Review of the State of Knowledge of Municipal Effluent Science and Research

Review of Existing and Emerging Technologies
Review of Wastewater treatment Best management Practices

Report Prepared for:

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EXECUTIVE SUMMARY

This report addresses Tasks 2 and 3 of the CCME Project #352-2005 titled “Review of the State of Knowledge of Municipal Effluent Science and Research”. The Task 1 Report was issued in June of 2005.

The objectives for Tasks 2 and 3 are as follows:

1. (Task 2) Prepare an annotated summary of existing and emerging treatment technologies for treatment of conventional pollutants, harmful substances and emerging pollutants from the Task 1 report. The technologies will be assessed for their applicability to variations in Canadian climates, environments, regions and receiving waters.
2. (Task 3) Provide a review of best management practices for specific issues related to municipal wastewater treatment, including but not limited to:
    - Infiltration and inflow to municipal sewer systems
    - Reduction and treatment of sanitary and combined sewer overflows (SSOs and CSOs)
    - Management of hauled wastes such as septage, landfill leachate or industrial/commercial wastewaters
    - Small or remote community wastewater issues, including treatment cost and pollutant management
    - Discharges of treated effluents to marine environments
    - Lagoon issues, including ice cover and ammonia removal in winter, and algae removal in summer
    - Flow reductions to wastewater treatment plants using alternative technologies and source control plans, including water reuse and reclamation technologies
    - Aging collection system needs and upgrading practices
    - Wastewater treatment facility performance monitoring and quality control practices.

Advanced and Off-the-Shelf Technologies

Technologies reviewed as advanced and off-the-shelf processes included: biological nutrient removal; membrane bioreactors; Integrated fixed film activated sludge; moving bed bioreactors, biological aerated filter; sand filtration; membrane filtration (microfiltration, nanofiltration, reverse osmosis); chemically enhanced precipitation; constructed surface wetlands; and constructed subsurface wetlands.

Most of the technologies involving an advanced biological treatment process are expected to provide a level of treatment for the various substances that is higher than conventional nitrifying activated sludge. Processes that may not be as acceptable include the constructed wetlands processes with respect to nutrients and emerging contaminants. Chemically enhanced precipitation does not increase removal of ammonia-nitrogen well compared to nitrifying activated sludge. Without disinfection, BNR processes will not have adequate pathogen reduction, but with disinfection pathogen removal would be considered excellent. Much more information on the emerging innovative technologies is required to completely assess the process capabilities for removing the various types of substances in municipal effluents.

Most of the innovative biological processes are applicable to a wide range of conditions in Canada, in terms of discharge to different receiving environments (marine, freshwater, land), particularly in temperate climatic zones. In rural areas, operators may not have the technical expertise or resources to operate the innovative biological systems. The non-biological process of chemically enhanced precipitation may not reduce ammonia concentrations to required levels, whether for concerns about eutrophication or for effluent toxicity considerations. Constructed wetlands are a good technology for remote areas of Canada, but sustained periods of freezing conditions, especially in the Arctic and sub-Arctic, would require the inclusion of winter storage so that the wastewater is discharged to the wetland during above-freezing temperatures.. Land availability would likely restrict the use of constructed wetlands for treatment in large urban areas.

There are many gaps in our knowledge of treatment removal efficiency for toxicity, metals, pesticides, PAHs and hydrocarbons in the advanced processes such as membrane bioreactors, IFAS, MBBRs, and BAFs, as well as sand filtration and chemically enhanced precipitation. In addition, a variety of emerging contaminants such as different PPCPs, fragrances, flame retardants, perfluorinated compounds and other contaminants of emerging environmental concerns need to be characterized for removal in wastewater treatment. Current analytical capabilities can be a significant limitation in this effort, however. It is clear that much more information on the advanced technologies is required

Source Control

Certain metal and organic substances in wastewater can interfere with the microorganisms involved in aerobic and anaerobic treatment. The concentrations of substances that have been reported to interfere with biological treatment process are typically in the mg/L concentration range, which is generally higher than most substances would be found in raw wastewater. The mixed liquor solids of activated sludge can adsorb many of the metal and organic compounds, resulting in concentrations that are significantly increased compared to the raw wastewater levels.

Most municipalities have in place a sewer use bylaw that regulates the concentrations and quantities of substance discharged to municipal sewers for treatment. The sewer use regulations are generally targeted at businesses such as restaurants and industrial dischargers. Bylaws are intended to limit the discharge of substances to the sewer to prevent overloading of the treatment facility and possible discharge of toxic substances in effluents. Controlled parameters typically include pH, solvent extractable material of mineral or synthetic origin, solvent extractable material of animal or vegetable origin, biochemical oxygen demand, suspended solids, phosphorus, Total Kjeldahl nitrogen, phenolic compounds, chlorides and sulphates, fluorides, many individual heavy metals and cyanides. Some municipalities may also impose limits or include limits on other substances, such as a number of specific organic compounds. Industrial cooling waters, which may contain slimicides and corrosion inhibitors, and once-through cooling water, may also be prohibited from discharge to municipal sewers on the basis of both toxic substance and hydraulic loading concerns.

Materials subject to complete prohibitions in wastewaters discharged to sewers include: fuels, PCBs, pesticides, severely toxic materials, waste radioactive materials, hauled sewage, waste disposal site leachate, acute hazardous waste chemicals, hazardous industrial wastes, hazardous waste chemicals, ignitable wastes, pathological wastes, PCB wastes and reactive wastes.

Municipalities also implement pollution prevention programs to restrict the discharge of materials to sewers. Mercury in dental amalgams, silver from dental and hospital X-rays and photoprocessing wastes and fats, oil and grease from restaurants and large food service operations are specific examples.

Several substances, such as some metals and pesticides, are not readily removed by a basic level of secondary treatment (non-nitrifying conventional activated sludge). For such substances, when wastewater treatment has difficulty in achieving a high level of removal, source control may be the best option for prevention of discharge to receiving environments.

Best Management Practices

Best Management Practices originally were implemented in urban settings as flood and drainage controls. More recently, however, the BMPs serve several purposes such as treatment of stormwater and protection of receiving waters. There are a variety of Best Management Practices that can be implemented to restrict the entry of contaminants in aquatic environments.

The Best Management Practices for control of infiltration and inflow (I/I) involve urban runoff control, and include regulatory controls, source controls, detention facilities, infiltration facilities, vegetative practices and filtration practices. The BMPs are generally applicable to all regions of Canada, although harsh winter conditions in Northern Canada may restrict the implementation of some practices such as constructed wetlands or grassed swales to intermittent seasonal discharges.

The technologies for combined sewer overflow (CSO) reduction and treatment include source control, collection system controls, storage, physical treatment (racks and screening), chemical precipitation biological treatment and disinfection. Such technologies are applicable to most regions of Canada. Remedial plans to eliminate bacterial contamination of recreational swimming often include some form of stormwater detention. Higher storm flows can also be treated at the wastewater treatment plants when the step feed model of activated sludge is implemented. Permafrost in northern Canada may prevent the adoption of technologies where below-grade construction is required.

Sanitary sewer overflows (SSOs) can result from many causes including aging infrastructure, poor design, blockages by grease, obstruction from large solids (branches and roots). Most Canadian municipalities are faced with aging infrastructure. Implementation of sewer use programs will reduce blockages due to grease accumulation, and sewer maintenance programs, involving television cameras and maintenance records can identify blockages due to roots. The programs needed to prevent these problems can be implemented across Canada.

Review of the literature did not reveal any specific Best Management Practice for identification and removal of cross-connections. Monitoring of dry weather flows in storm sewers for evidence of sewage contamination is a common sense first step. Ranking of areas for removal of cross-connections as applied by the City of Edmonton is a practical approach for prioritizing areas of a municipality for reducing extraneous flows. The techniques appear to be applicable Canada-wide.

Discharge of septage to municipal wastewater treatment plants appears to have the potential for greater impact than does landfill leachate for mechanical plants such as conventional activated sludge or extended aeration processes. The elements of a best management practice for septage treatment at wastewater treatment facilities include construction of an equalization storage facility at the reception site, equipped with an odour control device. Coarse screening of the septage prior to discharge to the treatment facility, as practiced by the Capital Regional District, may be advantageous.

The contribution of municipal landfill leachate to daily wastewater treatment plant flow is very small. Nitrifying wastewater treatment facilities were deemed capable of meeting target effluent concentrations in winter operation. Facultative lagoons were similarly deemed capable of meeting effluent quality target with the exception of ammonia-N. The elements of a best management practice for leachate treatment at wastewater treatment facilities include construction of an equalization storage facility at the reception site, equipped with an odour control device. Intermittent sand filtration was recommended as a polishing step to achieve ammonia-N target concentrations in lagoon effluents.

The problems faced by small municipalities with funding for required treatment levels, hiring and maintaining staff and understanding the technicalities of wastewater treatment are common across Canada, but may be particularly acute in the Canadian North. Many resources are available through technical associations, government agencies and internet portals. Funding opportunities may be available by participating in technology demonstration projects.

Most developed nations have implemented either long outfalls to deep water and/or secondary treatment to deal with common problems of bacterial levels, elevated nutrient, which can contribute to depleted dissolved oxygen levels, plastics floatable materials, and sediments with elevated levels of heavy metals, pesticides and other substance. Treatment of wastewater to secondary levels or higher offers environmental improvements in nutrient removal and reduced levels of potentially toxic substances either dissolved or associated with suspended solids. Canadian coastal cities have not generally matched the tendency of other developed nations to move to secondary treatment, although there is some indication, such as with Charlottetown and Summerside in PEI, that this is changing.

Other than Iqaluit (estimated population of 6500), there are no large Canadian municipalities in Northern Canada located on marine coasts. Prevailing currents off Canada's east and west coasts tend to bring colder Arctic waters down, and so effluents are generally discharged into cold marine waters. Organic substances discharged in municipal wastewater to Arctic marine environments (the Arctic Ocean. Hudson Bay) would tend to persist for long periods because both biodegradation and volatilization to the atmosphere are slow under cold conditions (relative to southern Canada).

Facultative lagoon treatment is one of the most common methods of treatment for small communities across Canada. Most of the problems experienced in lagoon treatment are common to all locales. In winter, biological removal of ammonia in facultative lagoons is curtailed and ammonia concentrations in effluent discharges may exceed regulatory limits. Toxic gases such as hydrogen sulphide accumulate under ice cover, and produce foul odours and potentially toxic effluents when the ice cover breaks up in spring. Aerated lagoons are less susceptible to the winter problems experienced by facultative lagoons because aeration in the initial cell reduces the potential for ice cover. Depending on whether the lagoon discharge is seasonal or continuous, the end-of-pipe effluent may be acutely lethal to test organisms. Technologies such as intermittent sand filters and static aerators may reduce some of these toxicity and odour concerns.

Source control is a measure that can be adopted across Canada to reduce total wastewater flow. Programs can be provided that are either incentives (grants) or disincentives (financial penalties and fines). Improvements in domestic plumbing devices, (low-flush toilets, low-flow shower-heads) in new developments can significantly reduce wastewater volumes. Water reclamation is not practiced to any extent at this time in Canada, but with the apparent onset of global warming, the need to practice water reclamation and reuse appears inevitable, as it has already become well-entrenched in the southern U.S.

Canadian municipalities need to maintain their infrastructure to provide safe drinking water and proper sanitation. In, Ontario alone, the investment required to return Ontario's current water and wastewater systems to a state of good repair - and maintain that condition for the indefinite future – is estimated to be between $30 and $40 billion over the next 15 years (Water Strategy Expert Panel, 2005). Other provinces are faced with similar challenges. There are many best practices provided by Infraguide Canada that municipalities can use to understand the condition of their infrastructure and take the necessary measures to attack the problem.

Benchmarking is a procedure that Canadian municipalities can conduct on their own through voluntary programs such as Qualserve, offered by the American Water Works Association. Adoption of ISO Certification by Canadian wastewater treatment facilities is in its infancy. There is a growing trend in the U.S. for this level of environmental management. Municipalities that have become certified as ISO 14001 compliant indicate that many advantages result.

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1.0 INTRODUCTION

1.1 Background

In November 2003, the Canadian Council of Ministers of the Environment (CCME) agreed to develop a Canada-wide strategy for municipal wastewater effluent (MWWE). The Strategy involves three principal tenets, including:

- Harmonizing the regulatory framework among the federal, provincial and territorial jurisdictions;
- Coordination of science and research activities; and
- Use of an environmental risk management model to guide decision making.

