water with nitrates • algae-related taste and odour problems in drinking water • health risk from consumption of shellfish contaminated with algal toxins • blockage of water intakes by filamentous algae and weeds • interference with passage of boats by submerged weeds • degradation of shorelines and impairment of recreational uses by nuisance algae • economic losses from biotoxin-related closures of shellfish growing areas
Toxic contaminants (bioaccumulative and non-bioaccumulative)	• increased concentrations of toxic contaminants in water and sediments	• acute or chronic toxicity (affecting reproduction, growth, survival), resulting in changes in species abundance and diversity • bioaccumulation of toxic contaminants	• acute or chronic toxicity (affecting reproduction, growth, survival), resulting in changes in species abundance and diversity • bioaccumulation of toxic contaminants • biomagnification of contaminants at higher food web levels	• health risk from consumption of contaminated fish and shellfish • health risk from contaminated drinking water • economic losses from closures of fish and shellfish growing areas contaminated with metals and/or organic compounds

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Table 3: Ecological and socioeconomic effects of municipal wastewater effluents

Effluent component	**Observed effects**			
	Ecological effects			**Socioeconomic effects**
	Water quality, habitat	**Plants**	**Animals**	**Health, economy, recreation**
Endocrine-disrupting chemicals (see *Continuing and emerging problems* section)			• deformities and embryo mortality in birds and fish • impaired reproduction and development in fish • depressed thyroid and immune functions in fish-eating birds • feminization of male fish and reptiles	• risks to human health from consumption of contaminated food (e.g., fish and shellfish) and water • economic and recreational losses due to restrictions on consumption
Physical				
Increased water flow (stormwater discharge)	• stream- or riverbed erosion leading to increased concentrations of suspended solids in the water • bank erosion leading to increased concentrations of suspended solids • flooding • habitat washout		• loss of habitat • washout • downstream drift of bottom-dwelling invertebrates	• economic and recreational losses due to reduced fish abundance
Suspended solids	• reduced water clarity • transport of adsorbed contaminants • sedimentation-related changes to water flow	• reduced photosynthesis and plant growth due to reduced water clarity	• blanketing of spawning grounds • reduced growth or survival of species • blockage of migration or dispersal routes by accumulated sediments	• economic and recreational losses due to reduced fish abundance

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Table 3: Ecological and socioeconomic effects of municipal wastewater effluents

Effluent component	Observed effects: Ecological effects			Observed effects: Socioeconomic effects
	Water quality, habitat	Plants	Animals	Health, economy, recreation
BOD	• reductions in dissolved oxygen in water column and sediments due to buildup of oxygen-consuming material		• fish kills, loss of species, reduced biodiversity	• economic and recreational losses due to reduced fish abundance
Heating of the receiving water	• ambient water temperature increase	• succession from cold-water to warm-water algal species	• succession from cold-water to warm-water fishery	• economic and recreational losses due to changes in fisheries
Floating debris	• reduced aesthetics		• entanglement leading to starvation, exhaustion, and infection from wounds • ingestion of debris leading to blocked digestive tract	• health risk from waste on beaches (e.g., medical waste) • loss of tourism revenue due to reduced aesthetic value • increased costs for beach and park maintenance
Biological				
Pathogens (bacteria, viruses, protozoa)	• increased concentrations of pathogens in water and sediments		• increased concentrations of pathogens in filter-feeding shellfish (bivalve molluscs)	• health risk from consumption of contaminated drinking water, fish, and shellfish • health risk from recreational exposure to contaminated water and sediments • restricted recreational use (swimming and fishing) • economic losses due to closures of fish and shellfish growing areas and beaches

(Source: Derived, in part, from Chambers et al. 1997)

Ecological impacts and their significance

Municipal wastewater effluents are responsible for the degradation of several ecosystems across the country. Impacts may arise from an increase in nutrient loads, decreased levels of dissolved oxygen, and releases of toxic substances, many of which can bioaccumulate and biomagnify in aquatic wildlife. Physical changes to the environment can also occur, including thermal enhancement, increased water flow, leading to potential flooding and erosion, an increase in suspended solids, and the release of floating debris to the country's waters.

Nutrient enrichment

One of the most widely recognized and studied environmental effects of municipal wastewater effluents is nutrient enrichment (Welch 1992). Some nutrients, particularly phosphorus and nitrogen, are essential for plant production in all aquatic ecosystems. However, an oversupply of nutrients can lead to the growth of large algal blooms and extensive weed beds. Such a condition is known as eutrophication, and it degrades aquatic ecosystems in a number of ways.

In lakes where large algal blooms are present, the death of the vast numbers of phytoplankton that make up the blooms may smother the lake bottom with organic material. The decay of this material can consume most or all of the oxygen dissolved in the surrounding water, thus threatening the survival of many species of fish as well as bottom-dwelling vertebrates and invertebrates. Some algal blooms, in both lakes and marine coastal areas, also contain substances that are poisonous to both humans and wildlife.

In rivers and streams, the addition of nutrients tends to encourage the growth of periphyton, the stringy algae that grow on rock surfaces, and rooted aquatic plants. Excessive enrichment, however, can result in deoxygenation of the water and a consequent decline in the productivity of periphyton, as well as reductions in populations of bottom-dwelling invertebrates and fish and losses of some species.

In marine coastal waters, nutrients stimulate the rapid growth of phytoplankton and larger varieties of algae, which reduces the amount of light reaching seagrasses on the bottom. As the seagrasses, which stabilize the bottom sediments, die off, the water becomes more turbid and increasingly inhospitable to bottom plant life. Meanwhile, the phytoplankton, which float near the surface where there is greater light exposure, thrive and continue to multiply. With the disappearance of the seagrasses, many fish and bottom-dwelling organisms lose an important element of their habitat and are no longer able to survive.

The net effect of eutrophication on an ecosystem is usually an increase in the abundance of a few plant types (to the point where they become the dominant species in the ecosystem) and a decline in the number and variety of other plant and animal species in the system. Sportfish are among the species most often lost when water bodies become eutrophic. Probably one of the best known examples of a eutrophied lake in recent years, and its subsequent recovery, is Lake Erie (Box 2). However, local eutrophication problems remain a concern in several Canadian Great Lakes communities. Most rivers in the populated regions of Canada also show signs of nutrient enrichment downstream of municipal wastewater outlets or areas of intensive agriculture. In addition, periodic fish kills in Halifax Harbour have been linked, in part, to phosphorus inputs from raw sewage.

Box 2: Recovery of Lake Erie

Lake Erie is one of the most widely recognized examples of how an aquatic ecosystem can be damaged by excessive nutrient loadings and how controls on nutrient inputs can lead to its restoration. The damage began in the 1800s, when soil erosion as a result of the clearing of land for agriculture and settlement increased phosphorus loadings to the lake. Another, more dramatic, rise in phosphorus loadings began in the 1940s, as more and more people were connected to sewage systems that discharged to the lake and detergents with high phosphorus content came into use.

Concern about the persistent foam from detergents, the increasing degradation of visible water quality, and other environmental problems prompted authorities to undertake scientific studies of the causes and impacts of pollution in the lake. In 1970, a binational study confirmed a link between increasing concentrations of nutrients, particularly phosphorus, and the appearance of nuisance algae. To resolve the problem, modelling exercises suggested that phosphorus loadings would have to be reduced from roughly 28 000 tonnes a year to about 11 000 tonnes. In 1972, with the signing of the Canada–U.S. Great Lakes Water Quality Agreement, the two countries agreed to take steps to reduce phosphorus loadings to the recommended level of 11 000 tonnes per year.

Four main strategies were employed to achieve this target:

- The use of phosphorus in detergents, which at the time accounted for about 25% of the phosphorus in sewage, was gradually phased out.
- MWTPs were constructed in communities where none existed, and primary treatment plants were upgraded to secondary treatment.
- Specialized treatment was employed to decrease phosphorus concentrations in sewage treatment plant effluent to 1 milligram per litre or less at plants handling more than 265 000 litres per day.
- Because phosphorus from agricultural fertilizers and manure was also a major contributor to the problem, farmers were encouraged to adopt practices that reduced runoff and erosion from their fields.

By the mid-1980s, the total phosphorus load to Lake Erie had been reduced by more than 50%. Since then, it has continued to oscillate around the recommended level of 11 000 tonnes annually.

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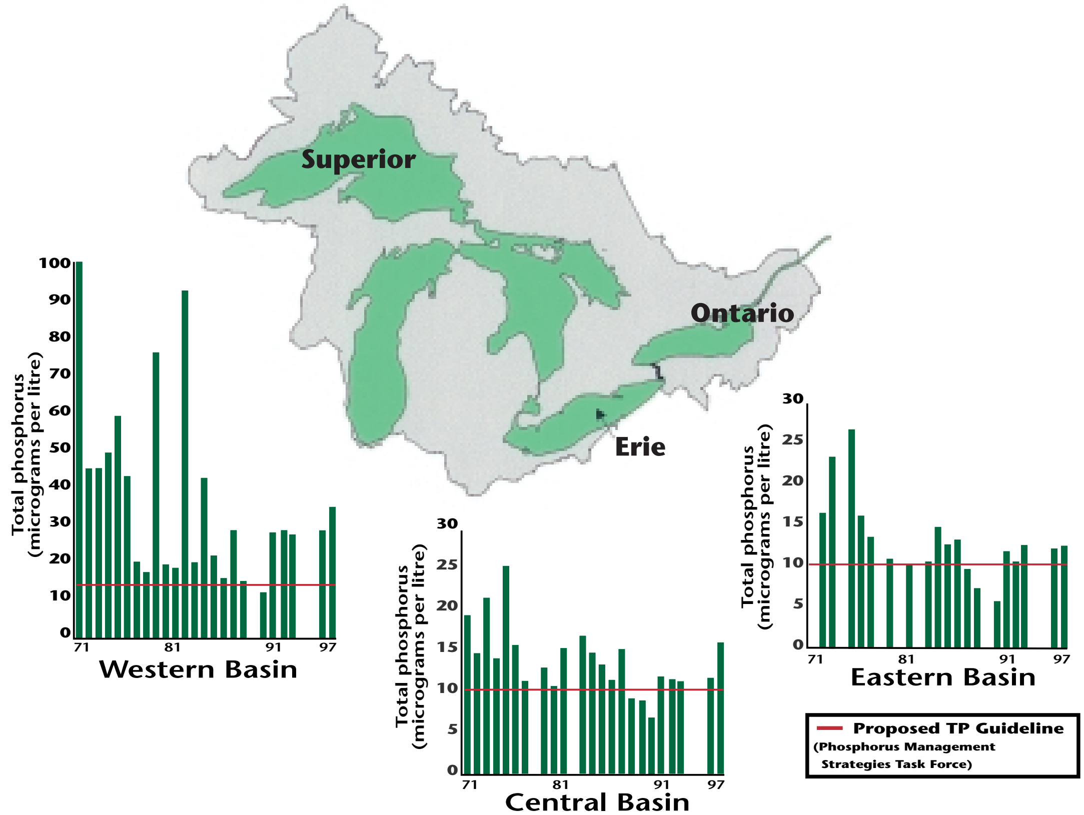


(Source: Environment Canada 1999c)

Depletion of dissolved oxygen

Although nutrients in wastewater contribute to oxygen depletion through eutrophication, other constituents of wastewater effluents do so more directly. Wastewater effluents contain large quantities of organic solids, and the bacterial breakdown of this material and the oxidation of chemicals in it can consume much of the dissolved oxygen in the receiving water. The amount of oxygen consumed by decay processes over a period of days is known as the BOD in a laboratory analysis of the effluent. Oxygen consumed over a couple of hours through chemical reactions is known as the chemical oxygen demand of the effluent.