For the Strategy to be effective the Development Committee (DC) must understand the current state of knowledge on MWWE; i.e., the science and research, evolving treatment technologies and best management practices. Consequently, the DC has commissioned this study to provide a comprehensive review of the current state of knowledge of MWWE science and technology regarding the treatment of conventional pollutants as well as emerging substances of concern.

1.2 Objectives

As expressed in CCME's Request for Proposal (RFP) for this study, the objectives of the entire study are to:

1. Prepare a comprehensive consolidated inventory of harmful substances and emerging problematic substances found or likely to be found in Canadian MWWE. Identify substance sources, typical effluent concentrations, and an annotated assessment of effects on the natural aquatic environment and on human health associated with the various substances or groups of substances.
2. Prepare an annotated summary of existing and emerging treatment technologies for treatment of conventional pollutants, harmful substances and emerging pollutants from objective 1. The technologies will be assessed for their applicability to variations in Canadian climates, environments, regions and receiving waters.
3. Provide a review of best management practices for specific issues related to municipal wastewater treatment, including but not limited to:
    - Infiltration and inflow to municipal sewer systems
    - Reduction and treatment of sanitary and combined sewer overflows (SSOs and CSOs)
    - Management of hauled wastes such as septage, landfill leachate or industrial/commercial wastewaters
    - Small or remote community wastewater issues, including treatment cost and pollutant management
    - Discharges of treated effluents to marine environments
    - Lagoon issues, including ice cover and ammonia removal in winter, and algae removal in summer
    - Flow reductions to wastewater treatment plants using alternative technologies and source control plans, including water reuse and reclamation technologies
    - Aging collection system needs and upgrading practices

- Wastewater treatment facility performance monitoring and quality control practices.

This report addresses the first study objective and constitutes the deliverable for Tasks 2 and 3.

2. TASK 2 – IDENTIFICATION OF TECHNOLOGIES

2.1 Description of Conventional Wastewater Treatment Processes

The objective of this chapter is to identify the "off-the-shelf" and advanced treatment processes that are available to address the substances of concern identified in the Task 1 Study. To understand the description of the advanced treatment processes, it is necessary to have a brief introduction to the conventional treatment processes that form the backbone of wastewater treatment in Canada.

2.1.1 Primary treatment

The goal of primary treatment is to reduce the concentrations of the larger inorganic and organic solids in the raw wastewater. The wastewater is first passed through screens to remove the large solids, and then the flow is slowed in a tank (called a settler or clarifier) so that the water is held for a period of 2 to 6 hours. During this time additional solids are allowed to settle by gravity to the bottom of the tank, from where they are drawn off for separate solids treatment. Removal efficiencies of biochemical oxygen demand (BOD) and suspended solids are in the range of 25-40% and 50-70%, respectively. The soluble materials in the water phase, such as ammonia, are not removed in this process. The primary effluent is often treated with chemical disinfection prior to release. By itself, the technology is typically unable to meet effluent limits for conventional pollutants such as BOD_5 and suspended solids. Chemically assisted primary treatment, in which inorganic or organic flocculants are introduced into the wastewater, helps to improve the effluent quality over primary treatment alone. This process is discussed in greater detail in Section 2.3.

2.1.2 Secondary treatment

Secondary treatment is used to remove the soluble organic matter and suspended solids in the primary treated wastewater. Secondary treatment involves biological processes which use the soluble organic matter (BOD) as a food source to grow and multiply. The biological process may consist of microbial biomass maintained in suspension in a tank (suspended growth system), or attached to a support medium (fixed film system). Air is generally supplied to ensure that the organisms have sufficient oxygen to grow. More recently, hybrid reactors using both types of systems have been developed as advanced treatment (see Section 2.3). The activated sludge process is the most common type of suspended growth treatment. Lagoons systems are a form of biological treatment, but their use in Canada is so widespread, and there are several variations, so that they are discussed in a separate subsection.

After the biological process tank, another tank is provided with an extended holding time of 6-10 hours to allow the biomass involved in BOD removal to settle to the bottom. The settled solids are either recycled back to the main biological treatment tank to control the solids inventory there, or they are wasted from the system for solids treatment.

Both carbonaceous and nitrogenous matter can exert BOD. Carbonaceous BOD is removed by 80 to 95 % in conventional activated sludge (CAS) systems; however, the nitrogenous BOD may receive little or no treatment in CAS. The conversion of nitrogen in activated sludge is represented by the nitrification process, in which ammonia-nitrogen undergoes a two-step biological oxidation to nitrate-nitrogen. Many plants in Canada are being required to promote nitrification to avoid the potential toxic effect of ammonia on aquatic biota. Nitrate is a more benign form of nitrogen than ammonia in the aquatic environment.

Lastly, effluents from secondary treatment undergo disinfection for reduction of pathogenic organisms, chiefly bacteria and viruses. Chemical disinfection in Canada is most commonly accomplished using either gaseous chlorine or sodium hypochlorite (bleach) solution. Without additional dechlorination process, chlorinated effluents will likely be toxic to the aquatic receiving environment. In recent years, ultraviolet (UV) light has grown in popularity for disinfection of secondary effluents because it leaves no toxic residual, it is safer to handle than chlorine gas, and it is more effective in inactivating parasites such as *Giardia* and *Cryptosporidium* than is chlorine.

2.1.3 Lagoon treatment

There are a number of different types of lagoons operating in Canada, and the following section is provided to help define the different types of lagoon operation. Use of lagoons (also called wastewater stabilization ponds) is one of the more common biological treatment processes used by smaller and remote communities in Canada, principally due to its low cost and simplicity of operation. Lagoons with several months of storage capacity may produce effluent quality similar to secondary or even tertiary mechanical treatment due to extended storage times.

The most common types of lagoon treatment in Canada are noted in Table 1. The simplest type of lagoon is a facultative pond, in which facultative bacteria exist in both aerobic and anaerobic environments. Aerobic conditions are maintained near the pond surface where wind and wave action, and photosynthesis supply oxygen to the water. Anaerobic conditions prevail in the deeper part of the lagoon near the bottom, where a sludge layer accumulates.

Aerated lagoons typically have an initial mechanically aerated cell followed by one or more non-aerated cells for additional waste stabilization and polishing. Aeration may be applied only to maintain sufficient dissolved oxygen (D.O.) for biological oxidation of soluble carbonaceous material, or a higher intensity of aeration may be applied for mixing to maintain solids in suspension, as well as providing D.O. At the lower aeration intensity, solids may accumulate and anaerobic conditions prevail on the bottom of the cell, even with aeration provided at the surface of the cell.

Lastly, some locations may have storage or polishing lagoons, which are intended to provide further effluent polishing and seasonal nitrification (Metcalf and Eddy, 1991). The organic loading rate on the polishing lagoons is much lower than that for aerated or facultative lagoons. Typical storage times are 6 to 12 months, although it is suggested that in the Canadian High Arctic, some storage ponds may have up to 2 years of retention (Townshend and Knoll, 1987).

In most cases, lagoon operation is either seasonal or continuous. The discharge mode is typically dependent on the climatic conditions, and on the receiving body of water. Seasonal discharge is required when receiving bodies of water are frozen (e.g. in northern Canada), or when the receiving water flow rate is too low to accommodate the effluent loading from the lagoon (e.g. southern Canada and arid zones). In a limited number of lagoon applications, typically in

Canada's North, effluents may never be discharged, serving as exfiltration lagoons. The cells in lagoon systems may also be operated in series or in parallel. Operation of cells in series is recommended when higher BOD and coliform bacteria removal efficiencies are needed (Metcalf and Eddy, 1991).

One of the major operational problems associated with lagoon operation is the concentration of photosynthetic algae in the discharge. Algae concentrations may be higher than suspended solids concentrations specified in operating certificates or permits. In such cases, there are a number of processes that can be used to reduce algae levels, including additional settling ponds or tanks; chemical precipitation; dissolved air flotation; fine screens; filters and natural treatment systems (Metcalf and Eddy, 1991).

BOD_5 removal can range from approximately 80 to 95 %, depending on the loading and retention time. Effluent suspended solids concentrations can range from approximately 40 to 250 mg/L. Phosphorus removal efficiency is dependent on the levels of suspended solid in the lagoon effluent, with most of the phosphorus in the particulate state. Higher levels of removal efficiency can be achieved with chemical flocculation and precipitation, or by suspended solids removal processes. Partial ammonia-nitrogen removal may be achieved in lagoon with extended storage time during warmer months. Partial ammonia-nitrogen oxidation can increase the effluent total BOD_5 concentration, so distinction may need to be made between total and carbonaceous BOD_5 removal when considering effluent limits. Additional ammonia removal may be achieved with intermittent sand filters or wetlands treatment. The long retention times of lagoon systems can result in significant reduction of fecal coliform bacteria, on the order of 3 log (99.9 %) reduction or more (EPA, 1983). Because of very high influent densities, of 10^6 to 10^7 organisms per 100 mL, however, effluent concentrations may exceed required effluent limits typically in the range of 200 organisms per 100 mL. Disinfection of lagoon effluents by chemicals (chlorine or hypochlorite) or by UV light would reduce the effluent concentrations to low levels.

Removal of metals in wastewater is highly variable, depending on the specific metal, and lagoon operation. The pH of facultative lagoons can vary in a daily cycle as photosynthesis (daytime) and respiration (night time) dominate by turns. As the pH varies, precipitation of metals may also vary. The redox condition in facultative lagoons may also affect metal concentrations, as sulphide present in the anaerobic zone of a facultative lagoon can readily precipitate metals.

Similarly, certain organic substances can be removed at very high removal efficiencies by the long retention time in a lagoon. Other substances may be highly recalcitrant and display a low overall removal efficiency. Contaminant removal mechanisms can include biodegradation, surface volatilization, stripping in an aerated cell, sorption to solids that settle to the sludge layer. There is some evidence that photo-oxidation may play a role in removal of a number of certain specific organic substances. Removal of specific substances, including those of emerging concerns, are found in Section 2.1.2.

Table 1. Typical Design Parameters for Canadian Lagoon Systems

Lagoon Parameter	Lagoon Type		
	Facultative	Aerated Cell	Polishing/Storage
Depth (m) [1]	1.5-2	1.8-6.1 [2]	1.7-2.7
Retention time (d) [1]	Minimum 60	Single cell: 20 Cell followed by polishing: 3-10	6-24
BOD_5 Loading (kg/ha.d) [1]	22.4-56.1	Not specified	7-20
BOD_5 Conversion (%) [2]	80-95	80-95	60-80
Principal BOD_5 Conversion Products [2]	Algae, CO_2, CH_4, bacterial cell mass	CO_2, bacterial cell mass	Algae, CO_2, bacterial cell mass, nitrate
Algae concentration [2] (mg/L)	5-20	Not applicable	5-10
Effluent suspended solids (mg TSS/L) [2]	40-60	80-250 (aerated cell only)	10-30
pH [2]	6.8-8.5	6.5-8.0	6.5-10.5

[1]Townshend and Knoll (1987)
[2]Metcalf and Eddy (1991)

2.2 Context of Trace Substance Removal in Wastewater Treatment

2.2.1 Removal by Secondary Substrate Utilization

Municipal wastewater treatment plants have been designed traditionally to remove the conventional pollutants, represented as biochemical oxygen demand (BOD_5), suspended solids, nutrients (nitrogen and phosphorus) and pathogenic organisms. In the past, they have not been designed for “removal” of trace inorganic and organic substances, although there is evidence that some level of removal has occurred, based on comparison of influent and effluent concentrations.

In conventional wastewater treatment, the soluble organics measured as BOD_5, at concentrations that may be 3 to 6 orders of magnitude higher than the specific trace organic substances, provide the primary substrate or food source by the wastewater microbes. Some of the trace organics are co-utilized as a food substrate by the microorganisms, in what is termed secondary substrate utilization. Some metals such as cobalt, chromium, zinc and iron are essential micronutrients, and may be used in microbial cell synthesis as well. Non-biological removal mechanisms include stripping and volatilization, precipitation, sorption to colloidal or larger particles, hydrolysis and photolysis. The contributions of the latter two mechanisms, based on documented fate studies, are small in comparison to the other mechanisms.

More recently, interest has grown in implementation of water reclamation and indirect potable reuse of treated municipal wastewater effluent. As a result, processes such as ozonation, advanced oxidation (e.g. UV light and hydrogen peroxide) and membrane applications (nanofiltration and reverse osmosis), are being included in the traditional treatment plant design to specifically address the removal of these trace substances.