Since dissolved oxygen is essential to most aquatic life, oxygen depletion can have serious effects on aquatic life (Box 3). These effects may be immediate and short-term or may extend over months or years as a result of the buildup of oxygen-consuming material in the bottom sediments (Hvitved-Jacobsen 1982).

The amount of oxygen that can be dissolved in water depends on water temperature, elevation above sea level, and salinity. More oxygen can dissolve in cold water than in warm water. Similarly, fresh water holds more oxygen than salt water, and water at lower elevations (where the air pressure is greater) holds more oxygen than water at higher elevations. Harmful episodes of oxygen depletion often occur during summer when the water is warm and can hold less oxygen. However, serious depletion episodes can also occur in winter when ice cover on rivers and lakes prevents the replenishment of the water's dissolved oxygen from the air (Chambers and Mills 1996). In Canada, many northern ice-covered rivers may be vulnerable to the effects of wastewater effluent on winter oxygen levels.

Box 3: Depletion of dissolved oxygen in the Fraser River estuary

In the 1980s, studies were carried out to assess the impact of sewage from the Iona Island treatment plant on fish and the receiving environment of Sturgeon Bank in British Columbia's Fraser River estuary. Prior to 1988, effluent from the treatment plant was discharged at high tide onto the intertidal area of the bank. At low tide, the effluent was conveyed seawards across extensive sandflats by a dredged channel that extended more than 6 kilometres into the Strait of Georgia. A rock jetty paralleled the effluent channel on its north side for about 4 kilometres and effectively restricted the dispersion of effluent to the southern portion of the bank. When the bank was submerged by the tide, the oxygen demand of the effluent and sludge beds in the vicinity of the outfall progressively reduced the dissolved oxygen in the receiving waters. The dissolved oxygen depression frequently extended more than 4 kilometres into the Strait of Georgia, but tended to be close to the jetty at low tide. Many organisms encountering this oxygen-deficient water became stressed or were killed.

As both bottom-dwelling species such as flounder and halibut and pelagic or upper-water species such as herring were affected, it was clear that oxygen depletion had occurred throughout the water column. Fish in oxygen-depleted waters typically rise to the surface to breathe and in doing so become easy prey for predatory birds. Herons and gulls on Sturgeon Bank usually congregated around oxygen-deficient waters where fish could be found at the water's surface.

Many dead flatfish of different age classes were found on the intertidal sandflats of Sturgeon Bank. In addition, catches of flatfish began to decline in the fishing area adjacent to the Fraser River just after the Iona Island treatment plant came into operation (Birtwell 1996).

The realization of these significant ecological impacts led in 1988 to the extension of the Iona outfall diffuser beyond the estuary and into the Strait of Georgia, thus eliminating the old discharge point on Sturgeon Bank. Scientists have since studied the re-establishment of aquatic life in the vicinity of the old outfall and measured changes in water and sediment quality. Several improvements have been seen, and oxygen concentrations in the water above the sediments have recovered from the low levels experienced when the outflow was on the bank (Environment Canada 1998a).

Low dissolved oxygen levels affect the survival of fish by increasing their susceptibility to disease, slowing growth, hampering swimming ability, altering feeding, migration, and reproductive behaviour, and making them less adept at avoiding predators. Extreme oxygen depletion results in rapid death. Low dissolved oxygen levels can also affect fish indirectly by reducing the populations of organisms that they eat (Alberta Environmental Protection 1996).

Long-term reductions in dissolved oxygen concentrations can result in changes in species composition. An increase in food supply in the form of more detritus tends to lead to a less diverse assortment of bottom fauna, dominated by worms and midges. This tends to favour bottom-feeding fish such as suckers and carp. In Lake Erie, for example, the populations of cisco, whitefish, walleye, sauger, and blue pike declined drastically over the 40-year period when loadings of nutrients to the lake were increasing. The total fish catch, however, did not decline. Instead, the catch of more desirable species was replaced with such species as carp, buffalo fish, freshwater drum, and rainbow smelt (Welch 1992).

Direct toxicity to wildlife

The toxic impacts of municipal wastewater on wildlife may be acute and occur within a short period of time, or they may be cumulative and appear only after an extended period of time (Hvitved-Jacobsen 1986; Harremoes 1988). Acute impacts from treatment plant effluents are generally caused by high levels of ammonia and chlorine, high loads of oxygen-demanding materials, or toxic concentrations of heavy metals and organic contaminants. Cumulative impacts result from a gradual buildup of pollutants in the receiving water or in its sediments and biota and become apparent only after accumulation exceeds a certain threshold. Because of the complexity and variability of municipal effluents, however, and the variety of environmental factors that affect their biological activity individually and in combination, it is not easy to arrive at broad generalizations about the toxicity of municipal wastewater effluents (Welch 1992; Chambers et al. 1997).

Laboratory toxicity tests using planktonic algae, zooplankton, and fish have been conducted for effluents from many Canadian treatment plants to determine the level at which concentrations become lethal or cause physiological or behavioural changes.[9] Although organisms differ in their responses to complex effluents (and to specific substances within these effluents), un-ionized ammonia has been shown to be the most frequent cause of toxicity in municipal wastewater effluents. Municipal treatment plants are, in fact, the leading quantifiable source of ammonia entering aquatic ecosystems throughout Canada.

Freshwater organisms are most at risk from exposure to ammonia (Environment Canada 2000). Some of the most sensitive species include rainbow trout, freshwater scud, walleye, mountain whitefish, and fingernail clams. Aquatic insects and micro-crustaceans are more resistant to ammonia, although there is a large variation in sensitivity among aquatic insects (Environment Canada 2000). The major impact of ammonia in aquatic ecosystems is likely to occur through chronic toxicity to fish and bottom-dwelling invertebrates, resulting in reduced reproductive capacity and reduced growth in the young.

The zone of impact from the toxic components of municipal wastewater effluents varies considerably with discharge conditions, such as river flow rate, temperature, and pH. For example, waters most at risk from municipal wastewater-related ammonia are those that are routinely basic in pH with a relatively warm summer temperature combined with low flows. Under estimated average conditions, some municipal wastewater discharges could be toxic for 10–20 kilometres from their point of release. Severe disruption of bottom flora and fauna has been noted below municipal wastewater discharges, and normal bottom conditions may not resume until as much as 20–100 kilometres from the discharge site.

[9] For a detailed review of laboratory toxicity tests of municipal wastewater effluent components, please refer to Environment Canada (1997).

Bioaccumulation and biomagnification of contaminants

Substances that are found only in low or even barely measurable concentrations in water can sometimes be found in very high concentrations in the tissues of plants and animals. This is due to a phenomenon known as bioaccumulation. Bioaccumulative substances tend to be very stable and long-lived chemically and are not easily broken down by digestive processes. Many of them are more soluble in fat than in water and therefore tend to accumulate in fatty tissues rather than being excreted from the body. A limited number of these contaminants can undergo a further phenomenon whereby their concentrations increase even more dramatically by being passed up the food chain from prey to predator. During this phenomenon, each predator receives the contaminants that each of its prey has accumulated in a lifetime and passes its own accumulation on when it is eaten by predators at the next level in the food chain. This process is called biomagnification; because of it, concentrations of a persistent toxic substance in an animal at the top of the food chain, such as a herring gull or a beluga whale, can be 10 million times greater than concentrations in the water.

Because of these processes, even very low concentrations of certain substances in wastewater are of concern. Examples of persistent, toxic, bioaccumulative substances that have been detected in municipal wastewater include PCBs, dioxins and furans, organochlorine pesticides, and mercury and other heavy metals. Only a few metals and organic chemicals, such as mercury and DDT, are known to biomagnify throughout food webs, even though many substances can bioaccumulate. The effects of bioaccumulating substances on wildlife are well documented and include reduced reproductive success, physical deformities, tumours and lesions, reduced growth rates, and impairment of the central nervous system (Box 4). Although there are several other sources of persistent, bioaccumulative, toxic substances in the environment, including industrial discharges and deposition of atmospheric contaminants, municipal wastewater remains one of the most significant (Government of Canada 1996).

Box 4: Toxic contaminants and the plight of the beluga

High concentrations of many persistent, toxic, bioaccumulative substances have been found in top predators in various regions across Canada. One notable example is the St. Lawrence population of the beluga. Since 1885, when there were approximately 5000 St. Lawrence belugas, the population has dwindled to somewhere between 300 and 700 individuals. As a result of this decline, the beluga has been placed on the species at risk list of the Committee on the Status of Endangered Wildlife in Canada.

The decline of this population has been attributed, in part, to high levels of contaminants in the fatty tissues of the whales. PCBs, DDT, and mirex concentrations are, respectively, 25, 32, and 100 times higher in St. Lawrence male belugas than in Arctic-population males. These contaminants come chiefly from prey species, particularly the American eel, which migrates from the highly urbanized Great Lakes and Upper St. Lawrence region. American eels are thought to be the source of all the mirex (a flame retardant and pesticide whose use is now banned) and up to 50% of the other toxic chemicals in the whales. These high levels of contaminants are thought to be responsible for decreased reproductive success, the appearance of rare diseases, and suppressed immune systems in the belugas (Beland et al. 1993; Beland 1996).