2.2.2 Defining “Removal” Efficiency

Reported removal efficiencies in the technical literature can have several meanings. The most common application of the term removal refers to a comparison of the influent and effluent concentrations of a substance. This definition, in essence, is the reduction of the particular substance through the liquid treatment train. In general, in this report, this definition is used, as the scope of the report is focused on municipal effluents.

There are at least two drawbacks to this definition of removal efficiency. The first is that it neglects the transfer of the substance to the gas (air) and solid (sludge) phases. Simple transfer of a substance to wastewater biosolids destined for land application, or to the atmosphere, does not encompass treatment in a holistic sense. The second drawback is that the substance may be modified biologically (metabolized) to a similar substance, which has environmental effects that may be similar or even worse than the original compound. To account for this type of substance behaviour in wastewater treatment, some researchers, especially in Europe, refer to the transformation of the parent (original) substance to a metabolite (daughter product) as primary elimination. True removal is thus considered to be the actual mineralization of the parent compound to carbon dioxide and water. Where possible in the report, the concept of primary elimination is discussed. This terminology cannot always be used, however, because it is not always specified in the original technical literature.

The surfactant nonylphenol ethoxylate is a good example representing this discussion. It has a long chain composed of multiple ethylene oxide (EO) units(e.g. 13-20 units). As aerobic biological treatment progresses, the chain is shortened sequentially be removal of the EO units, until only 1 or 2 remain of the original chain. Ultimately, through anaerobic treatment the ethoxylate may simply become nonylphenol, which as a potential endocrine disrupting substance is more potent than the original parent ethoxylate.

2.2.3 Analytical Limits of Detection for Trace Substances

Trace and emerging substances are typically found at very low concentrations in wastewater, for example, in the µg/L or ng/L level. This alone makes their analysis difficult, but it is further complicated by the complex wastewater matrix, which may result in significant interferences of the target analyte.

The precision and accuracy of analytical procedures are lowest at the analytical detection limit. Many of the trace and emerging contaminants of concern are found near or below the analytical detection limit, leading to reported results that appear questionable. There are three scenarios to consider, involving a series of measurable influent and effluent concentrations close to the detection limit. The scenarios are provided in Table 2.

Table 2. Removal Efficiencies at the Detection Limit

Scenario	Influent Concentration, ng/L	Effluent Concentration, ng/L	Removal Efficiency, %	Remark
1	4	1	75	Good removal
2	3	2	33	Poor removal
3	2	3	-33	Negative removal/formation

If the accuracy of the procedure is only + 100% near the detection limit, then it is possible to observe removals that range from high (e.g. 75%) to a negative removal. Removal efficiencies in such cases need to be reviewed critically to assess their validity. When dealing with substances near the detection limit, reported removal efficiencies both within one plant and between several plants may appear to be highly variable.

Negative removal efficiencies may imply either formation of a substance or an issue of low detection limits that would not be statistically different than 0 or a positive removal efficiency. Chloroform is a substance that is usually formed when effluent treatment involves chlorine disinfection, and so a calculated negative removal efficiency would be a true assessment. In other cases, when concentrations are close to detection limits, a negative removal efficiency is a statistical artifact of sampling and analytical variability. The question of statistical reliability can be addressed by the collection and analysis of additional samples, but this effort is tempered by the cost of the collection and analysis of the additional samples.

Negative removals may also occur when discrete samples are collected in a treatment plant without consideration of hydraulic detention times. For example, if a transient spike of material has passed through a treatment plant, and is captured in the effluent sample, but not the influent, then a negative removal efficiency would be correctly calculated.

2.2.4 Issues of Trace substances in Solids/Biosolids

The scope of this project is focused on municipal effluents rather than on partitioning of the substances to other media, namely solids and air. It is a fact, however, that some of the substances identified in this report do partition to some extent to wastewater solids. Such contaminants are lipophilic (hydrophobic), and may generally be characterized as non-polar, higher molecular weight and often are highly halogenated. Compounds in this group include polyaromatic hydrocarbons, PCBs and chlorinated dioxins and furans, and many pesticides.

Inorganic contaminants as well may accumulate in solids, either as insoluble precipitates or as metal ions sorbed onto organic solids. Pathogenic organisms such as parasite ova concentrate in settled wastewater solids as well.

The environmental issues of substances of concern identified in effluents are not intended to be minimized herein, but are outside of the scope of this project, and need to be addressed by a separate study.

2.3 Overview of Off-the-Shelf and Advanced Treatment Processes

For the purposes of this section, processes that are considered to enhance conventional secondary treatment (i.e. conventional activated sludge with short solids retention time (SRTs less than approximately 5 – 6 days)) have been examined. The following section provides a brief overview of the technologies and the context within which their contribution to contaminant removal was assessed.

The processes evaluated in this section are provided in Table 3, which explains the role of the technology relative to the non-nitrifying conventional secondary treatment process (conventional activated sludge, CAS). The processes evaluated are designated for their role either as a replacement for the CAS process, for retrofitting or upgrading the CAS process, or for following the CAS process for further effluent polishing. Note that some technologies may be implemented by more than one procedure.

Table 3. Role of Advanced and "Off-the-Shelf" Technologies Relative to Conventional Secondary Treatment

Technology	Role of Technology Relative to CAS		
	Retrofit/Upgrade	Replace	Add-on
Biological Nutrient Removal	X		
Membrane Bioreactor	X	X	
Integrated Fixed Film/Activated Sludge	X	X	
Moving Bed Bioreactor	X	X	
Biological Aerated Filter		X	
Sand Filtration			X
Membrane Filtration			X
Enhanced Chemical Precipitation	X		
Surface Wetlands			X
Subsurface Wetlands			X

2.3.1 Technology Descriptions

2.3.1.1 Biological Nutrient Removal (BNR)

BNR processes are suspended growth activated sludge processes that incorporate additional cells that typically include anoxic and anaerobic environments. These technologies were developed to enhance the biological removal of nitrogen (ammonia through nitrification and nitrate through denitrification) and phosphorous (enhanced biological phosphorous removal). To achieve satisfactory removal of nitrogen and phosphorous these processes are typically operated at extended solids residence times. Adoption of BNR technology is often sufficient to reduce effluent ammonia-N concentrations below those exerting toxic effects. The extended solids residence times permit the establishment of cultures of microorganisms that have slow growth rates such as nitrifying and denitrifying bacteria. It is also believed that the extended solids residence time facilitates the culturing of microorganisms that are capable of degrading xenobiotic organic compounds such as endocrine disruptors, pharmaceuticals and personal care products. The presence of anoxic and anaerobic environments in the BNR process may enhance the degradation of substances that are more susceptible to reductive transformation mechanisms (i.e. chlorinated organics).

Advantages of BNR technology are that is now well understood, and can be retro-fitted to existing plant configurations in many cases. It is adaptable to climate extremes, with operation as far north as Edmonton. The disadvantages besides greater cost than conventional secondary treatment, is that it is more sophisticated to operate and requires greater operation training and skill. In more extreme cold, the reaction kinetics of the process may slow significantly, and so more tank volume may be required to increase detention time, thus increasing the process costs.

BNR plants are slowly increasing in numbers, principally in British Columbia, Alberta and Ontario, mostly as a result of the need to reduce the nutrients to very sensitive receiving waters such as Lake Okanagan.

2.3.1.2 Membrane Bioreactors (MBR)

MBR processes consist of suspended growth basins where membranes are employed for suspended solids separation prior to effluent discharge. The use of membranes for solids separation allows for the establishment of processes with extended solids residence times, as discussed above for ammonia-N and xenobiotics in BNR processes. This facilitates the biodegradation of substances that are facilitated by slow-growing microorganisms. In addition, the high level of solids removal that can be achieved with membranes should minimize the discharge of substances that tend to associate with the solids. This would include hydrophobic organic compounds that are not degraded, as well as metals that are either present as precipitates or adsorbed to the solids.

The advantages of membrane bioreactors include a small footprint relative to conventional secondary treatment for new installations, ease of retro-fitting the membrane units in existing plants, higher solids concentrations in the reactor to promote nitrification and biodegradation of organic substances, and lower volumes of waste solids for disposal. There are varying pinions on the maintenance requirements of MBRs. Earlier units may have been equipped with membranes that are less robust than those today, and also may not have been as easy to prevent fouling. Newer units are better designed in these features. The degree of maintenance carried out by plant staff may also affect the reported operation of the membrane systems. The disadvantages of the MBR process are that there are variable reports on membrane life, membrane replacement costs are high, the membranes require cleaning at regular intervals, and the operation is more complex than conventional treatment, requiring a higher level of operator training. When treating very cold wastewater, the membrane flux rate may decline. The slower kinetics of BOD conversion and biodegradation in cold wastewater may dictate the use of larger tanks.

Adoption of MBR systems is increasing very slowly across Canada, since it is a relatively new technology. As more suppliers enter the field, and as membrane life and cleaning are reduced as issues, the technology will likely see wider adoption.

2.3.1.3 Integrated Fixed Film Activated Sludge Processes (IFAS)

IFAS processes consist of activated sludge processes where media is added to the aeration basin to facilitate the development of a biofilm-based culture in the basin. Hence, this process incorporates both suspended and biofilm-based cultures of organisms. The development of a biofilm on the carrier allows the process to maintain an extended solids retention time and hence should facilitate the growth of slow growing microbial cultures that are capable of degrading xenobiotics.

The advantages of IFAS processes are that they encourage higher biomass concentrations, which promote nitrification and biodegradation of some organic substances, and that they can be retrofitted to existing process tanks with relative ease. The disadvantages of the process are that it is more costly than conventional secondary treatment, and that operational problems have been reported, especially with rope-like material (breakage, worm infestations). The number of suppliers of the technology is also relatively limited. The slower kinetics of BOD conversion and biodegradation in cold wastewater may dictate the use of larger tanks.

This technology has not been adopted to any extent in Canada.

2.3.1.4 Moving Bed Biofilm Reactors (MBBRs)

MBBRs represent a group of treatment technologies that consist of an aeration basin that contains a high volumetric fraction of biofilm carrier. The biofilm carrier is typically some configuration of floating plastic media. Several proprietary carriers are currently available. MBBRs do not recycle suspended biomass to the aeration basin and hence biodegradation is primarily achieved by the biofilm-associated organisms. MBBRs typically have reduced hydraulic residence times (HRTs) and extended solids residence times (SRTs) as compared to conventional activated sludge processes. The extended SRTs should facilitate the biodegradation of xenobiotic compounds.

The advantages of MBBR process is that it encourages higher biomass concentrations, which promote nitrification and biodegradation of some organic substances, and that they can be retrofitted to existing process tanks with relative ease. The disadvantages of the process are that it is more costly than conventional secondary treatment, and that the technology is relatively new operational problems have been reported, especially with rope-like material (breakage, worm infestations). The number of suppliers of the technology is also relatively limited. The slower kinetics of BOD conversion and biodegradation in cold wastewater may dictate the use of larger tanks.

The technology has not been adopted to any extent in Canada.

2.3.1.5 Biological Aerated Filters (BAFs)

BAFs represent biological wastewater treatment processes where the treatment reactor contains fine particles (e.g. expanded clay or polystyrene beads) that acts as a biofilm carrier and also serves to filter solids-associated contaminants. BAFs can have a variety of configurations that include both upflow and downflow hydraulics. In addition, some BAF processes incorporate anoxic zones to facilitate denitrification processes. BAFs have reduced HRTs and extended SRTs as compared to conventional activated sludge processes. The extended SRTs should facilitate the biodegradation of xenobiotic compounds. The filtration mechanism may also facilitate the retention of solids-associated pollutants.

The advantages of the BAF process is that it can carry higher levels of biomass, and contain anoxic and aerobic zones, thus making it amenable for BNR and higher levels of biodegradation of organic substances. It typically requires a smaller footprint than conventional secondary treatment. Because it acts as a filter, effluent suspended solids, and any associated contaminants are low. Disadvantages of the process include complexity of operation, requiring more sophisticated operator training, the number of suppliers of the technology is relatively limited, and the slower kinetics of BOD conversion and biodegradation in cold wastewater may dictate the use of larger tanks.

There are limited installations of this technology in Canada, principally in Quebec.