Physical changes to receiving waters

Thermal enhancement

Because aquatic life forms have characteristic temperature preferences and tolerance limits, an increase in the average temperature of a water body can have important ecological effects. These include changes in the variety and abundance of species as well as enhanced algal growth (Welch 1992). Municipal wastewater effluents can be a source of thermal enhancement because they are usually warmer than the water bodies that they empty into. Warm urban surfaces such as roads and rooftops, for example, add heat to rainwater as it runs off these surfaces and flows into storm or combined sewers. Further warming may occur in runoff control facilities, particularly stormwater ponds with extended detention times. In fact, studies have shown that, in summer months, stormwater pond effluent might be up to 10°C warmer than the inflow (Schueler 1987). Effluent from wastewater treatment plants may also contribute to thermal enhancement. Temperature enhancement becomes more noticeable during periods of low flow, particularly when the effluent is discharged into standing water bodies.

Increased water flow

Flow is one of the most important physical factors affecting the structure of aquatic habitats. Increased or more variable water flow from urban runoff and wastewater effluents can cause habitat changes in any receiving water. However, the most serious impacts occur in small urban creeks. Urbanization increases the volume of surface runoff by reducing the infiltration of rainwater into the ground and reducing evapotranspiration from vegetation. Urban drainage systems also provide better conveyance channels that can remove surface runoff at a faster rate and thus increase peak runoff flows.

The environmental effects of increased wastewater flows include bank erosion and flooding, erosion of stream- or riverbeds, and washouts, all of which result in habitat degradation (Schueler 1987; Borchardt and Statzner 1990). Some flow impacts, such as flooding and washout, are instantaneous, while others, such as changes in the physical structure of the stream and the resulting loss of habitat, are long-term. The broader ecological impacts can include changes in the food web and losses of critical species. Fishing is the most affected beneficial water use (Lijklema et al. 1993).

Increased suspended solids

Suspended solids occur naturally in surface waters as a result of erosion, transport of material from the lake or river bottom, and tributary inflows. They are also added by erosion caused by human activity and by effluents. Municipal wastewater effluents are responsible for a long-term continuous input of suspended solids to the environment.

Suspended solids released into receiving waters, mainly from stormwater or CSO discharges, can cause a number of direct and indirect environmental effects, including reduced sunlight penetration (and consequently reduced photosynthesis), smothering of spawning grounds, physical harm to fish, and toxic effects from contaminants attached to suspended particles (Horner et al. 1994). The growth and survival of some species may also be affected, either through direct effects (e.g., abrasion of sensitive tissues) or through indirect effects caused by changes in the food web or interference with dispersal or migration (e.g., the blockage of zones of passage). Such effects can manifest themselves on various time scales. A single large rainfall or runoff event can cause significant immediate impacts, but generally the long-term effects are more important.

Floating debris

Our rivers, lakes, and oceans contain an astonishing amount of debris from human sources. Debris that originates on land includes plastic bags, fast food containers, pop cans, plastic chip and candy bags, coffee cups, cigarette butts, tampons, condoms, and plastic ring six-pack holders. If this debris is carried to a treatment plant, it is generally screened out.

Marine mammals and seabirds are particularly at risk from this material. Plastic bags floating on the water's surface resemble the jellyfish that are eaten by many species of fish, dolphins, and turtles. Death can result from a blocked digestive tract, from toxic by-products produced by the digestion of some plastics, or through starvation from a false sense of being full. Wildlife entangled or snared in plastic debris face starvation, exhaustion, infection from wounds, or drowning.

Even though the oceans would seem to have an infinite capacity to disperse and absorb such materials, ocean currents tend to concentrate them in areas where currents meet. One such area is the northern Sargasso Sea in the Atlantic Ocean, which is a favourite spawning place for fish. It is difficult to determine how much debris is present in any given ocean area, but one study estimated that 8 tonnes of debris wash up on the shores of Sable Island, off the Nova Scotia coast, every year. About 92% of this material is plastic. On the west coast, Fisheries and Oceans Canada has estimated that between 100 000 and 500 000 pieces of debris are floating in British Columbia's coastal waters.

Although MWTPs screen out solid material in raw sewage, municipal wastewater effluents are still a significant source of debris in the environment. Stormwater and CSOs are major contributors; in many of Canada's coastal areas, however, the still-widespread practice of discharging raw sewage directly to the oceans provides a large and constant inflow of floating debris.

Human health and socioeconomic impacts

In Canada, the cost of treating health problems related to water pollution is estimated at about $300 million per year (Health Canada 1997). Canadians may be exposed in a variety of ways to chemicals and pathogens in water. They may ingest small amounts of pollutants in their drinking water, absorb contaminants through their skin while bathing or swimming, or inhale airborne droplets or vapours while showering. They may also ingest food, such as fish and shellfish, that has been contaminated by waterborne pollutants (Health Canada 1997). In addition to such human health impacts, pollution from wastewater effluents can reduce the social and economic benefits that we derive from the use of water. These impacts include periodic closures of urban beaches, closures of commercial fisheries because of fish and shellfish contamination, and aesthetic problems (with associated losses in tourism income).

Contamination of drinking water and waterborne diseases

Waterborne diseases caused by bacteria, viruses, and protozoa are the most common health hazards associated with drinking water (and recreational waters) in Canada (Health Canada 1997). Human and animal wastes are the main sources of these microbial contaminants. Most municipalities treat and disinfect water used for drinking; thus, widespread outbreaks of waterborne infections are rare. Even so, isolated incidents of microbial contamination of drinking water in Canada from CSOs, stormwater, and inadequately treated sewage have been reported (Box 5). These are usually associated with either poorly functioning water treatment facilities or the complete lack of such facilities and a dependence on good-quality raw water.

Box 5: Microbial contamination of drinking water in Canada from combined sewer overflows, stormwater, and inadequately treated municipal wastewater treatment plant effluents

Most reported outbreaks of waterborne disease in Canada are due to the protozoa *Giardia* and *Cryptosporidium*. Protozoa are capable of surviving for long periods of time in the aquatic environment as dormant cysts or oocysts and are generally more resistant to chlorination than pathogenic bacteria or viruses.

Giardia causes giardiasis, which is a long-lasting gastrointestinal disease. Fecal contamination from wild and domestic mammals has often been implicated in water-related outbreaks of giardiasis. Despite the potential for disease transmission by animals in Canada, most water-related outbreaks have been traced back to human sewage contamination (Health Canada 1998). In 1988 and 1989, five outbreaks of giardiasis from contaminated drinking water, involving 18 people, were reported in Canada. Since then, further outbreaks have occurred. Those related to sewage contamination include outbreaks in Temagami, Ontario, in 1994 and Dauphin, Manitoba, in 1996. The latter incident involved over 30 confirmed cases of giardiasis (Government of Manitoba 1997). The potential for giardiasis outbreaks is greater in northern regions, since cold water and ice cover provide ideal conditions for the proliferation of parasites (Yukon Department of Renewable Resources and Environment Canada 1996).

Cryptosporidium is even more resistant to chlorination than *Giardia*. In 1996, an outbreak of cryptosporidiosis, an intestinal illness similar to giardiasis, was reported in Kelowna, British Columbia, where an estimated 15 000 people became ill. Heavy rains and snowmelt in the spring may have contributed to the outbreak. It has also been suggested that unusual wind conditions reversed the normal flow patterns in Lake Okanagan and pushed the sewage discharge back towards the city's water intake. Cryptosporidiosis can be fatal in people who have weakened immune systems, such as AIDS patients.

Health Canada has indicated that the true incidence of waterborne diseases is likely much higher than reported, as the majority of cases involve mild, flu-like symptoms that do not require medical treatment (Health Canada 1997).

Ironically, another potential human health risk associated with municipal wastewater effluents results from the use of chlorine as a disinfectant in both wastewater and drinking water treatment. The use of chlorination to disinfect drinking water began in Canada around 1916. The provision of chlorinated water from this point on virtually eliminated typhoid fever, cholera, and other waterborne diseases and was one of the great achievements of public health policy in Canada during the 20th century. Unfortunately, chlorine's potent oxidizing power causes it to react with naturally occurring organic material in raw water to produce hundreds of chlorinated organic compounds, referred to generically as chlorination by-products (CBPs). These by-products were first reported in drinking water in 1974. The most common CBPs are called trihalomethanes (THMs), a group of chemicals that includes chloroform, bromodichloromethane, chloro-di-bromomethane, and bromoform. Canadians may be exposed to THMs by drinking chlorinated water or beverages produced with chlorinated water, by inhaling airborne THMs released from tap water, or by absorbing THMs directly through the skin, particularly during showers (Health Canada 1997). Although only a few CBPs have been tested so far, the evidence suggests that they may pose a significant risk of cancer, particularly bladder cancer, to humans (Wigle 1998).

In addition to the health risks associated with contaminated water, communities may have to deal with taste and odour problems caused by large accumulations of algae. Additional filtration may provide a remedy for these problems, but at increased cost to the municipality (Anderson and Quartermaine 1998). The City of Toronto, for example, recently spent $6 million to install granulated carbon filters at its four filtration plants to deal with algae-related odour problems.

Water degradation and recreational water uses

Nearshore recreational areas can be easily contaminated by bacteria and other pathogens that are present in CSOs, stormwater, and poorly treated sewage. Contact with microbially contaminated waters may cause gastrointestinal disorders and minor skin, eye, ear, nose, and throat infections.

E. coli and/or fecal coliforms are generally used as indicators of contamination by pathogens that cause such diseases as hepatitis B, enteritis, cholera, and typhoid fever (Box 6). The current federal guideline for recreational water quality states that between 1 and 2% of recreational water users would be at risk of gastrointestinal illness at an *E. coli* (or fecal coliform) concentration of 200 per 100 millilitres (Health and Welfare Canada 1992). Many of the provinces and territories, however, have their own guidelines for recreational water quality.

Credit: Vincent Mercier, Indicators and Assessment Office

Box 6: Fecal coliforms: What can they tell us about water quality?

Fecal coliforms include several species of bacteria that naturally inhabit the guts of humans and animals. Because they are expelled from the gut in feces, they eventually end up in sewage and urban runoff. Some fecal coliforms, such as certain strains of *E. coli*, can be pathogenic — that is, they can cause disease (Health Canada 1997). Other disease-causing bacteria, viruses, and protozoa, originating from infected individuals, can also be transmitted to water bodies through wastewater discharges. Fortunately, the more advanced types of wastewater treatment, especially those with disinfection (e.g., ultraviolet radiation or chlorination), are effective at reducing pathogen numbers in the final effluent.

Identifying and enumerating all the disease-causing viruses, bacteria, and protozoa in wastewater on a regular basis would require an extraordinary amount of time, labour, and money (Droste 1997). However, if fecal coliforms are present in the water, one can assume that other pathogens that have passed through human and animal digestive systems will also be present. Thus, municipal and provincial/territorial authorities measure fecal coliform levels to estimate the degree to which water is contaminated by fecal pathogens. Fecal coliforms are especially useful for this purpose because they generally occur in high numbers in wastewater, can easily be identified and counted, and have been correlated with the presence of other pathogens (Geldreich 1978; Droste 1997).

In Canada, coliform counts are used to determine whether beaches should be open for recreation, whether water is fit for consumption, and whether shellfish growing areas should be open for harvesting. Although the total fecal coliform count has historically been the most widely used indicator, other bacterial indicators, such as *E. coli* and fecal streptococci counts, are now more commonly used in Canada.

Beaches are closed by local authorities when contaminant levels exceed guideline thresholds and remain closed, often for several days, until contaminant levels have returned to safer values. It is difficult to obtain comprehensive beach closure data on a national level due to differences in data collection methods by the municipalities. However, some beach closure data do exist. For example, between 1986 and 1994, 44% of Ontario's Great Lakes beaches, most of them on Lake Ontario, were subject to closure notices at one time or another (Edsall and Charlton 1997). During the year 2000 swimming season in Manitoba, 46 beaches were monitored and 5 (11%) exceeded recreational guidelines at least once. Beach closures in Canada occur most frequently after heavy rainfalls.

Large quantities of algae can also interfere with recreational uses and reduce the aesthetic appeal of the shoreline. Algal blooms can cause increased water turbidity and discoloration, unpleasant odours, excessive fouling of fishing gear, and foaming along coastlines. In places where the nuisance species *Cladophora* has taken hold, long strands that break off in late summer and during storms can accumulate along shorelines to a thickness of a metre or more. The accumulations make swimming undesirable, and subsequent decay generates noxious amounts of ammonia, which may render adjacent properties unusable and lower their value. Increased plant growth can also cause problems for boaters.

A more serious threat from algal growth comes from certain species of blue-green algae that produce potent toxins that can damage the liver or nervous system. These toxins have also been blamed for animal poisonings in Alberta, Saskatchewan, Manitoba, and Ontario. Although the foul appearance and odour of the water deter people from drinking it, accidental exposures may occur during recreational activities, such as swimming, canoeing, and sailing.

Other wastewater problems that interfere with recreational uses include floating debris, which diminishes the aesthetic appeal of a shoreline area and makes it less attractive to tourists (Box 7), and stresses from increased water flow, suspended solids, BOD, and thermal enhancement, which can diminish the abundance and variety of fish in an area and hence its potential for sport fishing. In Nova Scotia, for example, the Survey of Recreational Fishing reported that the total number of recreational fish caught by anglers declined by nearly 1.7 million fish, or 45%, between 1990 and 1995. This resulted in a $5.5-million decline in total recreational fishing expenditures on food and lodging, transportation, and fishing services between these years. The disposal of untreated municipal wastewater effluents was partly responsible for these declines (Wilson 2000a).

Box 7: Tourism and untreated sewage

The *Norwegian Sky*, the second largest cruise ship in the world at 76 000 tonnes, recently visited St. John’s, Newfoundland, and contributed over $200 000 to the local economy. Visits to the harbour by large ships are now possible because of the widening of the harbour entrance in the Narrows. However, St. John’s appeal as a tourist destination is somewhat compromised by the release of 120 million litres of raw sewage and stormwater runoff into the harbour every day from the surrounding municipalities. Much of this is deposited on the harbour floor. When the organic waste is decomposed by anaerobic bacteria, highly odorous hydrogen sulphide gas accumulates. When large ship propellers churn up the sediment, the gas is released and can cause some people to become ill from the smell.

Tour boat operators also report that tourists are displeased when they spot wastes (condoms, sanitary napkins, tampons, toilet paper, and other flushable material) in the water, both inside St. John’s Harbour and while travelling along the coast. There is no doubt that sewage pollution in Canada’s coastal communities is having a significant negative impact on the tourism industry.

Contamination of shellfish growing areas

The marine coasts of Canada support a shellfish industry that had a total landed value of over $1 billion in 1997 (Statistics Canada 2000). Unfortunately, this industry may not achieve its full potential, because large areas along both the Atlantic and Pacific coasts are closed to harvesting as a result of sewage contamination or the presence of dangerous levels of toxins and pathogens from both natural and human sources. Shellfish consist of crustaceans, such as lobsters and crabs, and bivalve molluscs, such as clams, mussels, and oysters. It is the consumption of bivalve molluscs that poses the greatest threat to human health. Because bivalve molluscs filter large volumes of water to extract suspended food particles, any harmful bacteria, viruses, and toxic substances present in the water can be concentrated in these organisms to much higher levels than occur in the surrounding waters.

Municipal wastewater effluents and urban runoff contribute to three types of pollution that affect shellfish: chemical pollution, bacteriological pollution, and pollution from natural biotoxins found in toxic forms of algae. Most closures of shellfish harvesting areas in Canada are the result of bacteriological pollution, while natural biotoxins account for the next largest number of closures. Only a few shellfish fisheries have been closed specifically because of chemical contamination. In those cases, dioxins and furans, pesticides, and mercury and other metals were the principal contaminants involved.

Bacteriological contamination is usually associated with the discharge of urban runoff or sewage effluent that has not undergone disinfection. Shellfish in areas exposed to these discharges can become contaminated with fecal bacteria, and consumption of these shellfish can lead to illnesses such as gastroenteritis, salmonellosis, typhoid fever, cholera, and hepatitis (Menon 1988; Nelson 1994; Nantel 1996).

Contamination from natural biotoxins occurs in both fresh and salt water when nutrients from sewage discharges, for example, stimulate the growth of toxic species of microscopic algae. The toxins produced by these algae can reach undesirable concentrations when large masses of them form what are known as algal blooms. These toxins become increasingly concentrated along the food chain as the algae are consumed by shellfish and other marine life. Although the shellfish are only marginally affected by the toxins, a single clam can accumulate enough toxin to kill a human adult (Anderson 1994). In Canada, three serious forms of poisoning from algal contamination have occurred: paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), and diarrhetic shellfish poisoning (DSP) (Health Canada 1997).

PSP is caused by toxins produced by the dinoflagellate species *Alexandrium fundyense*. PSP toxins may occur in lobsters, clams, oysters, and mussels. Although PSP episodes are rare in Canada, with only a few cases reported per year, PSP continues to be a problem in three regions of the country: the St. Lawrence estuary, the lower Bay of Fundy, and the entire coast of British Columbia (Health Canada 1997).

ASP is caused by domoic acid, a toxin produced by tiny algae called diatoms, which can occur in intense blooms. In the world's only confirmed outbreak of ASP, which occurred in November and December of 1987, more than 100 Canadians became ill and 3 people died after eating contaminated mussels from Prince Edward Island.

DSP is the result of toxins produced by species of the dinoflagellate genus *Dinophysis*. DSP toxins occasionally occur in clams and mussels. In 1990, the first reported outbreak of DSP in North America occurred in Nova Scotia after 13 people ate contaminated mussels. Since then, there has been one other confirmed episode of DSP, but the actual number of cases is likely much higher, as the symptoms can easily be confused with those of stomach flu (Health Canada 1997).

In response to concerns about shellfish contamination from algae and other sources, the Government of Canada developed the Canadian Shellfish Sanitation Program and the Canadian Shellfish Water Quality Protection Program. The main aims of these programs are to ensure that growing areas for clams, mussels, oysters, scallops, and other bivalve molluscan shellfish meet approved federal water quality criteria, that sources of pollution discharges to these areas are identified, and that all shellfish sold commercially are harvested, transported, and processed in an approved manner. Shellfish are now routinely tested for phytoplankton toxins that could be a serious threat to human health.

Closures of harvesting grounds have seriously limited the economic potential of all of Canada's major shellfish fisheries. On the coast of British Columbia, for example, there were 246 shellfish closures due to contamination by pathogens under the *Fisheries Act* as of July 1999, encompassing an area of about 1050 square kilometres. Multiple pollution sources accounted for the largest area of closures, followed by sewage outfalls, agriculture/hinterland drainage, boat sewage discharges, urban runoff (including septic seepage), and pulp mill pollution (Environment Canada 1999d). The area of B.C. coastline closed to shellfish harvesting has increased substantially since Environment Canada began routinely assessing water quality for shellfish consumption in the early 1970s. Only part of this increase can be attributed to expanded monitoring activities, however.

In Quebec, of the 196 shellfish zones that were evaluated in 1999, 114 (58%) were permanently closed and a further 21 (11%) were closed from June 1 to September 30 (Environment Canada 1999e). Private residences, municipal sewage treatment plants, and agricultural runoff were responsible for the 114 zones that were permanently closed. Municipal sewage was also directly responsible for the closure of 34 of the 190 soft clam and blue mussel harvesting areas in Quebec (Nantel 1995).

On the Atlantic coast (excluding Quebec), nearly 36% or 2092 square kilometres of the areas surveyed as suitable for direct harvesting of shellfish were closed in 1995 (Statistics Canada 2000). In 1999, the closed area was nearly the same, 2065 square kilometres (Menon 2000). Losses to the local economy have been estimated at about $10–12 million.

The risk of harvesting shellfish from polluted waters increases with proximity to highly urbanized or agricultural areas. The pollution conditions are often aggravated by rainfall, which can result in sewage-contaminated runoff or effluent from overloaded sewage treatment systems reaching the shellfish beds. Areas that are near towns, villages, and other human habitation are often closed year-round.

Contamination of fisheries

Several toxic substances are known to accumulate in fish, and provincial/territorial authorities routinely issue advisories about safe consumption limits for species caught in certain areas. Five contaminants or groups of contaminants account for most of these advisories: mercury, PCBs, mirex/photomirex, toxaphene (a pesticide), and dioxins (OMOE 1999). Although these contaminants come from a wide variety of sources, all of them have been detected in municipal wastewater effluent.

There are also concerns about the effects of algal toxins on the finfish aquaculture industry. As caged fish cannot avoid areas where there are blooms, fish kills could result from the direct uptake of toxins, deoxygenation of the surrounding water, or clogging of the fishes' gills. Phytoplankton blooms are already a threat to the $100-million aquaculture industry in the Bay of Fundy (Percy 1996), and water temperatures and phytoplankton populations are now regularly monitored in an effort to prevent any problems.

Wild fish kills can also result when toxins from blooms are passed through the food web. Anchovies in B.C. waters, for example, have been known to be affected by domoic acid. Hundreds of tonnes of herring were also poisoned on the Atlantic coast in 1976 and 1979 by PSP toxins accumulated through the food web.

Credit: Corel Photo CD #185033

3 Managing municipal wastewaters in Canada

Who manages municipal wastewaters in Canada?

In Canada, responsibility for the collection and treatment of municipal wastewater, the administration and performance of wastewater facilities, and the control of environmental and health impacts of municipal wastewater is shared across all levels of government.