2.3.1.6 Sand Filtration

Sand filtration is often employed as a tertiary treatment process to enhance the removals of suspended solids and solids-associated substances (i.e. phosphorous). In some applications it may be possible to achieve some nitrification and denitrification in a tertiary sand filter. The contribution of tertiary filtration to contaminant removal will to some extent depend upon the efficiency of the upstream treatment processes. Hence, if the upstream processes are discharging low concentrations of contaminants the sand filter acts to "polish" the effluent. In this regard the removal efficiencies may not be high however the quality of the effluent is enhanced somewhat.

The advantage of sand filtration is that it is a widely understood and adopted technology, and can be readily retrofitted to existing plants. Removal of additional solids from secondary effluent also results in increased removals of phosphorus and other substances adsorbed to the solids. Operation is generally simple, although some additional operator skill is needed for the associated instrumentation governing operation and backwashing. The disadvantage is that it must be enclosed in a heated building for year round operation; sand filters cannot be used out-of-doors in sub-freezing weather.

Sand filters are common in use in Ontario as a tertiary treatment technology. Adoption of this technology in other parts of Canada is dictated by the need for high quality effluents, as it is in Ontario.

2.3.1.7 Membrane Filtration

Membrane processes (ultra-filtration, nano-filtration, reverse osmosis) can be employed as tertiary treatment process to provide a high quality effluent that might be considered in water re-use scenarios. Depending upon the pore size employed varying degrees of solids removal can be achieved. Reverse osmosis and nano-filtration can remove virtually all dissolved organics as well as pathogens.

The advantages of membrane treatment are that it produces effluents of very high quality suitable for reclamation and non-potable reuse, it can be retrofitted fairly easily to existing treatment plants, and it serves as a barrier for most pathogens, with the potential exception of viruses. The disadvantages of membrane treatment are that it requires pretreatment by sand filtration to reduce particulates, and the membranes are subject to fouling and thus have higher operational costs than conventional treatment. The costs for electricity to operate the high pressure pumps in reverse osmosis and nano-filtration units are high. Replacement costs for membranes are high. The operation of membrane units requires more highly trained operators. The process produces a highly concentrated stream of contaminants that must be disposed of, typically off-site, which entails other costs.

Membrane filtration of wastewater effluents has not been adopted to any extent in Canada.

2.3.1.8 Chemically Enhanced Precipitation with Solids Separation

Coagulants and precipitating agents (i.e. organic polymers, ferric iron, alum) can be added to wastewater treatment processes to enhance the formation and separation of solids that can be more readily removed from the wastewater stream. This is commonly employed for phosphorous removal. The agents may be added to either a conventional secondary treatment process (i.e. activated sludge) or be incorporated as part of a tertiary treatment technology (i.e. sand filtration). In both cases the effectiveness of the agent will be a function of the solids separation efficiency. In addition, the effectiveness of the chemical addition will depend upon its effectiveness in forming a solid-associated contaminant. For example, the removal of organic contaminants that are not entrapped into or adsorbed onto the solids will not be enhanced by chemical addition.

The advantages of chemically enhanced precipitation are ease of operation without highly skilled operators, ease of retrofitting to existing primary clarifiers, and enhanced removal of substances such as phosphorus, and those substances, both inorganic and organic, which are sorbed onto colloidal and particulate matter. It is not significantly affected by cold weather operations. The disadvantage of chemically assisted precipitation is that it is generally ineffective in reducing concentrations of soluble substances such as ammonia and soluble BOD, and the process will generate greater volumes of residual solids (sludge) for treatment and/or disposal.

Chemically enhanced precipitation is employed at a limited number of treatment facilities in Canada, usually at locations that discharge to a high volume receiving water. It is commonly used to reduce concentrations of solids and phosphorus prior to secondary biological treatment.

2.3.1.9 Engineered Surface Wetlands

Surface wetlands typically consist of a series of ponds that contain cultivated plants of some type. Surface wetlands can remove nutrients such as phosphorous and nitrogen by plant uptake. Suspended solids are typically removed by sedimentation and filtration processes. Hence, solids associated contaminants will be removed by this mechanism. Dissolved organic substances may be removed through adsorption onto plant matter or biodegradation that is performed by bacteria that are present in biofilms that establish on the plants. The UV portion of the sunlight spectrum inactivates pathogenic microorganisms and photo-oxidizes some chemical substances if the sunlight is able to penetrate into the pond. Wetlands have been employed either for secondary treatment or tertiary treatment of wastewaters. The removal efficiencies that can be achieved in tertiary treatment wetlands can be expected to be higher than those of secondary treatment due to the reduced loading of contaminants. In some applications in the Canadian North, natural wetlands are used and have no treated effluent; instead the treated wastewater seeps (exfiltrates) into the ground.

The advantages of surface wetland treatment are that it is a low technology treatment process, and thus requires no significant operator skill. Wetland treatment, either natural or constructed, can produce high quality effluents. The wetlands are often sites of enhanced wildlife biodiversity and refuge. The operating costs of wetlands are low. The disadvantages of wetlands treatment include the large footprint required, making them generally unsuitable for larger municipalities with high wastewater flow rates, and that winter operation and efficiency would be curtailed during sub-freezing conditions. The temperature issue is avoided in the Canadian North by restricting discharges to limited times of the year through the use of storage lagoons.

Engineered surface wetlands have been applied in a minor role in Canada. There is more potential for wetland treatment seen in the Canadian North (Ferguson, Simek and Clark, 2003). Natural wetlands with some enhancements are used for treatment, however; constructed wetlands are not as suitable in the North due to slow growth rates and harsh winters. The inactivation of pathogens and photo-oxidation of chemical substances may be enhanced by long hours of sunlight in the Canadian North .

2.3.1.10 Engineered Subsurface Wetlands

Subsurface wetlands typically consist of a porous media (i.e. gravel) through which the wastewater is directed. Plants are often grown in the media to facilitate oxygen transfer into the subsurface and hence promote aerobic conditions. Biodegradation of organic contaminants is facilitated by bacteria that establish biofilms of the porous media. Hence it can be expected that extended SRTs are maintained in the process. This should facilitate the establishment of a culture of slow-growing bacteria that are often associated with biodegradation of xenobiotic compounds. These wetlands facilitate suspended solids removal through sedimentation and filtration mechanisms and hence the removal of solids-associated contaminants is enhanced. Wetlands have been employed either for secondary treatment or tertiary treatment of wastewaters. The removal efficiencies achieved in tertiary treatment wetlands can be expected to be higher than those of secondary treatment due to the reduced contaminant loadings.

The advantages of constructed subsurface wetland treatment are that it is a low technology treatment process, and thus requires no significant operator skill. It can produce high quality effluents. The wetlands are often sites of enhanced wildlife biodiversity and refuge. The operating costs of wetlands are low. The disadvantages of constructed subsurface wetlands treatment include the large footprint required, making them generally unsuitable for larger municipalities with high wastewater flow rates, and that winter operation and efficiency would be curtailed during sub-freezing conditions.

This technology has not been adopted to any extent in Canada.

2.3.1.11 Technology Summary

Table 4 provides an overview of the capabilities if the different technologies described above for removing various types of effluent substances. Comparison of the different technologies can only be accomplished using a benchmark technology. For this discussion conventional non-nitrifying activated sludge will be used as the bench-mark. The advanced biological processes noted in Table 4 include biological nutrient removal (BNR), membrane bioreactor (MBR), integrated fixed film activated sludge (IFAS), moving bed bioreactor (MBBR) and biological aerated filter (BAF). These technologies will produce higher quality effluents than the benchmark technology because they maintain more biomass in the system for a longer period of time. As a result, there is more opportunity for the organic substances of concern, as well as select other substance such as ammonia-nitrogen, to be degraded microbially. All the biological processes would require some form of disinfection (chemical or ultraviolet light) to reduce concentrations of microbes prior to discharge.

Chemically enhanced precipitation (CEP) as the main treatment technology is not as effective as the bench-mark technology for removal of the substances present in the liquid phase. Ammonia-nitrogen and other soluble substances are not reduced to any extent by CEP. Emerging substances of concern, such as some PPCPs also are present in the liquid phase, and so would not be reduced by CEP alone. Consequently CEP would be most effective when combined with some form of innovative biological treatment as described in the previous paragraph.

Sand filtration is not a stand-alone technology for wastewater treatment. It does remove solids in a wastewater stream, and so is effective for any substances of concern that would be adsorbed onto the solids. The wastewater stream to be filtered should be reduced in suspended solids to the extent practical to prevent excessive filter backwashing. Membrane filtration similarly is not considered a stand-alone wastewater treatment because of the need to prevent excessive membrane fouling. As a result, it is best applied for treating effluents that are already substantially reduced in suspended solids and high molecular weight materials that blind the membrane pores.

Wetlands treatment can be effective for some classes of contaminants as the principal form of treatment, but may be subject to variable removal efficiencies; dependability for high removal efficiencies of substances cannot always be assured. Wetlands treatment and overland flow are effective as a polishing step for other biological processes including facultative lagoon effluents.

Table 4. Removal of Substances by Advanced and "Off-the-Shelf" Wastewater Treatment Processes

Technology	Substance											
	BOD	NH_4	NO_3	P	Solids	Toxicity	Metals	Pesticides	PAH's	Hydrocarbons	Emerge	Pathogens
BNR	G-E[1]	G-E[1]	G-E[1]	G[1]	G-E[1]		G-E[1]	P-E[1]			G-E[2,3]	P-F[1]
MBR	E[25,28]	E[27,28]	G-E[28,29]	G[27,28]	E[27,28]						G-E[7]	E[26]
IFAS	E[13,16]	E[13,16]	G-E[16]		G-E[13]							
MBBR	G-E[14]	G-E[14]	G-E[15]									
BAF	E[17]	G[18]-E[20]	G-E[19]	F[18]	E[18]						G-E[6-7]	
Sand filtration	G-E[30]	G-E[30]	G-E[30]		G-E[30]						P[11]	G[5]
Membrane filtration	G-E[32]	G-E[32]	G-E[32]	G-E[32]	G-E[32]		G-E[32]	G-E[32]	G-E[32]	G-E[32]	E[4,9]	G-E[32]
Chemically enhanced precipitation		P[21]		G-E[1]	G-E[21]							E[5,21]
Wetlands (surface)	F-E[31]	P-F[31]		P-G[31]	F-E[31]		F-E[31]				P[12]-F[8]	F-E[22]
Wetlands (subsurface)	G-E[30,31]	P[33]		P-G[33]	G-E[30,31]		G-E[24]	G-E[24]			E[10]	G-E[22,23]

P = less than 20 %
F = partial removal, 20 -50 %
G = good removal 50 -90 %
E = excellent removal 90 + %

Note: See references listed below

References to Table 4.

1.) Droste R. 1997.
2.) Clara et al. 2005.
3.) Andersen et al. 2003.
4.) Drewes et al. 2002.
5.) Suwa and Suzuki. 2003.
6.) Johnson et al. 2005.
7.) Joss et al. 2004.
8.) Gray and Sedlak. 2005.
9.) Xu et al. 2005.
10.) Belmont and Metcalf. 2003.
11.) Thomas and Foster. 2005.
12.) Kolodziej et al. 2003.
13.) Christensson and Welander. 2004.
14.) Andreotolla et al. 2000.
15.) Rusten et al. 2000.
16.) Munch et al. 2000.
17.) Villaverde et al. 2000.
18.) Thogersen and Hansen. 2000.
19.) Pujol and Tarallo. 2000.
20.) Payraudeau et al. 2000.
21.) Vaughn et al. 2004.
22.) Proakis. 2003.
23.) Nokes et al. 2003.
24.) Jin. 2004.
25.) Soriano et al. 2003.
26.) Ueda and Horan. 2000.
27.) Frederickson and Cicek. 2005.
28.) Kraume et al. 2005.
29.) Lesjean et al. 2003.
30.) U.S. EPA. 1992.
31.) U.S. EPA. 2000.
32.) Metcalf and Eddy. 2003.
33.) U.S. EPA. 1993.

Most of the technologies involving an advanced biological treatment process are expected to provide a level of treatment for the various substances that is higher than conventional nitrifying activated sludge. Processes that may not be as acceptable include the constructed wetlands processes with respect to nutrients and emerging contaminants. Chemically enhanced precipitation does not increase removal of ammonia-nitrogen compared to nitrifying activated sludge. Without disinfection, activated sludge and BNR processes will not have adequate pathogen reduction, but with disinfection pathogen removal would be considered excellent

The table has many gaps in it. According to Table 4, treatment removal efficiency for toxicity, metals, pesticides, PAHs and hydrocarbons is lacking for membrane bioreactors, IFAS, MBBRs, BAFs, sand filtration and chemically enhanced precipitation. As well, a variety of emerging contaminants such as different PPCPs, fragrances, flame retardants, perfluorinated compounds and other contaminants of emerging environmental concerns need to be characterized for removal in wastewater treatment. Current analytical capabilities can be a significant limitation in this effort, however. It is clear that much more information on the innovative technologies is required to complete all the entries in the table.

The technologies presented in Table 3 have been assessed for application to variations in Canadian climates receiving environments, and regions. The results appear in Table 5.

Table 5. Applicability of Treatment Technologies for Variations in Canadian Scenarios

Technology	Receiving Environment			Climate		Service provided	
	Marine	Fresh	Land	Arctic	Temperate	Urban	Rural
BNR	Excellent	Excellent	Excellent	long retention times in cold may reduce efficiency	Excellent	Excellent	Complex; operator capability
MBR	Excellent	Excellent	Excellent	potential decline in flux rate	Excellent	Excellent	Complex; operator capability
IFAS	Excellent	Excellent	Excellent	heating costs involved	Excellent	Excellent	Complex; operator capability
MBBR	Excellent	Excellent	Excellent	heating costs involved	Excellent	Excellent	Complex; operator capability
BAF	Excellent	Excellent	Excellent	heating costs involved	Excellent	Excellent	Complex; operator capability
Sand filtration	Excellent	Excellent	Excellent	heating costs involved if continuous operation	Excellent	Excellent	
Membrane filtration	Excellent	Excellent	Excellent	potential decline in flux rate	Excellent	Excellent	Complex; operator capability
Chemically enhanced precipitation	Ammonia may be an issue	Excellent	Excellent	No issue of cold	Excellent	Excellent	Excellent lower operator skill
Wetlands (surface)	Excellent	Excellent	Excellent	natural wetlands used	Excellent	Land available?	Excellent
Wetlands (subsurface)	Excellent	Excellent	Excellent	Inappropriate; permafrost consideration	Excellent	Land available?	Excellent

The non-biological process of chemically enhanced precipitation may not reduce ammonia concentrations to required levels, whether for concerns about eutrophication or for effluent toxicity considerations. Most of the innovative biological processes are applicable to a wide range of conditions in terms of discharge to different receiving environments (marine, freshwater, land), particularly in temperate climatic zones. The criteria for rating the marine/freshwater/soil environments are primarily based on reduction of nutrients, suspended solids and soluble organic matter. Effluents treated by the innovative processes should result in very good effluent quality that would make them excellent candidates for discharge to the designated receiving environments.

Treatment processes with long hydraulic retention times would not be expected to be appropriate treatment under northern winter conditions. Constructed wetland may be a good technology to use in temperate climates in Canada. Although long periods of freezing conditions in the Arctic and sub-Arctic might reduce the value of constructed wetlands as an acceptable technology, there are reports that wetland treatment is successfully used for municipal wastewater treatment in the Canadian North if winter storage and pretreatment of suspended solids loads are included as part of the treatment scheme (Ferguson Simek Clark, 2003). Land availability would likely restrict the use of constructed wetlands for treatment in large urban areas. BNR processes likewise may suffer in the colder Arctic conditions.

With respect to other biological processes, such as MBR, IFAS, MBBR, BAF, they may be able to operate in Arctic conditions because of shorter hydraulic retention times. Membrane processes may result in reduced flux rates, requiring greater capacity and resulting in higher capital cost. Freezing of mechanical moving parts is a separate issue from whether the biological processes function as they are intended. Where feasible, Northern Canadian wastewater treatment processes should be covered or enclosed to minimize temperature effects.

Considering population distributions across Canada, operators in rural areas may not have the technical expertise or resources to operate the innovative biological systems. Operator retention is a problem.

2.3.2 Removal of Emerging Contaminants by Wastewater Treatment Processes

2.3.2.1 Fragrance Compounds

Simonich et al. (2002) reported on the removal of 16 fragrances in 17 U.S. and European wastewaters. Primary treatment reduced concentrations by 14.6 to 50.6 %. Contaminant distribution profiles in raw wastewater and primary effluent were similar. A combination of primary plus secondary treatment provided the ranges of removal efficiencies shown in Table 6.

Table 6. Removal of Fragrances by Primary and Secondary Treatment (Simonich et al., 2002)

Primary plus Secondary Process Type	Range of Removal Efficiencies, %
Activated Sludge	87.8 – 99.9
Carousel (oxic/anoxic reactor)	58.6-99.8
Oxidation ditch	88.9 – 99.9
Trickling filter	71.3 – 98.6
Rotating biological contactor	80.8 – 99.9
Lagoons	96.7 – 99.9

Based on the data provided, it is clear some types of fragrance compounds are more easily removed than others, and that some processes are less efficient than others (e.g., Carousel, trickling filter, RBC) than others. Lagoons, because of their long retention times and opportunity for biodegradation and photo-oxidation, provide removal efficiencies better than most other biological processes.

Lee et al. (2003a) found that removal of synthetic musk compounds by activated sludge treatment plants in Ontario was variable, both between removal of the different compounds within a treatment facility, and between the same fragrance at different treatment plants (Table 7). None of the treatment facilities displayed high removal efficiencies of any of the fragrances. The Guelph facility and on Hamilton sampling result in particular were found to have poor removals of most of the fragrances during this sampling campaign. As noted previously in Section 2.2.3, negative removals are indicative of either analytical variability at concentrations near the detection limit, collection during non-steady-state plant operation, or formation of the substances during treatment. For these substances, the reason for the negative removals determined in the table, likely results from the first two explanations.

Table 7. Removal Efficiencies of Fragrance Compounds by Ontario Activated Sludge Treatment Plants (Lee et al., 2003a).

Facility	Removal Efficiency (%)						
	ADBI	AHMI	ATII	HHCB	AHTN	Musk Xylene	Musk Ketone
Burlington	53.3%	37.5%	56.1%	-366.1%	52.1%	78.8%	11.2%
Dundas	55.6%	46.2%	43.0%	56.8%	54.1%	-200.0%	-9.1%
Guelph	-275.0%	0.0%	-487.5%	-96.4%	-130.2%	7.5%	-126.2%
Hamilton 1	-57.1%	-40.0%	10.2%	-54.6%	-46.5%	51.0%	14.2%
Hamilton 2	11.8%	0.0%	18.9%	17.5%	-3.4%	-260.0%	-722.2%
Toronto Highland Creek	40.5%	44.4%	47.5%	50.3%	55.6%	14.7%	-11.6%
Toronto North 1	43.2%	41.7%	54.7%	27.6%	42.0%	12.2%	-12.8%
Toronto North 2	60.0%	58.3%	78.7%	42.8%	57.7%	6.7%	-117.8%
Waterdown	53.1%	58.3%	55.0%	51.5%	48.1%	78.8%	25.0%

Kreuzinger et al. (2004) investigated removal of emerging wastewater substances at an Austrian wastewater treatment facility that uses biological nitrogen removal and chemical phosphorus removal, followed by polishing lagoon, gravel filter and infiltration ponds. The results are provided in Table 8.

Table 8. Removal of Polycyclic Musk Fragrances at an Austrian WWTP (Kreuzinger et al. 2004)

Musk Fragrance	Removal Efficiency (%) after	
	BNR	Polishing lagoon + Gravel Filter
Galaxolide (HHCD)	80.5%	92.9%
Tonalide (AHTN)	84.9%	94.0%

The Austrian data for these two common musks are very good following BNR treatment, but additional removal can be accomplished by retention in a polishing lagoon and filtration.

2.3.2.2 Pharmaceuticals

Pharmaceuticals are among the best characterized emerging substances in wastewater. For descriptions of the various classes of drugs found in wastewater, the reader is referred to the Task 1 report of this project. Metcalf et al. (2003) monitored neutral and acidic drugs in Canadian wastewater treatment facilities (Table 9). Only salicylic acid (metabolite of ASA), ibuprofen, naproxen and carbamazepine were detected in plant influents and effluents with regularity. Salicylic acid was not evaluated because no influent concentrations of the parent compound ASA were measured. Primary treatment resulted in minimal reductions of the three drugs. The neutral drug carbamazepine was generally not well removed by any of the secondary, lagoon or tertiary processes. [Negative removals are indicative of either formation of the substances during treatment, or collection during non-steady-state plant operation].

Under some conditions in lagoons, removals in the range of 50 to 60 % of carbamazepine may be achieved, but it is not clear what parameters control the removal as two other lagoons demonstrated 0 % removal.

The acidic drugs ibuprofen and naproxen are generally well removed by lagoons, secondary and tertiary treatment. Plant Q appeared to be an exception, but it was characterized as having both short hydraulic retention (7 hr) and short solids retention (1.9 d) times (Metcalf et al., 2003).

Table 9. Removal of Pharmaceuticals by Treatment Process (from Metcalf et al., 2003)

Facility	Process Type	% reduction		
		Ibuprofen	Naproxen	Carbamazepine
J	Lagoon		99.6%	50.0%
K	Lagoon	98.7%	99.4%	0.0%
L	Lagoon	99.2%	99.7%	60.0%
M	Lagoon	99.8%	99.2%	0.0%
R	Primary	0.0%	26.9%	20.0%
O	Secondary	80.6%		-41.7%
P	Secondary	-52.8%		-109.1%
B	Secondary /Cl_2	90.1%	99.2%	0.0%
C	Secondary /Cl_2	89.3%	99.4%	-33.3%
I	Secondary /Cl_2	99.8%	99.6%	10.0%
Q	Secondary /Cl_2 (seasonal)	51.5%	32.2%	12.5%
N	Secondary /UV	99.7%	98.4%	-88.9%
D	Secondary /UV (seasonal)		98.8%	38.5%
E	Secondary /UV (seasonal)		99.6%	50.0%
F	Secondary /UV (seasonal)	98.6%	99.0%	-14.3%
A	Tertiary/UV	96.5%	98.3%	-10.5%
G	Tertiary/UV		98.9%	-50.0%
H	Tertiary/UV	99.8%	99.6%	-33.3%

Note: blank cells indicate no data for influent, or outlying data.

Removal efficiencies of select pharmaceuticals in activated sludge treatment plants in Ontario were reported by Lee et al. (2003b), and are summarized in Table 10. Removal efficiencies were highly variable and dependent on the specific pharmaceutical, with high removal efficiencies for salicylic acid and ibuprofen, and low removal efficiencies for gemfibrozil and diclofenac.

Table 10. Median Removals of Pharmaceutical Compounds by Ontario Activated Sludge Facilities (Lee et al., 2003b)

Pharmaceutical	Removal Efficiency (%) by Activated Sludge
Salicylic Acid	98
Ibuprofen	87
Gemfibrozil	5
Naproxen	70
Triclosan	81
Ketoprofen	18
Diclofenac	0
Indomethacin	40

Two treatment facilities in the U.S. with secondary treatment, chemical phosphorus removal and tertiary anthracite filtration have generally high removal efficiencies for a number of pharmaceuticals (Braghetta et al. 2002), as indicated by Table 11. The analgesic drug diclofenac was the most poorly removed pharmaceutical in this study of two facilities. In contrast to the observations of Metcalf et al. (2003), carbamazepine was removed very efficiently (>99 %) in both plants. The data do not permit a determination of the reasons.

Table 11. Removal of Pharmaceuticals in Two American Tertiary Treatment Plants (Braghetta et al., 2002)

Pharmaceutical	Treatment Plant	
	A	B
Gemfibrozil	96.3	98.8
Carbamazepine	99.6	99.4
Sulfamethoxazole	99.6	98.6
Trimethoprim	99.6	99.4
Acetaminophen	98.2	93.5
Diclofenac	55.2	62.0
Ketoprofen	64.3	93.6
Caffeine	99.6	Nd
Paraxanthine	93.7	99.5
Cotinine	89.2	99.0
Cimetidine	100	98
Ranitidine	100	Nd
Albuterol	83	Nd
Metformin	97	96
Dilitiazem	99	100
Diphenhydramine	96	Nd

Nd = not detected

Removal of pharmaceutical compounds by a Sydney area wastewater treatment facility and the Berlin Germany facility are summarized in Table 12 (Khan and Ongerth, 2002). At the Australian facility, primary treatment did not achieve much removal of the compounds, while secondary treatment was highly effective with the exception of ketoprofen. The Berlin treatment plant was highly efficient at removing ibuprofen, paracetamol (acetaminophen), and morphine, but was not able to substantially reduce levels of ketoprofen or carbamazepine (Khan and Ongerth, 2002). The negative removals of ketoprofen may indicate either analytical variability or potential formation. Ketoprofen possibly may be a metabolite of another similar anti-inflammatory pharmaceutical.