Municipal governments

Municipal governments have the most direct responsibility for wastewater by having the statutory mandate to provide sewage treatment. Municipalities also have the power, usually through a provincial/territorial Municipal Act, to control discharges into the sewer systems. Many municipalities have taken advantage of these powers to pass sewer use by-laws that are meant to reduce the toxicity of the effluents and establish source control. For example, the Regional Municipality of Ottawa-Carleton is active in reducing or eliminating toxic inputs to its treatment systems through the Industrial Waste Sewer Use Control Program. All industrial, institutional, and commercial facilities that discharge non-domestic wastewater or have their liquid waste hauled to the wastewater treatment plant are required to comply with the *Sewer Use By-law*, which sets limits for various pollutants being discharged into sewers.

Provincial/territorial governments

The provincial/territorial governments are primarily responsible for the regulation of municipal sewage treatment operations, and most provinces/territories maintain legislative control through waste control statutes that apply directly to sewage effluent. Operators of wastewater systems are required to seek approval from their provincial/territorial governments, and these provincial/territorial permits or licences may specify maintenance and treatment requirements on top of what is already stipulated in regulations. The approvals may also contain specific limits on the discharge of effluents. For example, British Columbia's *Waste Management Act* requires all municipalities to have a provincially approved Liquid Waste Management Plan. Discharges without such a plan are illegal in this province. The provinces/territories also generally have cost-sharing agreements with the municipalities for sewage-related infrastructure projects.

Federal government

Currently, there is no federal legislation directly governing the deposit of harmful substances by municipalities into their wastewater. There are two acts, however, that do have the potential to apply to municipal wastewater. The *Fisheries Act* is enforced federally by both Fisheries and Oceans Canada and Environment Canada and addresses a general prohibition against the release of a "deleterious substance" into waters frequented by fish. The *Canadian Environmental Protection Act* governs the release of toxic substances to the environment and allows the federal government to create regulations to control or eliminate the use of such substances.

Other

Private industry, research and educational institutions, conservation authorities, and individual Canadians also have an important influence on decisions concerning wastewater management. Actions by all of these groups have ensured that the standard of wastewater management in Canada compares well with that of any other country. However, municipal wastewater is still a major contributor to the degradation of aquatic habitat, the fouling of recreational waters, the contamination of shellfish growing areas, and other environmental and health concerns.

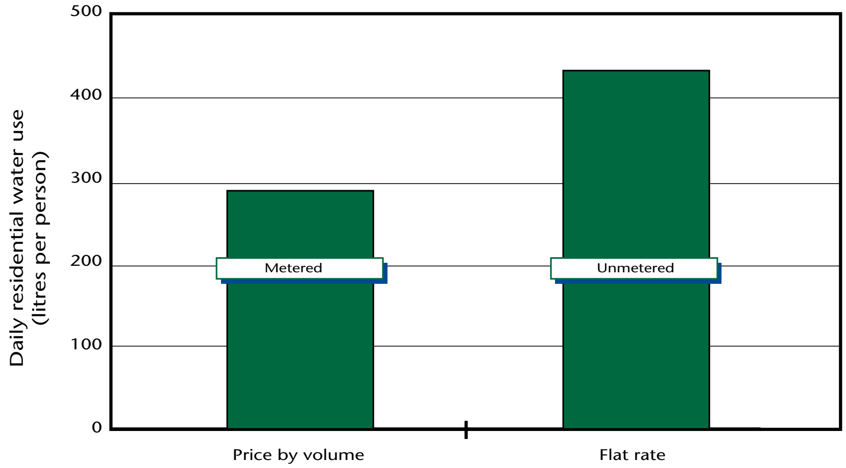
What are we doing about it?

Several approaches are being taken to modify our everyday activities and to improve the way in which we deal with these wastes. Actions such as public education and changes in water pricing have resulted in reducing per capita water use by changing attitudes towards water conservation and encouraging water-efficient technology. Another type of action includes the improvement of wastewater treatment capacity by bringing new treatment facilities into operation where none existed and by upgrading existing facilities where they did not provide an adequate level of treatment. Other actions include federal, provincial/territorial, and municipal programs that help communities deal with the local impacts and management of municipal wastewater effluents.

Water conservation: Water metering and pricing, water-efficient technologies

Because excessive water use in Canada increases the need for treatment capacity and reduces treatment efficiency, a major contribution to improving wastewater quality is simply the reduction of municipal water usage. Water pricing has been shown to be an effective means of achieving this objective in Canada and in other industrialized countries (Environment Canada 1994; NRTEE 1996). Generally, as the price of water increases, the amount used decreases and so, in turn, does the amount of wastewater generated (NRTEE 1996). In Canada, metered households that paid for water by volume used about 288 litres per capita per day in 1999, compared with 433 litres per capita per day for households that paid a flat rate (Figure 6).

Figure 6: Effect of metering on residential water use in Canada, 1999

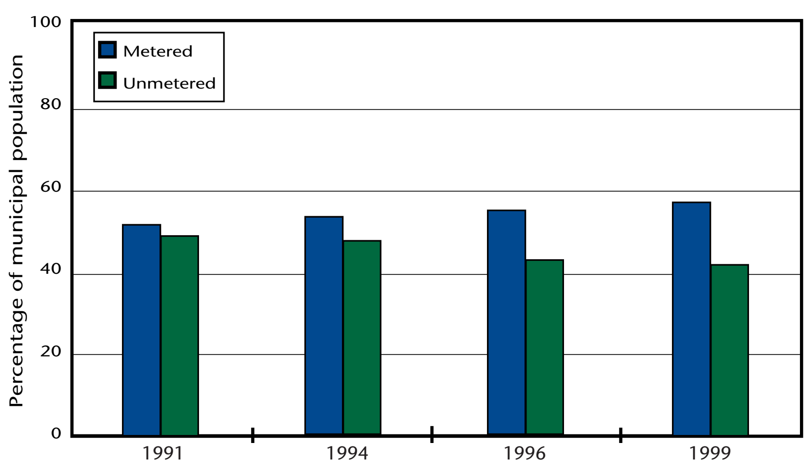


Note: A municipality was considered "metered" if more than 75% of the population served water was metered and "unmetered" if less than 25%. The few centres with 25-75% of the population metered were not included in the analysis.

(Source: Adapted from Environment Canada 1999b)

As Figure 7 shows, the percentage of Canada's municipal population with water meters increased from 52.6% to 57.0% between 1991 and 1999. That means that there is still considerable room for using water pricing as both a conservation and a cost recovery tool. Canadian water prices are currently amongst the lowest in the world. They are less than half those of OECD countries and cover roughly half of the costs of supplying water and treating wastewater (NRTEE 1996; Environment Canada 1998b). These extra costs have generally been paid by federal and provincial/territorial subsidies, but these subsidies are now threatened by tighter budgets and lower grants to municipalities, and many municipalities are likely to place more of the cost of providing water services on the consumer.

Figure 7: Municipal population with water meters in Canada, 1991–1999



(Source: Adapted from Environment Canada 1999b)

Under a full-cost, user-pay system, water users pay a fair price that covers the total cost of water and wastewater services and is based on the actual quantity used. Those who use more water pay more, and those who use less pay less. This method makes water users aware of the true value of water resources and gives them an incentive to use it more efficiently (Environment Canada 1993; NRTEE 1996).

In the past, low consumer prices, along with the belief that Canada's clean water supply was unlimited, have resulted in low demand for water-efficient technologies (NRTEE 1996). With rising water prices and greater social awareness of the need for sustainable development, interest in these technologies is now increasing. Technologies and methods that could be used to diminish water demand include:

- retrofitting existing plumbing with flow control devices, such as pressure-reducing valves, low-flow showerheads, low-flush toilets, and faucet aerators;
- reusing wastewater for other applications, such as irrigation, and recycling water for reuse in the same application that it was originally used in;
- imposing municipal water use restrictions (e.g., restricting water use at certain times of day or for certain applications, such as lawn watering);
- using xeriscaping (drought-resistant landscaping) to reduce irrigation needs; and
- educating the public about water conservation at the household level.

Together, these practices can substantially reduce the amount of water Canadians use and, in so doing, reduce not only the environmental pressures caused by wastewater effluents but also the costs associated with water and wastewater services.

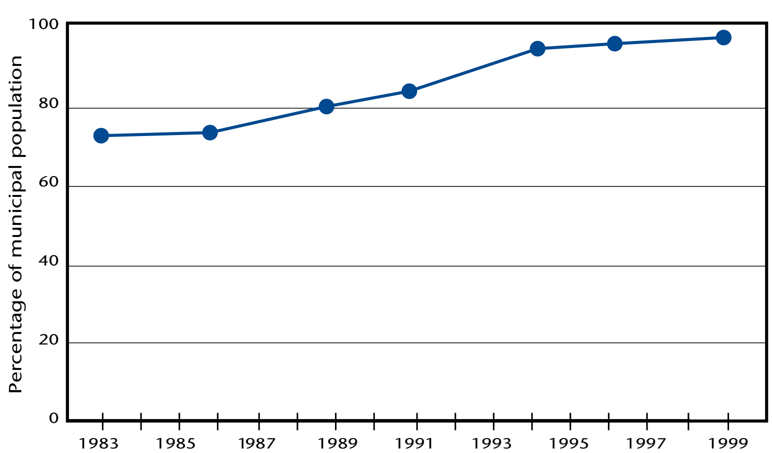
Upgrading wastewater infrastructure and treatment

Because wastewater impacts are caused not only by untreated or inadequately treated sewage but also by stormwater and CSOs, improvements have been made in the capacity to manage all of these wastewater types to reduce the release of contaminants and the flow of wastewater.

Sewage treatment

Over the past decade or so, Canada has considerably improved its sewage treatment capacity. As Figure 8 shows, the percentage of the municipal population on sewers served by wastewater treatment has increased from slightly more than 70% in 1983 to 97% in 1999. Most of this increase is accounted for by improvements in Quebec, where the municipal population served by some level of treatment increased by about 80% between 1986 and 1994.

Figure 8: Municipal population with wastewater treatment in Canada, 1983–1999 (based on the municipal population serviced by municipal sewer systems)

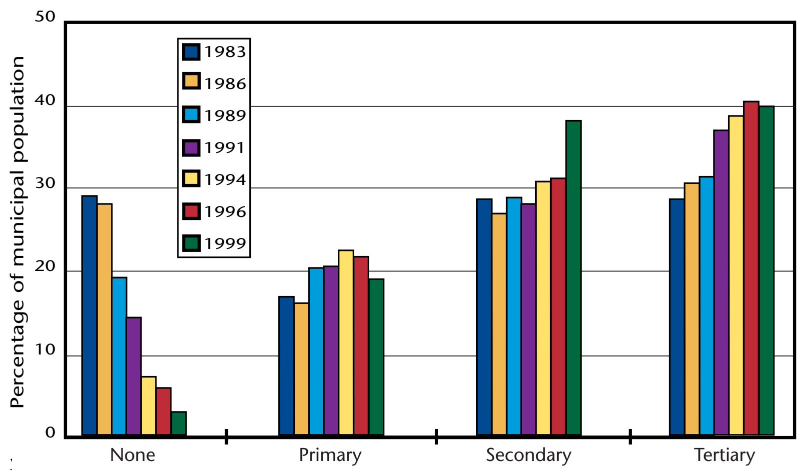


Note: See Figure 2 for treatment definitions.

(Source: Adapted from Environment Canada 1999b)

The degree of treatment is also improving. In 1999, secondary and advanced (tertiary) treatment were provided to 78% of the municipal population, up from 56% in 1983, and primary treatment was provided to 19%, up from 16% (Figure 9). A recent example of these improvements includes the Annacis Island and Lulu Island treatment plants in the Greater Vancouver Regional District. They were upgraded from primary to secondary level in 1998, serving a combined population of about 1 million people. Another example is the ongoing upgrade of the Gold Bar Wastewater Treatment Plant from secondary to advanced-level treatment with biological nutrient removal. The plant services over 640 000 people from Edmonton and the surrounding area and should be completely functional by 2005.

Figure 9: Level of municipal wastewater treatment in Canada, 1983–1999 (based on the municipal population serviced by municipal sewer systems)



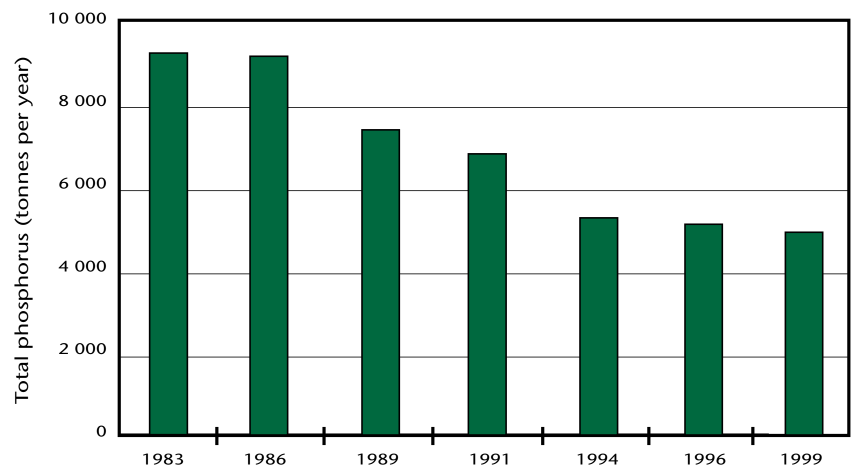
Note: See Figure 2 for treatment definitions.

(Source: Adapted from Environment Canada 1999b)

The effects of these improvements in sewage treatment are illustrated by the decline in phosphorus loadings that has taken place over the same time period (Figure 10). For Canada as a whole, estimated yearly loadings of phosphorus fell by 44% between 1983 and 1999, despite the 24% increase in the urban population served by sewers during this period (OMOE 1993; Environment Canada 1999b). Loadings of other conventional parameters, such as BOD and TSS, have shown similar trends.

In spite of this progress, many parts of the country continue to discharge untreated or poorly treated sewage into Canadian waters. The problem is significant in Atlantic Canada, where even some larger centres, such as St. John's, Newfoundland, and Halifax, Nova Scotia, still discharge raw sewage. Across this region, communities without treatment facilities account for slightly more than 40% of the population with sanitary sewers.

Figure 10: Total estimated phosphorus loadings to Canadian waters from wastewater treatment plants in Canada, 1983–1999



(Source: Adapted from Environment Canada 1999b)

Stormwater

Until very recently, stormwater was not considered a serious pollution problem, and, consequently, few treatment measures were developed. Considerable progress has been made over the past decade, however, in developing and improving methods for controlling stormwater pollution. These methods are often referred to as best management practices (BMPs). Many of these practices aim to control stormwater volume and reduce contaminant loadings by modifying urban landscapes and existing sewer systems. These practices generally fall into one of the following categories: policies and source controls, site BMPs, community BMPs, and watershed-level measures (Marsalek 2000).

Policies and source controls include a variety of non-structural measures aimed at reducing the quantities of contaminants that enter the wastewater system. Public education programs that discourage people from dumping motor oil and other hazardous substances down their drains or from making illicit connections to the sewer system are an example of such measures. So too are urban planning approaches that limit low-density development, reduce the area covered by impervious surfaces, and provide vegetated buffer zones to absorb runoff and protect streams and wetlands. Other examples include the encouragement of procedures to prevent spills during the handling and transporting of chemicals and simple measures such as increased street sweeping and drainage system maintenance, which can greatly reduce the quantities of coarse particles, debris, and other contaminants that are eventually discharged into receiving waters.

Site BMPs are intended to confine runoff within the area in which it occurs. Many communities are now encouraging the adoption of lot-level source controls such as enhanced detention of water on rooftops, disconnection of downspouts from storm sewers, and reduced lot grading to slow down the flow of the runoff.

Other effective approaches for stormwater management include biofiltration by grass filters and the use of swales (broad, shallow channels with dense vegetation on the sides and bottom) as an alternative to gutters and sewers. These measures promote infiltration into the soil, retard the flow of runoff water, and enhance runoff quality by removing pollutants through settling, filtration, adsorption, and biological uptake.

Some communities are installing infiltration trenches or drain fields that allow stormwater to percolate into the subsoil through crushed stone or sand filters, and filter through fabric liners. These systems not only reduce the volume and rate of runoff but also remove pollutants and recharge the groundwater. Stormwater quality can also be improved by the installation of water quality inlets in the sewer system. These are essentially storage tanks that provide some stormwater treatment through sedimentation and skimming of floatables (oil and grease). Oil/grit separators installed downstream of the sewer inlets perform a similar function.

Community BMPs treat larger volumes of stormwater collected over a wider area before final discharge to a receiving water. The most commonly used community BMPs are stormwater management ponds and constructed wetlands. Stormwater management ponds provide a storage area to reduce flow peaks and permit the settling of suspended solids and attached pollutants such as phosphorus. Constructed wetlands use a marsh environment to reduce the levels of particles and dissolved pollutants through physical, chemical, and biological processes that occur naturally in wetlands. Ponds and wetlands are often used in tandem to maximize treatment capacity. Some municipalities may also use community infiltration facilities. These consist of infiltration trenches and basins that are similar to those used in site-level BMPs but are constructed on a larger scale.

Watershed-level measures apply an integrated approach that recognizes the multiplicity of stresses that affect stormwater quality in a given watershed area. These measures try to control such impacts through restrictions on land use, implementation of site-level BMPs, and the protection of natural features and resources, such as wetlands, floodplains, buffer zones, meadows, and soils. Watershed planning can also assist in the selection of suitable sites for facilities such as stormwater ponds and wetlands.

Combined sewers

About 6.7 million Canadians, mostly in older parts of larger municipalities, were serviced by combined sewers in 1969 (Waller 1969). The present number is likely somewhat smaller because of population declines in older city areas and the replacement of some combined sewers with separate storm and sanitary systems. Sewer separation, however, is an extremely expensive way of solving the combined sewer problem, and it creates an additional stormwater problem in the process. To reduce separation costs, some local governments, such as the City of Vancouver, have implemented combined sewer separation programs on a replacement of aging infrastructure basis. By dealing with approximately 1% of the system per year, this program will result in the elimination of combined sewers in Vancouver by 2050. Some communities have opted instead to build large underground storage tanks or storage tunnels to hold CSOs and stormwater for later treatment and disposal. Although less expensive than sewer separation, this alternative is also costly.

Much attention is now being given to more innovative and cheaper approaches to CSO control. The city of Hamilton, for example, has been experimenting with a sophisticated computerized control system that redirects heavy stormwater flows to underutilized parts of the sewer network, where wastewater can be held until such time as it can be redirected for treatment. High-rate satellite treatment systems, such as one being tested in Toronto, can provide an adequate level of primary treatment for heavy flows that cannot be sent to the main wastewater treatment plant and would otherwise be discharged as raw sewage (Kok et al. 2000). Integrated management approaches that combine a variety of controls at different levels also offer a cost-effective way of dealing with stormwater and CSO problems (Ellis and Marsalek 1996).

Source control

Municipalities have a key role to play in reducing the number, quantity, and concentration of substances entering sewer systems and MWTPs. Source control will improve the success of treatment processes and will improve the quality of MWTP effluents. This requires that municipal wastewater system managers know which substances are likely to be present in sewer systems in order to effectively remove them from the effluent. A useful management tool that has been developed for these purposes is the *Directory of Sources of Contaminants Entering Municipal Sewer Systems* (CWWA 2000).

Implementing these changes

Funding for programs to improve municipal wastewater infrastructure and address municipal wastewater issues comes from all levels of government. An important example of these programs is the regional ecosystem initiatives, involving the collaboration of the federal, provincial, and territorial governments, communities and community groups, industry, and Aboriginal peoples to remediate targeted ecosystems across the country. A major issue that has been targeted through these initiatives is the effect of municipal wastewater effluent on the environment. There have been several significant accomplishments in this regard, many of which are highlighted below:

- The Atlantic Coastal Action Program, launched in 1991, is developing and implementing a variety of projects to improve wastewater quality at two sites in Newfoundland, two in Prince Edward Island, four in Nova Scotia, and five in New Brunswick. Plans for a primary treatment facility for St. John's have been developed under the program.

- The St. Lawrence River Basin in Quebec is another area where treatment facilities are needed. As of 1996, 16% of the riverside population continued to discharge untreated wastewater into the river (Environment Canada 1998c). However, the addition of new wastewater treatment capacity, through the Programme d'assainissement des eaux municipales du Québec, has significantly reduced the amount of untreated municipal wastewater discharged into the St. Lawrence River. A better understanding of MWTP effluents will be developed under the St. Lawrence Vision 2000 Action Plan to support corrective actions.

- In areas that are already served by treatment, many facilities cannot meet the higher treatment standards required to eliminate certain impacts, such as eutrophication. Others no longer have enough capacity to serve the needs of rapidly growing communities.