Table 12. Removal of Pharmaceutical Compounds by an Australian and Berlin Germany Treatment Plants (Khan and Ongerth, 2002)

Pharmaceutical	Removal Efficiency (%)		
	Sydney		Berlin
	Primary	Secondary	
Ibuprofen	17.3%	91.9%	98.4 - 99.2
Paracetamol	73.4%	99.6%	96.9 - 99.1
Gemfibrozil	16.1%	83.2%	70.2 - 97.3
Naproxen	19.0%	94.9%	31.6 - 65.5
Ketoprofen	-13.3%	34.4%	-33.3 - 39.1
Carbamazepine	No data	No data	4.2 - 22.4
Morphine	26.9%	92.3%	84.5 - 98.6

The Braunschweig (Germany) wastewater treatment facility is a biological nitrogen removal plant with chemical phosphorus removal. Ternes et al. (2003a) reported on the removal of select pharmaceuticals on two occasions, as indicated in Table 13. With the exception of iopromide, removal efficiency of the compounds, including carbamazepine, sulfamethoxazole and diatrizoate were poor. The removal efficiencies of carbamazepine and sulfamethoxazole are quite variable. Potential reasons for this include improved performance in warmer weather, analytical variability near the detection limits.

Table 13. Removal of Pharmaceuticals at the Braunschweig (Germany) BNR Facility (Ternes et al., 2003a)

Pharmaceutical	Removal Efficiency (%)	
	Mar-02	May-02
Diatrizoate	15.6%	19.1%
Carbamazepine	-11.8%	40.9%
Iopromide	82.7%	82.8%
Sulfamethoxazole	-125.0%	0.0%

2.3.2.3 Estrogenic Compounds

A survey of the estrogenic compounds 17β-estradiol and estrone in Canadian wastewater treatment facilities was conducted by Servos et al. (2005). The removal efficiencies of the two estrogenic compounds by process type are presented in Table 14.

Table 14. Removal of Estrogenic Compounds by Canadian WWTPs (Servos et al., 2005)

Plant	Process Type	Removal Efficiency (%)	
		17β-estradiol	Estrone
J	Lagoon	98.4	93.3
M	Lagoon	98.1	96.1
L	Lagoon	95.9	95.3
K	Lagoon	80.5	46.4
R	Primary	-1	-28.6
P	Secondary	97.1	95.1
O	Secondary	96.1	80.6
I	Secondary /Cl_2	98.2	95.1
B	Secondary /Cl_2	96.8	72.7
C	Secondary /Cl_2	39.5	-54.8
Q	Secondary /Cl_2 (seasonal)	-18.5	-62.4
N	Secondary /UV	94.7	82.1
E	Secondary /UV (seasonal)	98.3	85.4
D	Secondary /UV (seasonal)	92.7	96.7
F	Secondary /UV (seasonal)	75.9	-45.8
H	Tertiary/UV	98.8	97.8
G	Tertiary/UV	93.3	96.5
A	Tertiary/UV	82.9	66.7

The hormone 17β-estradiol was in general more readily removed from all treatment processes than was estrone. Secondary and Tertiary treatment as well as lagoon treatment, were usually capable of removing both compounds in excess of 90%. Secondary treatment plants C and Q were noticeable exceptions. In the section on pharmaceutical compounds above, it was noted that plant Q had very short hydraulic and solids retention times. No such explanation is available for plant C.

Ternes et al. (1999; 2004) listed estrogenic compounds found in German and Brazilian wastewater treatment facilities. The Wiesbaden Germany plant employing biological nitrogen removal was highly efficient at removing the estrogenic compounds, while the German activated sludge plant was less so (Table 15). Without access to operating data, the reason for the poorer performance of the German facility cannot be explained. Activated sludge treatment at the Brazilian facility was more effective in removing the estrogenic compounds than was a trickling filter (Ternes et al, 1999).

2.4.2.4 DEET

Removal of the insect repellent DEET was found to be seasonally variable in a German secondary treatment plant (Knepper, 2004), with 0 % removal in winter to 90 % removal in late summer. The variable removal efficiency may be due to acclimation effects, as higher levels occur in spring through summer, and also due to more rapid biodegradation rate as wastewater temperatures increase through spring and summer.

Table 15. Removal of Estrogenic Compounds by German and a Brazilian Wastewater Treatment Facilities (Ternes et al., 1999, 2004).

Compound	Removal Efficiency (%)			
	Wiesbaden	Activated Sludge - Germany	Trickling filter - Brazil	Activated Sludge - Brazil
E1 (Estrone)	98.5%	5%	67%	83%
E2 (17b-estradiol)	93.7%	64%	92%	99.9%
EE2 (17a-ethinylestradiol)	87.8%	negative removal	64%	78%
16a-hydroxyestrone	Not reported	68%	nd	nd
Reference	Ternes et al., 2003	Ternes et al., 1999	Ternes et al., 1999	Ternes et al., 1999

Nd = not detected

2.3.2.5 Polybrominated Diphenyl Ethers (Brominated Flame Retardants)

Literature on removals or concentrations of PBDEs in wastewater treatment or effluents is very scarce. Most concentration data for wastewater treatment systems is for sludge or biosolids samples on a dry weight basis. Because of their very high octanol-water partition coefficients (approximately 6.3 - 6.6) and high degree of bromination, it is anticipated that the predominant removal mechanism from the liquid wastewater phase is by sorption to solids, with the compounds being very poorly biodegradable. The reported concentration range of PBDEs in wastewater sewage sludges was 730 – 24,900 ug/kg expressed on a dry solids basis (Environment Canada, 2004).

2.3.2.6 Other Emerging Contaminants

The following emerging contaminant groups were found to have virtually no wastewater treatment removal data:

- Chlorinated paraffins
- Polychlorinated naphthalenes
- Polydimethylsiloxanes
- Polyfluorinated compounds
- Sunscreens
- Preservatives (parabens)

2.4 Identification of Inhibitory Concentrations of Substances

Certain organic and metal substances may be discharged in municipal sewage at concentrations that inhibit the microorganisms used in aerobic and anaerobic biological wastewater treatment processes. Often these substances are well-known industrial-based contaminants, for which municipal sewer use bylaw limits have been established.

In aerobic treatment, the most common type of inhibition is for activated sludge. Within that process, additional inhibition data may be available for the nitrification process. Other substances may cause destabilization of the flocculation process, resulting in higher effluent suspended solids, or by causing excessive foaming, or reduction in oxygen transfer efficiency. In anaerobic treatment, the methane-forming bacteria are typically more adversely affected by inhibitory substances at lower concentrations than are the acid-forming bacteria. A notable exception, however, is aluminum, which inhibits the acid-forming bacteria at lower concentrations than the methane-forming bacteria.

Substances that have been reported to interfere with biological treatment process are provided in Table 16 (EPA, 1986). Concentrations of these substances are typically in the mg/L concentration range, which is generally higher than most substances would be found in raw wastewater. The mixed liquor solids of activated sludge can adsorb many of the metal and organic compounds, resulting in concentrations that are significantly increased compared to the raw wastewater levels.

McCarty (1964) reported the toxicity of common monovalent and divalent cations to anaerobic digestion. The inhibitory levels are summarized in Table 17.

Table 16. Inhibitory Concentrations of Substances to Biological Wastewater Treatment Processes

Substance	Threshold Inhibitory Effect (mg/L)		
	Activated Sludge	Anaerobic Digestion	Nitrification
Acetaldehyde		440 (1)	
Acrolein		11.2 (1)	
Acrylonitrile		212 (1)	
Acrylic Acid		865 (1)	
Aniline		2420 (1)	
Benzene	125		
Benzidene	5	5	
Carbon Tetrachloride		2.9	
Catechol		2640 (1)	
Chlorobenzene		0.96	
Crotonaldehyde		456 (1)	
Ethyl acetate		969 (1)	
Ethyl benzene		339 (1)	
Formaldehyde		72 (1)	
Hexachlorobenzene	5		
Lauric Acid		521 (1)	
Propanol		5410 (1)	
Resorcinol		3190 (1)	
Vinyl acetate		689 (1)	
1,2-Dichloroethane		1	
1,1,2,2-Tetrachloroethane		20	
1-Chloropropane		149 (1)	
1-Chloropropene		7.6 (1)	
2,4,6-Trichlorophenol	50		
Chloroform		1	10
1,2-Dichlorobenzene	5	0.23	
1,3-Dichlorobenzene	5		
1,4-Dichlorobenzene	5	1.4	
2,4-Dinitrotoluene	5		
2,6-Dinitrotoluene	5		
1,2-Diphenylhydrazine	5		
Dichloromethane		100	
Chloromethane		3.3	
3- Chloro-1,2-propanediol		663 (1)	
2-Chloropropionic acid		868 (1)	
Trichlorofluoromethane		0.7	
Naphthalene	500		
Nitrobenzene	500	12.3 (1)	
2,4-Dinitrophenol	1		150

Table 16 (continued)

Substance	Threshold Inhibitory Effect (mg/L)		
	Activated Sludge	Anaerobic Digestion	Nitrification
Pentachlorophenol	0.95	0.2	
Phenol	200	2450 [(1)]	4
Anthracene	500		
Phenanthrene	500		
Tetrachloroethylene		20	
Trichloroethylene		20	
Arsenic	0.05[(1)]		1.5
Cadmium	1	5.2	0.02
Chromium (VI)	1	3 (soluble); 200-250 (total) [(1)]	5
Chromium (III)	10	2 soluble; 180-420 (total) [(1)]	50
Copper	1	0.48 (soluble); 50-70 (total) [(1)]	0.5
Cyanide	0.1	0.34	4
Lead	0.1	0.5	
Mercury	0.1		1365
Nickel	1	30 (total)[(1)]	10
Silver	5		
Zinc	1[(1)]	1 (soluble) [(1)]	1.5

Note: EPA (1986) unless otherwise noted
[(1)] Metcalf and Eddy (2003)

Table 17. Inhibitory Concentrations of Cationic Substances to Anaerobic Digestion

Substance Cation	Inhibitory Concentration, mg/L	
	Moderately Inhibitory	Strongly Inhibitory
Sodium	3500-5500	8000
Potassium	2500-4500	12000
Calcium	2500-4500	8000
Magnesium	1000-1500	3000
Ammonium	1500-3000	>3000

Soluble sulphide concentrations above 200 mg/L in an anaerobic digester were reported to be toxic, while a digester acclimated at up to 200 mg/L of soluble sulphide can operate without significant inhibition (McCarty, 1964). Gossett et al. (1978) indicated that aluminum concentrations of 250 mg/L or higher in feed material cause a reduction in biogas production of 80 – 84 % of the control value, and for 200 mg/L of ferric chloride in the digester feed, the biogas production rate declined to 78 % of the control rate.

Surface active agents (surfactants) in wastewater are present from use of detergents and similar products. Ethoxylated alkylphenols are representative of non-ionic surfactants. The surfactants reduce the ability of diffused aeration systems to transfer oxygen to the wastewater mixed liquor, thus reducing treatment effectiveness (EPA, 1989). No concentrations of surfactants were reported at which the effect is seen.

When wastewater treatment facilities experience a high ratio of monovalent cations (sodium and potassium) to divalent cations (calcium and magnesium), flocculation of mixed liquor biomass in secondary clarifiers may not proceed optimally. Such conditions may occur in regions of Canada in which source water is very soft, such as in the Canadian Shield or in the Rocky Mountains. The divalent cations react much better with the exocellular polymers of activated sludge organisms to promote flocculation than do monovalent cations (Higgins et al., 2000). When the ratio of monovalent to divalent cations was greater than 2 on a chemical equivalent basis, flocculation and dewatering properties of solids suffered.

2.5 Pre-Treatment and Source Control Technologies

2.5.1 Sewer Use Control Programs

Many municipalities have in place a sewer use bylaw that regulated the concentrations and quantities of substance discharged to municipal sewers for treatment. The sewer use regulations are generally targeted at businesses such as restaurants and industrial dischargers. The Ontario government in 1988 published a model sewer use bylaw that municipalities were to adopt to control industrial and non-industrial toxic discharges to municipal sewers. In addition to prohibition of material such as glass, ashes, bones, wood, blood and animal tissues (to name a few representative materials), the limitations on specific substances were as follows:

pH range of not less than 5.5 or greater than 9.5
Solvent extractable material of mineral or synthetic origin: not to exceed 15 mg/L
Solvent extractable material of animal or vegetable origin: not to exceed 150 mg/L
Biochemical oxygen demand not to exceed 300 mg/L
Suspended solids: not to exceed 350 mg/L
Phosphorus not to exceed10 mg/L
Total Kjeldahl nitrogen: not to exceed 100 mg/L
Phenolic compounds: not to exceed 1 mg/L
Chlorides and sulphates: not to exceed 1500 mg/L of either substance
Aluminum or iron: not to exceed 50 mg/L of either substance expressed as either Fe or Al
Fluorides: not to exceed 10 mg/L

In addition, a maximum limit of 5 mg/L was placed on the following substances, expressed on an elemental basis: antimony, bismuth, chromium, cobalt, lead, manganese, molybdenum, selenium, silver, tin, titanium and vanadium. A maximum limit of 3 mg/L, expressed on an elemental basis, was placed on copper, nickel and zinc in discharges to sewers. Total cyanide limitation in discharges to sewers was 2 mg/L, while the maximum limit for arsenic and cadmium was 1 mg/L. The maximum limit for mercury in discharges to sewers was 0.1mg/L.

Materials subject to complete prohibitions in wastewaters discharged to sewers include: fuels, PCBs, pesticides, severely toxic materials, waste radioactive materials, hauled sewage, waste disposal site leachate, acute hazardous waste chemicals, hazardous industrial wastes, hazardous waste chemicals, ignitable wastes, pathological wastes, PCB wastes and reactive wastes.

Some municipalities may impose more stringent limits or include limits on other substances. The City of Toronto, for example, in its sewer use bylaw, includes a number of specific organic substances, as indicated in Table 18.

Table 18. Concentrations of Specific Organic Substances in City of Toronto Sewer Use Bylaw

Substance	Limit, mg/L	Substance	Limit, mg/L
Benzene	0.01	Chloroform	0.04
1,2-dichlorobenzene	0.05	1,4-dichlorobenzene	0.08
Cis-1,2-dichloroethylene	4	Trans-1,3-dichloropropylene	0.14
Ethyl benzene	0.16	Methylene chloride	2
1,1,2,2-Tetrachloroethane	1.4	Tetrachloroethylene	1
Toluene	0.016	Trichloroethylene	0.4
Xylenes (total)	1.4	Di-n-butyl phthalate	0.08
Bis (2-ethylhexyl) phthalate	0.012	Nonylphenols	0.02
Nonylphenol ethoxylates	0.2	Aldrin/dieldrin	0.0002
Chlordane	0.1	DDT	0.0001
Hexachlorobenzene	0.0001	Mirex	0.1
PCBs	0.001	3,3'-Dichlorobenzidene	0.002
Hexachlorocyclohexane	0.1	Pentachlorophenol	0.005
Total PAHs	0.005		

As noted in Section 2.4, industrial surfactants may interfere with the effectiveness of oxygen transfer in secondary wastewater treatment, and as a result may also be subject sewer use concentration limits.

2.5.2 Pollution Prevention (P2) Practices

Industries in the U.S. were expected to implement pollution prevention practices through the 1990s as a result of a law called the Pollution Prevention Act, passed in 1990 (Freeman et al., 1992). A number of initiatives undertaken by major industrial corporations, including Dow Chemical, Amoco, Chevron, General Dynamics, IBM and Monsanto, to reduce quantities of hazardous wastes generated were highlighted in the review article by Freeman et al. (1992). Industries can adopt many measures to limit discharges to municipal sewers through P2 practices, including adoption of cleaner technologies, making operational changes to reduce waste (improved housekeeping to reduce spills, leaks and water usage), adopting material changes to reduce wastes (use of water-based inks, adhesives and cleaners rather than organic solvents-based materials), and making production process changes to reduce waste (in surface finishing operations, using counter-current rinsing and bath dragout recovery tanks, adoption of plating bath renovation processes including reverse osmosis, evaporation and ion exchange).

2.5.2.1 Mercury and Silver

Although most metal contaminants have been addressed in sewer use control programs, two metals in particular have drawn special control programs because of their toxicity at very low concentrations. Mercury is still widely used in dental amalgams for filling cavities. Studies suggest that dental offices are responsible for between 9 and 50 % of mercury in municipal wastewater (NC DENR, 2004). Even small discharges of mercury can result in sewer use bylaw exceedances, resulting in release of mercury to the environment in treated effluents and biosolids. As a result many municipalities have implemented special dental mercury control programs. The Capital Regional District in 2001 published a manual on Environmental Regulations and Best Management Practices for Dental Operations in the Capital Regional District. Best management practices for dental mercury amalgam includes use of a primary chair-side trap for larger particles and vacuum pump filters (secondary traps) for smaller particles and dissolved metal. Used traps are to be collected by a waste disposal vendor (CRD, 2001).

Medical and dental operations, hospitals, and photo-processors use silver in film development. During processing on photographic or X-ray film, silver is removed from the film or paper and is released to the fixing bath, typically as a silver thiosulphate complex (NC DEHNR 2005). The major sources of silver in wastes include the fixer solutions and rinsewaters. On-site recovery techniques for concentrated silver solutions include electrolytic recovery, metal replacement and chemical precipitation. For more dilute solutions, ion exchange and reverse osmosis can be used alone or in combination with the other recovery techniques (NC DEHNR 2005). Electrolytic silver recovery produces almost pure silver on an electrode. In metal replacement treatment, silver either accumulates on a support material such as steel wool (which also goes into solution as the replacement metal), or it forms as a bottom sludge. Chemical precipitation is accomplished by mixing the silver-bearing solution with sodium sulphide, sodium borohydride or sodium dithionite to produce silver sulphide.

The State of Vermont designates used fixer solution as a hazardous waste, and requires that used fixer solutions be recycled by a licensed hazardous waste reclamation facility, disposed of by a licensed hazardous waste hauler, or reclaimed on-site with a silver recovery unit of the type described above (Vermont DEC, 2002). In the Capital Regional District, X-ray wastes that contain silver, such as used-x-ray fixer or developer solution mixed with the fixer, are to be collected for off-site waste management, or treated in accordance with CRD's Code of Practice for Photographic Imaging Operations (CRD, 2001).

2.5.2.2 Fats, Oil and Grease (FOG)

One of the principal contributing factors to sanitary sewer overflows is grease accumulation on sewer walls which reduces the hydraulic capacity of the pipes (Georgia DNR, 2000). Restaurants and kitchens in academic facilities, hospitals and other health-care facilities can discharge substantial quantities of food-based oil and grease to sewers. Most agencies require that grease traps be installed between the kitchen sinks and the main sewer interceptors to remove the accumulated grease, and that waste haulers or rendering facilities collect the grease for recycle. Regulatory agencies generally recommend dry clean-up and separate recycling of oil and grease to keep it out the wastewater treatment system. Separated oil and grease can then be picked up by rendering companies for re-processing (Georgia DNR, 2000).

The Orange County Sanitation District (OCSD) has waste haulers that collect FOG from grease traps at restaurants and other locations, and then transport the grease to the treatment plant where it is added to the raw sewage (Fonda et al., 2004). Ultimately it ends up in the anaerobic digestion system as either floating scum or in the primary sludge solids. OCSD evaluated alternatives to this process, and ultimately decided to pump the FOG arriving at the plant directly to a dedicated anaerobic digester for energy recovery from the waste.

2.5.3 Candidate Substances for Source Control

In the Task 1 report of this project (Hydromantis, 2005), wastewater substances were categorized in the Appendix Table A.6 according to treatability by a variety of different processes. Potential treatability of these substances was evaluated using TOXCHEM+ predictive fate software (Hydromantis, Inc.). Categorization was based on removal efficiency as defined by the difference in concentrations in the raw wastewater and treated effluent from the various processes. A removal efficiency less than 50 % was rated as poor; removal efficiency ranging between 50 and 74 % was rated as moderate, a removal efficiency ranging from 75 to 94 % was rated as good, while removal efficiencies of 95 % or higher were rated as excellent. It should be noted that the removal efficiencies are calculated based on removal in the liquid phase only. Transfer of substances to other media, either by stripping to the atmosphere, or by sorption to residual solids removed to off-site locations, are not considered in this evaluation procedure. The Table A.6 in the Task 1 report included substances that were flagged as being of potential concern because effluent concentrations found in the technical literature exceeded at least one environmental benchmark value, which included CCME and EPA criteria for freshwater and marine environments, plus other provincial water quality, drinking water, recreational or agricultural benchmarks. A total of 66 substances were so identified in Table A.6.

Subsequent to issuing the Task 1 report, Table A.6 was revised to include only those substances for which effluent concentration data exceeded only the CCME or EPA freshwater and marine environment benchmarks (i.e., substances that were flagged as a result of provincial water quality, drinking water, recreational or agricultural benchmarks were removed). Exceptions are antimony, 1,2-dichloroethane and ethylbenzene; these substances are without CCME or EPA benchmarks, but exceed the values in the Canadian Drinking Water Guidelines. This revised listing, now with only 50 substances, is provided as Table 19. There are several substances in this table that are not readily removed by a basic level of secondary treatment (non-nitrifying conventional activated sludge). These substances, predominantly metals and pesticides, are highlighted by shading to indicate their poor removal (set as less than 50 % removal efficiency) in non-nitrifying activated sludge. One exception is mercury, which is extremely toxic and moderately removed in secondary treatment, and thus was included in this grouping. For such substances, when wastewater treatment has difficulty in achieving a high level of removal, source control may be the best option for prevention of discharge to receiving environments. A more in-depth review of effluent concentrations in the technical literature is recommended to ensure a decision on source control is based on a sufficient number of studies.

The substances fluoride, magnesium and nitrate were identified in Table 19 as generally having poor removal efficiencies in wastewater treatment, without a recommendation for source control. All three substances are inorganic, ionic species, and thus generally soluble in water. Nitrate is produced by the biological nitrification process, but may be removed to very low levels by denitrification in biological nutrient removal. Fluoride is often added to potable water for control of dental caries, while magnesium is typically present in water as a component of water hardness. Of the processes listed in Table 19, only reverse osmosis can significantly reduce concentrations of fluoride and magnesium. A number of chlorinated pesticides are also found in Table 19 with poor removal efficiencies. Most of these compounds are now banned from use, but appear likely from diffuse sources. Source control of these substances is therefore not recommended. Lastly, the data presented in Table 19 are removal efficiencies. Depending on the influent concentrations, processes providing an excellent level of treatment may still result in effluent concentrations than can exert adverse effects to biota in the aquatic environment.

Not included in this table are the emerging substances, such as pharmaceutical and personal care products, brominated flame retardants, perfluorinated octyl sulfonates and others identified in the Task 1 report. The origins of these substances in domestic wastewater are from use in our homes, and not from industrial sources. Thus, to limit the entry of these substances to wastewater collection systems, source control must occur at our dwellings, or by replacement of the substances with more environmentally acceptable substances by industry. Both options will entail large costs. Within domestic dwellings, it is probable that the grey water originating from bathing, dishwashing and laundry would need to be separated from toilet wastewater for treatment to very low concentrations (e.g., µg/L or ng/L level) by an on-site device. Retrofitting all dwellings in a community would be a very expensive procedure. Alternatively, the development of substitute products by industry requires extensive research and product testing. These actions are also very expensive, and may well be passed on to consumers.

Estimated treatment costs for the different process categories have been estimated for flow capacities of 5,000 m^3/d, 50,000 m^3/d and 500,000 m^3/d. Treatment process costs are estimated using Hydromantis' CAPDET Works software. The unit costs are expressed as costs per m^3/d of capacity treated, and are calculated by dividing the present worth of the process by the capacity flow rate. The present worth consists of the capital cost, plus a present worth component representing the operating and maintenance costs (operating, maintenance, material, chemicals, energy and amortization). CAPDET Works does not have costing algorithms for reverse osmosis units, and membrane suppliers were reluctant to disclose costs. Costs for the RO process were therefore estimated using professional judgment.

The costing exercise reveals that as capacity increases, the unit cost for treatment declines. This indicates that there is economy of scale in wastewater treatment, and reveals why smaller communities are faced with relatively higher costs for wastewater treatment than are larger communities, for the same effluent quality requirements. The costing assessment also demonstrates that increasing levels of treatment sophistication result in increasing costs per unit volume of wastewater treated. This trend is as expected. For the very highest level of treatment examined (i.e., BNR plus RO), which would be required to effectively treat all of the substances of concern to greater than 75 % removal, the costs for all levels of capacity examined would increase by a factor of 2 to 3 over the other processes.