Among the areas where such needs have been identified are the Fraser River estuary in British Columbia, the Athabasca and Wapiti rivers in northern Alberta, and the Canadian shores of the Great Lakes. With the support of regional ecosystem initiatives in these areas — namely, the Fraser River Action Plan, the Northern Rivers Ecosystem Initiative, and the Great Lakes 2000 program — some important improvements in wastewater treatment have been achieved. Two large sewage treatment plants in the Fraser River estuary serving approximately 1 million people, for example, have been upgraded to secondary treatment, and tertiary treatment is being implemented in plants at Grande Prairie and Jasper in Alberta.

Because of the very substantial costs involved in upgrading sewage treatment plants, however, many communities have been slow to implement much-needed improvements. The Great Lakes 2000 program has attempted to deal with this problem by identifying and promoting new technologies that will perform more effectively at lower cost. The program has also promoted the extensive use of process audits to identify ways in which plant capacity and performance can be improved by changes in operating procedures or small modifications to facilities. In several cases, such modifications have made it possible for municipalities to achieve their pollution control targets without resorting to expensive upgrades. For example, an optimization study evaluated ways to reduce the phosphorus release from the Collingwood, Ontario, sewage treatment plant without expanding the existing facility. The innovative use of existing technology provided an estimated $6 million in cost savings.

Another key program is Canada's National Programme of Action for the Protection of the Marine Environment from Land-based Activities, which intends to prevent marine pollution and protect coastal habitat, such as shellfish growing areas, from land-based human activities, including municipal wastewater effluents. This program is based on existing federal, provincial, and territorial programs, including the regional ecosystem initiatives and Environment Canada's shellfish programs. Various levels of government in Nova Scotia have also contributed to a project to investigate the true costs and benefits of sewage treatment and source control in Halifax Harbour (Box 8).

In the spring of 2000, the federal government announced a six-year investment in Canada's physical infrastructure totalling $2.6 billion. A portion of this is to be set aside for "green infrastructure" projects, such as municipal wastewater and domestic sewage initiatives. The federal government has also announced a $100-million Green Municipal Investment Fund and $25-million Green Municipal Enabling Fund to encourage investment by municipalities in best practice and innovative municipal environmental projects. These projects are to include improvements to water and wastewater treatment centres.

In addition to providing funding for water and wastewater projects, the federal government is showing leadership in the management of wastewater effluents through the adoption of sound environmental protection and engineering practices for wastewater management at federal facilities. Final effluent limits have been specified for many pollutants found in wastewater, and, in the event that non-specified materials are found in sewage, a rational approach for determining permitted effluent limits is used. These effluent guidelines are equal to or more stringent than the established standards or requirements of any federal or provincial/territorial regulatory agency (FCEMS WWWG 2000).

Box 8: Halifax Harbour case study: Is it economically beneficial to install municipal wastewater treatment plants?

Halifax Harbour, home to the largest urban population in the Atlantic provinces, has long been plagued by poor water quality and contaminated sediments from the ongoing disposal of untreated municipal wastewater effluents. Consequently, the harbour's ecosystem, aesthetic appeal, and urban quality of life (i.e., recreational value, commercial value, and well-being of its inhabitants) are being seriously impacted.

A recent study by GPI Atlantic (Wilson 2000b) has evaluated the costs and benefits of installing four new wastewater treatment plants in the harbour, as proposed under the Halifax Harbour Solutions Plan (HRM 1999a, 1999b). Although the construction of the infrastructure has an estimated price tag of $315 million over 10 years, followed by an operating cost of about $8.8 million per year, the treatment plan could actually generate between $38.5 and $392 million in **net benefits** over a 60-year period. The ensuing improvements in water quality and aesthetics would result in:

- reduced health risks from pathogenic microorganisms; although not accounted for in the analysis, economic benefits would probably result from a reduction in hospital admission and treatment costs, lost productivity in the workplace and in the home, and lost leisure time;
- enhanced habitat quality and increased likelihood that the harbour will support healthy wildlife populations, such as lobster and winter flounder (unaccounted);
- protection of the current $1 million a year lobster fishery and reopening 30–50% of the shellfishery ($0.23–0.38 million a year);
- increased property value of 5–10% (or $116–233 million);
- increased tourism revenue of 2–3% (or $478–717 million); and
- protection of the harbour ecosystem's capacity for decomposing nutrients from wastewater effluents ($58.1 million).

Although the proposed "advanced primary treatment plants" are not expected to remove all the contaminants from the municipal wastewater, significant reductions in suspended solids, oxygen-consuming material, bacterial contaminants, and nutrients should result. In addition to this treatment plan, source control programs, including education, legislation, and enforcement directed at households and industrial and commercial operations, are also recommended. These programs would limit or ban the discharge of many toxic contaminants in the sewer systems, thereby reducing water and wastewater treatment costs and potential future cleanup costs.

Continuing and emerging problems

This report has discussed what are currently the most visible issues involving wastewater management, but a variety of other problems also need to be addressed, and other potentially important issues are lurking in the wings. There is a growing awareness, for example, of the need to bring sewage treatment to small and isolated communities in rural areas and in the north, although doing so will involve a number of special problems. In the heavily populated regions of the south, much of the water and wastewater infrastructure is aging and in need of replacement or major repairs. Other, more recent concerns include a group of substances known as endocrine disrupters that appear to have considerable potential to harm wildlife and human health. These can enter the environment through a number of pathways, but urban wastewater is one of the most important.

Aging infrastructure

It has been suggested that more than half of the water pipes in Canada need repair, at a cost of roughly $6.1 billion. For example, the Ontario Sewer and Watermain Contractors Association indicated in 1992 that 25% of the water system in Ontario must be replaced and 50% of it must be restored within the next 60 years. Deteriorating water storage and distribution systems result in major water loss, sometimes comprising up to 30% of municipal water use in communities across Canada. Wastewater treatment plants are also deteriorating and being overused by growing populations, affecting their treatment efficiency. This leads to the release of inadequately treated wastewater or even raw sewage when equipment malfunctions or when volume capacity is exceeded.

Endocrine disruption

Endocrine systems coordinate and regulate communication between cells by releasing hormones that act as chemical messengers. Hormones play a number of important roles in the development of the human body and in the control of bodily functions. The sex hormones testosterone and estrogen, for example, have a critical influence on the development of the sexual characteristics of the fetus, while thyroid hormones influence brain development. Another hormone, insulin, controls the amount of sugar in the blood. Some synthetic chemicals, however, interfere with the normal functioning of endocrine systems in a variety of ways, often by mimicking the effects of natural hormones or blocking the cell receptors to which hormones attach. When this happens, important biological processes are upset and a variety of effects can result, some of them dramatic, others quite subtle.

Substances that can cause these effects include organochlorine compounds, which are widely used in pesticides and industrial chemicals, alkylphenolics such as nonylphenol, which are used in surfactants (a constituent of some detergents), and chemical contaminants such as dioxins and furans. Since these substances tend to be persistent and bioaccumulative, their effects typically show up in birds and fish, which are at the upper end of the food chain.

Endocrine-disrupting chemicals most commonly affect the immune system, the brain and nervous system, and the thyroid gland, but the greatest concern in recent years has focused on chemicals that mimic the effects of the female hormone estrogen and interfere with sexual development and reproduction. Birds exposed to chemicals and insecticides such as PCBs and DDT, for example, are much more prone to reproductive problems and physical deformities. In fish, exposure to endocrine disrupters has been linked to the appearance of female characteristics in males, reproductive problems, enlarged thyroid glands, and depressed thyroid and immune functions. Hermaphroditism has also been well documented in snails exposed to tributyltin, an antifouling agent that, until recently, was used in paints for boat and ship bottoms (Environment Canada 1999f).

Endocrine disrupters that typically occur in municipal effluents include a wide range of industrial chemicals and pesticides as well as natural estrogen and other hormones from human and animal wastes. Synthetic estrogens, such as estradiol, that are used in oral contraceptives are also present. Studies of fish collected downstream of sewage treatment plants in the United Kingdom have shown some evidence of endocrine disruption.

In Canada, the extent of estrogenic effects attributable to sewage effluents has not yet been established. Although some chemical analysis of effluents is currently being undertaken, it is still too early to conclude whether endocrine disruption in wildlife or humans is occurring as a result of chemicals present in municipal wastewater effluents. If municipal wastewater effluents are shown to be a significant source of exposure to endocrine disrupters, however, we will then have to face the major task of devising ways of controlling their entry into the wastewater system and removing any residues from the effluent. Since these substances are usually present only in extremely minute quantities, this will be a considerable challenge. It is also a challenge whose implications go well beyond the technology of wastewater treatment and could force major changes in the kinds of chemical substances we use and the way we use them.

4 Conclusion

Municipal wastewater effluents remain one of the most common contributors to a variety of local water pollution problems in many parts of the country. Beach closures, restrictions on shellfish harvesting, and degraded aquatic habitats that support fewer species are the most obvious of these problems, but the presence of persistent, bioaccumulative substances in municipal wastewater may also be contributing to other problems on a wider scale that may not immediately be apparent.

To remedy these problems and to diminish the overall impact of municipal wastewater effluents on the environment, Canadians need to devote more effort and resources to wastewater management and the improvement of our wastewater treatment capabilities. In the first instance, this means bringing wastewater treatment to areas that do not at present have such facilities and improving existing facilities where they are not providing an adequate level of treatment. In many older communities, however, the reduction or elimination of CSOs is the most pressing priority, and in virtually every part of the country, better management of stormwater is essential. While the improvement of treatment facilities will play an important role in achieving these objectives, it is also important to look beyond end-of-pipe controls and implement other solutions, such as water conservation and metering or urban planning arrangements that provide better management of surface runoff. Not only will these measures lessen the impact of municipal wastewater effluents on the environment, but they will also reduce the cost of the impact.

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Glossary

Accumulation	The storage and concentration of chemicals in aquatic sediments to levels above those present in the water. (see also Bioaccumulation)
Acute toxicity	A harmful effect that is produced during a short exposure period, usually 24–96 hours.
Aerobic	An environment where oxygen is present or a process that uses oxygen.
Ammonia (NH^3)	A chemical combination of nitrogen and hydrogen that occurs extensively in nature. It is a water-soluble gas that behaves as a weak base. It can exert toxic effects on aquatic life.
Ammonium (NH^4+)	The protonated form and conjugate acid of ammonia. It predominates under low-pH conditions.
Anaerobic	An environment where oxygen is absent or a process that does not use oxygen.
Bioaccumulation	The uptake and retention of chemical substances by plants and animals from both their environment and their food.
Bioavailability	For a given chemical, it is the portion of the total amount existing in the surrounding environs (e.g., water, sediment) that is available for uptake by plants and animals.
Biochemical oxygen demand (BOD)	A measure of the quantity of oxygen (in milligrams per litre) taken up in the biochemical oxidation of organic matter in the dark, in a specified time, and at a specified temperature.
Biomagnification	A cumulative increase in the concentrations of a persistent substance in successively higher levels of the food chain.

Chlorination	The application of chlorine or chlorine compounds to drinking water or wastewater, generally for the purpose of disinfection, but also to oxidize undesirable compounds or control odour.
Chronic toxicity	An adverse effect that is produced during a prolonged exposure period, usually greater than 96 hours. The end result can be mortality, although sublethal effects (e.g., inhibited reproduction or growth) are more common.
Coliform bacteria	Bacteria used as indicators of the presence of pathogenic microorganisms (see also Fecal coliforms).
Combined sewer	A sewer intended to receive wastewater and stormwater discharges.
Combined sewer overflow (CSO)	Discharge of excess flow into a nearby body of water from combined sewers during wet weather, when sewer capacity is exceeded.
Contamination	The introduction of pathogenic or undesirable microorganisms, toxins, and other deleterious substances that render water, air, soil, or biota unfit for use.
Conventional parameters (or conventional pollutants)	Measurements that are routinely made at most municipal wastewater treatment plants on the inflowing raw sewage and the treated effluent, including biochemical oxygen demand, total suspended solids, turbidity, pH, temperature, total phosphorus, total nitrogen, microbial organisms, and sulphides.
Cumulative effect	The change to an organism and/or ecosystem resulting from a series of successive actions or impacts.
Dechlorination	The partial or complete removal of residual chlorine in wastewater by any chemical or physical process.
Discharge point (or release point)	A distinct and identifiable source of pollution, such as an outfall pipe from a municipal wastewater treatment plant or a stormwater sewer.
Disinfection	The killing of waterborne pathogenic bacteria, viruses, and protozoa in potable water supplies or wastewater effluents with a disinfectant.
Effluent	A complex mixture of liquid waste that is discharged into the environment.
Endocrine disrupter	A substance that interferes with the normal communication between the messenger and receptor in the cell, so that the chemical message is not interpreted properly.
Endocrine system	The system in animals that controls events at the cellular level through changes in the concentration of hormones in the circulatory system.

Escherichia coli	A species of bacteria used as an indicator of the presence of pathogenic microorganisms. Abbreviated to *E. coli*.
Eutrophication	An increase in the productivity of plants, phytoplankton, and microorganisms resulting from nutrient (nitrogen and phosphorus) addition. Moderate nutrient addition can increase fish and larval aquatic insect production. High levels of nutrient addition can lead to excessive plant production, reduced water clarity, lowered oxygen levels, and, in some cases, fish kills.
Fecal coliforms	A group of bacteria found predominantly in the intestines of humans and other vertebrates, which are eliminated in feces. They are used as indicators of the presence of pathogenic microorganisms.
Gastroenteritis	An inflammation of the membrane lining the stomach and the intestines.
Gastrointestinal illness	A mild illness resulting in an inflammation of the stomach and intestines, which may cause stomach cramps, headaches, vomiting, and diarrhea.
Loadings	The total mass of a pollutant discharged to a water body per unit of time (kilograms per day). It is calculated by multiplying the mean concentration of the pollutant in the effluent by the mean effluent discharge volume.
Municipal wastewater effluent	Effluent discharged from municipal wastewater treatment plants, combined sewer overflows, and stormwater discharges.
Municipal wastewater treatment plant (MWTP)	A series of tanks, screens, filters, and other processes by which pollutants are removed from water. Synonymous with sewage treatment plant, wastewater treatment works, and water pollution control plant.
Nitrate (NO_3^-)	A compound containing nitrogen that can exist in the atmosphere or as a dissolved gas in water. Nitrates in water can cause adverse effects on humans and animals and act as a nutrient for plants.
Nitrite (NO_2^-)	An intermediate in the bacterial transformation of ammonia or ammonium to nitrate.
Nitrogen (N)	A key nutrient for aquatic and terrestrial plants and occurring in various forms (NO_2^-, NO_3^-, NH_3, NH_4^+).
Ozone	Gas molecule composed of oxygen. Ozone is administered to water or wastewater for the purposes of disinfection, oxidation, or odour control.
Phosphorus (P)	An important nutrient utilized by aquatic and terrestrial plants.

Polychlorinated biphenyls (PCBs)	A class of persistent organic chemicals with the potential to bioaccumulate through the food chain and cause reproductive failure. They are suspected carcinogens.
Polycyclic aromatic hydrocarbons (PAHs)	Organic compounds composed of at least two fused benzene rings, many of which are potential or suspected carcinogens.
Primary treatment	Effluent treatment process consisting of the removal of large particles by screens, followed by the removal of sediment and organic matter in settling chambers.
Raw wastewater	Wastewater before it receives any treatment.
Raw water	Water before it receives any treatment to make it suitable for drinking and/or other beneficial uses.
Receiving water	A river, lake, ocean, or other body of water into which wastewater or treated effluent is discharged.
Runoff	The portion of precipitation that runs off the surface of a drainage area and reaches a body of water or a drain or sewer.
Sanitary sewer	A sewer for the collection and transmission of wastewater from residences, commercial buildings, institutions, and small industries, but not from stormwater or runoff.
Secondary treatment	Effluent treatment process that follows primary treatment. A combination of biological or chemical processes with mechanical and/or gravitational methods to remove dissolved, colloidal, and suspended matter.
Separate sewer system	A sewer system in which urban runoff is conveyed by storm sewers and municipal sewage is conveyed by sanitary sewers.
Sewage	see Wastewater
Storm sewers	A sewer for the collection and transmission of stormwater runoff, land surface water, and water from soil drainage, but not including any domestic or industrial wastewater.
Stormwater	Water from rain or snowmelt that accumulates prior to entering a water body or filtering into soils.
Surfactant	Organic compounds, found in detergents, that increase the wetting properties of a liquid by decreasing the liquid's surface tension. Some are suspected endocrine disrupters.

Tertiary treatment	Advanced effluent treatment process that further reduces the concentration of suspended and dissolved substances in the secondary effluent by employing physical filtration, chemical precipitation, or biological action.
Total suspended solids (TSS)	Insoluble solids that either float on the surface of or are in suspension in water or wastewater. TSS is a measure of the amount of particulate matter in an aqueous sample. May also be referred to as suspended solids (SS).
Toxicity	The degree to which the health or well-being of an organism is adversely affected by a substance.
Trihalomethanes (THMs)	A group of chemicals that form as by-products of chlorine disinfection, including chloroform, bromodichloromethane, chlorodibromomethane, and bromoform.
Turbidity	A measure of the clarity of water.
Wastewater	Spent or used water of a community or industry, including runoff water and combined sewer overflow.
Water quality guidelines	Numerical limits or narrative statements recommended to protect specific water uses, such as drinking water supply, freshwater and marine life, crop irrigation water, livestock water, and recreational aesthetics.

For further information

For additional information on issues related to municipal wastewater effluents, consult the following:

National:

Canada's National Programme of Action for the Protection of the Marine Environment from Land-based Activities: *www.ec.gc.ca/marine*

Canadian Water and Wastewater Association: *www.cwwa.ca/e_index.htm*

Canadian Water Quality Guidelines: *www.ec.gc.ca/ceqg-rcqe*

Ecosystem Initiatives: *www.ec.gc.ca/ecos_e.html*

Environmental Indicator Bulletin on Municipal Water Use and Wastewater Treatment: *www3.ec.gc.ca/Ind/English/Urb_H2O/*

Freshwater web site: *www.ec.gc.ca/water/index.htm*

Infrastructure Canada web site: *www.tbs-sct.gc.ca/ino-bni/Main/main_e.asp*

Municipal Water Use Database (MUD) web site: *www3.ec.gc.ca/MUD/eng/Default.cfm*

Shellfish and Water Quality: *www.ns.ec.gc.ca/epb/factsheets/sfish_wq.html*

Pacific and Yukon Region:

British Columbia non-point source water pollution control:
www.elp.gov.bc.ca/wat/wq/bmp_c/npsaction.html

Capital Regional District liquid waste management plan: *www.crd.bc.ca/eng/lwmp*

Department of Fisheries and Oceans shellfish biotoxins web site:
www.pac.dfo-mpo.gc.ca/ops/fm/shellfish/Biotoxins/biotoxins.htm

Greater Vancouver Regional District sewerage web site: *www.gvrd.bc.ca/services/sewers/index.html*

Prairie and Northern Region:

City of Calgary wastewater web site: *www.gov.calgary.ab.ca/wwd/AboutWWD.html*

City of Edmonton wastewater treatment:
www.gov.edmonton.ab.ca/am_pw/drainage_services/wastewater_treatment.html

City of Regina sewage treatment plant:
www.cityregina.com/content/info_services/environmental/sewage.shtml

City of Winnipeg water and sewer services: *www.city.winnipeg.mb.ca/interhom/stats/#water*

Ontario Region:

City of Ottawa wastewater page: *http://city.ottawa.on.ca/city_services/water waste/27_2_3_en.shtml*

City of Toronto sewers and drains web site: *www.city.toronto.on.ca/sewers/index.htm*

Ontario Clean Water Agency: *www.ocwa.com*

Quebec Region:

Great Lakes/St. Lawrence River Water Quality Network:
http://biosphere.ec.gc.ca/cea/roab/proj/rmun/rmun_00000_a.html

Montreal Urban Community wastewater treatment plant:
www.cum.qc.ca/cum-an/station/accustaa.htm

Atlantic Region:

Halifax Harbour Solutions Project: *www.region.halifax.ns.ca/harboursol/index.html*

Appendix

Appendix 1: The biological, chemical, and physical constituents of wastewater effluents

Type of wastewater constituent	Selected examples
Biological	Bacteria e.g., fecal coliforms (e.g., *Escherichia coli*, *Campylobacter*) e.g., *Salmonella* Viruses e.g., hepatitis A virus Protozoa e.g., *Giardia* e.g., *Cryptosporidium*
Chemical	Nutrients Phosphorus Nitrogen (e.g., nitrate, nitrite, ammonia) Organic chemicals Pesticides (e.g., toxaphene, DDT/DDE) Surfactants (e.g., nonylphenol) Chlorinated solvents (e.g., tetrachloroethylene, trichloroethylene) Polycyclic aromatic hydrocarbons (PAHs) Polychlorinated biphenyls (PCBs) Endocrine-disrupting substances (e.g., PCBs, dioxins, furans contraceptives, nonylphenol) Inorganic chemicals Metals (mercury, cadmium, copper, iron, lead, nickel, zinc) Chloride and chlorine Cyanide Oil and grease Biochemical oxygen demand (e.g., organic matter)
Physical	Suspended solids Debris Grit