Table 19. Categorization of Wastewater Substances by Process Treatment

Substance	Treatment Technology						
	Primary Treatment	Facultative Lagoon	Secondary non-nitrify	Advanced Secondary	Tertiary		
					Nitrify + filter	BNR	Nitrify CAS + RO
2,4-D	Poor(6)	Moderate	Poor(6)	Poor(6)	Poor(6)	Poor(6)	Good
Aluminum	Moderate	Poor(5)	Moderate	Moderate	Good	Good	Excellent
Ammonia	Poor	Excellent	Moderate	Excellent	Excellent	Excellent	Excellent
Anthracene	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Antimony(1)(7)	Poor	Poor	Moderate	Moderate	Moderate	Moderate	Excellent
Arsenic(1)	Poor	Poor	Poor	Poor	Poor	Poor	Good
Benzo(a)anthracene	Moderate	Excellent	Good	Excellent	Excellent	Excellent	Excellent
Benzo(a)pyrene	Moderate	Excellent	Good	Excellent	Excellent	Excellent	Excellent
Bis(2-ethylhexyl)phthalate	Poor	Excellent	Good	Good	Good	Excellent	Excellent
Cadmium	Poor	Poor	Poor	Poor	Good	Moderate	Excellent
Chlordane	Poor(6)	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Chloroform	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Chlorophenol	Poor	Excellent	Moderate	Moderate	Good	Good	Excellent
Chromium (hexavalent) Chromium (trivalent)	Moderate	Moderate	Moderate	Good	Excellent	Good	Excellent
Copper	Poor	Poor	Moderate	Moderate	Moderate	Moderate	Excellent
Cyanide (1)	Poor(2)	Moderate	Moderate(2)	Moderate(2)	Moderate(1)	Moderate(1)	Excellent
DDT	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Dichlorobenzene (1,2-)	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Dichloroethane (1,2-) (7)	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Dichlorophenol (2,4-)	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Di-n-butyl phthalate	Poor	Excellent	Good	Good	Good	Excellent	Excellent
Endosulfan	Poor(6)	Excellent	Poor(6)	Poor(6)	Poor(6)	Poor(6)	Good
Ethylbenzene (7)	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Fluoranthene	Poor	Excellent	Good	Excellent	Excellent	Excellent	Excellent
Fluorene	Moderate	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Fluoride (1)	Poor	Poor	Poor	Poor	Poor	Poor	Good
Iron (1)	Moderate	Moderate	Good	Good	Good	Good	Excellent
Lead	Poor	Poor	Poor	Poor	Poor	Poor	Excellent
Lindane	Poor(6)	Excellent	Poor(6)	Poor(6)	Poor(6)	Poor(6)	Good
Magnesium (1)	Poor	Poor	Poor	Poor	Poor	Poor	Good
MCPA	Poor	Moderate	Poor	Poor	Poor	Poor	Good
Mercury	Moderate	Poor	Moderate	Moderate	Moderate	Good	Excellent
Nickel	Poor	Poor	Poor	Poor	Poor	Poor	Excellent
Nitrate(1)	Poor	Poor	Poor	Poor	Poor	Excellent	Good
Nonylphenol	Poor	Excellent	Good	Good	Good	Excellent	Excellent

Table 19 cont'd

Substance	Treatment Technology						
	Primary Treatment	Facultative Lagoon	Secondary non-nitrify	Advanced Secondary	Tertiary		
					Nitrify + filter	BNR	Nitrify CAS + RO
Nonylphenol ethoxylate[1]	Poor[4]	Excellent	Excellent	Excellent[1]	Excellent	Excellent	Excellent
pH	NA	NA	NA	NA	NA	NA	NA
Phenanthrene	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Phenols, Total	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Phosphorus (total)[1]	Poor	Good[3]	Good	Good	Excellent	Excellent	Excellent
Pyrene	Poor	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Quinoline	Poor	Excellent	Moderate	Good	Good	Good	Excellent
Selenium	Poor	Poor	Poor	Poor	Poor	Poor	Good
Silver [1]	Moderate	Good	Good	Good	Good	Good	Excellent
Sulphide (as H_2S)	Poor	Excellent (Summer) Poor (Winter)	Excellent	Excellent	Excellent	Excellent	Excellent
Tetrachloroethylene	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Toluene	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Trichlorophenoxyacetic acid (2,4,5-)	Poor[6]	Moderate	Poor[6]	Poor[6]	Poor[6]	Poor[6]	Poor[6]
Zinc	Poor	Poor	Poor	Poor	Poor	Poor	Excellent

Indicates substances that may be appropriate for source control (dark shading)

Indicates substances with poor removal that are not recommended for source control (light shading)

Estimate of removal efficiencies from TOXCHEM+ fate software (Hydromantis, Inc.) unless note (1)

Poor: <50 % removal efficiency

Moderate: 50-74 % removal efficiency

Good: 75-94 % removal efficiency

Excellent: ≥ 95 %removal efficiency

(1) based on professional judgment

(2) EPA (1982)

(3) assumes chemical phosphorus removal

(4) Giger et al, 1987

(5) added to wastewater for phosphorus removal in some treatment facilities

(6) source now are probably diffuse (e.g. applications from old stockpiles, or atmospheric deposition): recommend educational program for homeowners with stockpiles

(7) in absence of CCME or EPA aquatic benchmark, substance was included based on exceedance of Canadian Drinking Water Guideline values

3. TASK 3. BEST MANAGEMENT PRACTICES

3.1 Overview of Best Management Practices

According to the U.S. EPA (2004a), Best Management Practices were implemented initially in urban settings as flood and drainage controls. More recently, however, the BMPs serve several purposes such as treatment of stormwater and protection of receiving waters. There are a variety of Best Management Practices that can be implemented to restrict the entry of contaminants in aquatic environments. With respect to the RFP for this project, the BMPs to be investigated in this project include:

- Infiltration and inflow to municipal sewer systems
- Reduction and treatment of sanitary and combined sewer overflows (SSOs and CSOs)
- Management of hauled wastes such as septage, landfill leachate or industrial/commercial wastewaters
- Small or remote community wastewater issues, including treatment cost and pollutant management
- Discharges of treated effluents to marine environments
- Lagoon issues, including ice cover and ammonia removal in winter, and algae removal in summer
- Flow reductions to wastewater treatment plants using alternative technologies and source control plans, including water reuse and reclamation technologies
- Aging collection system needs and upgrading practices
- Wastewater treatment facility performance monitoring and quality control practices.

3.2 Infiltration and Inflow

3.2.1 Urban Stormwater

Urban stormwater affects the need for many of the Best Management Practices of Task 3 of this report. Stormwater is the runoff from surfaces in an urban area and can include runoff from lawns and gardens, building rooftops, parks, parking lots, roadways and virtually any surface in an urban setting. As a result, stormwater may contain many types of polluting substances. Sansalone et al. (2005) determined that the urban stormwater component of combined sewer overflows (CSOs) can contain metals (lead, zinc, iron, copper, cadmium, chromium, nickel and manganese), anions (bromide, cyanide, chloride and sulphates), petroleum products, PCBs, rubber particles, other volatile suspended solids and asbestos.

Surface runoff (stormwater) can contain a variety of substances including road oils and exhaust, automobile part wear (tires, brake pads), and atmospheric deposition of airborne contaminants like PCCDD/PCDF, PBDEs, POFS, PCBs, etc. plus conventional pollutants including BOD, TSS, nutrients from fertilizer applications. A U.S. survey of pollutants in stormwater found the contaminants listed in Table 20. The results showed that urban stormwater may have pathogenic organisms, pesticide residues, metals and other more conventional pollutants.

Concentrations of substance such as metals, nutrients and suspended solids tend to be higher in more arid and semi-arid regions, and decrease in areas of increased rainfall. The arid and semi-arid zones can accumulate substances over a longer period before they are flushed off with precipitation. PAHs did not tend to accumulate in arid regions, considered due to photo-decomposition (EPA, 2004a).

Table 20. Concentrations of Substances in Surveys of U.S. Urban Stormwater (EPA 2004a).

Substance	Concentration		No. of Events
	Mean	Median	
Suspended Solids, mg/L	78.4	54.5	3047
Total Phosphorus, mg/L	0.32	0.26	3094
Soluble Phosphorus, mg/L	0.13	0.10	1091
Total Nitrogen, mg/L	2.4	2.0	2016
Total Kjeldahl Nitrogen, mg/L	1.7	1.5	2693
Nitrite and Nitrate, mg/l	0.66	0.53	2016
BOD, mg/L	14.1	11.5	1035
COD, mg/L	52.8	44.7	2639
Organic Carbon, mg/L	No data	11.9	19
Oil and Grease, mg/L	3	No data	Not available
Fecal coliform, col/100 mL	15038	No data	34
Fecal Strep, col/100 mL	35351	No data	17
Cryptosporidium, organisms	37.2	3.9	78
Giardia, organisms	41.0	6.4	78
Cadmium, ug/L	0.7	No data	150
Chromium, ug/L	4	No data	32
Copper, ug/L	13.4	11.1	1657
Lead, ug/L	67.5	50.7	2713
Zinc, ug/L	162	129	2234
PAH, mg/L	3.5	No data	Not available
Methyl t-butyl ether, ug/L	No data	1.6	592
Chloride (snowmelt), mg/L	No data	116	49
Diazinon, ug/L	No data	0.55	76

3.2.2 Control of I/I

Restriction of stormwater inflow and infiltration (I/I) is one principal method of reducing CSO events. Of the two extraneous flows, inflow contributes the most flow to combined sewers (EPA, 1993). Inflow may be restricted by diverting stormwater away from storm drains, or by retarding the flow of stormwater to the drains. Leaks in manhole covers in pavement sags can be repaired by routine maintenance (Hodgson et al. 1996). Special fittings installed at drains restrict the rate at which water enters the collection system, causing temporary ponding. The water eventually drains away at a reduced rate, but the peak inflow rate is dampened (EPA, 1993). Inflow may also be reduced by re-directing flow from drains or low spots in the wastewater collection system to other locations, or to more pervious sites where it may soak into the land cover more easily (see the section on reduction of CSOs).

Infiltration typically results from entry of groundwater to the collection system through broken or cracked sewer pipes and appurtenances. Remediation may be accomplished by an initial assessment of the sewer condition with television cameras followed by either replacement of the defective sections, or by grouting or sliplining with cured-in-place liners. If the infiltration is a result of general sewer deterioration, house laterals may also need to be repaired.

It is desirable to keep the excessive flow and associated pollutants of urban stormwater from the combined sewer system. The pollution prevention practices that accomplish this objective are sometimes referred to as urban stormwater best management practices. According to the U.S. EPA (1993b), the BMPs include those summarized in Table 21.

Table 22 summarizes the requirements and pollutant removal characteristics of the structural BMPs of Table 20. Only the infiltration facilities have any capability of removing pathogens from stormwater. Moderate to high removals of suspended solids and metals in stormwater can be accomplished with most of the structural BMPs, while removal of the nutrients nitrogen and phosphorus is less certain.

One of the major factors contributing to urban stormwater is the geographic location, which has a dominant effect on annual precipitation. Figure 1 is a map of Canada indicating levels of precipitation (Natural Resources Canada, 2005). The Pacific and Atlantic coastal regions of Canada, including the Gulf of St. Lawrence receive the highest levels of precipitation, with the Rocky Mountains on the BC-Alberta border also receiving substantial moisture. By contrast the Prairie Provinces are considerably drier. The volumes of stormwater generated are expected to be reflected in the moisture zones.

Areas of heavy vehicular traffic such as freeways in urban settings will have stormwater with higher levels of polluting substances associated with road travel, including petroleum-based products (oils, PAHs), asbestos, zinc chromium and similar metals. Urban areas with substantial horticultural activities will likewise have higher levels of fertilizer nutrients and pesticides in urban stormwater, than in those areas that are either much colder (far North) or much drier.

Polluting substances can accumulate in winter months when snow is on the ground. Snowmelt and runoff in late winter or early spring can contribute more than 50 % of annual runoff loadings of suspended solids, nutrients, PAHs and some metals (Oberts, 1989 in EPA 2004a). When snow removal results in large accumulations or dumps, in which large loadings of the substances are accumulated, a rapid thaw or melting from rain can release much of the substance loading in a very short timeframe. Infiltration implies that contaminants are present in groundwater, and can mostly include mobile organic solvents (trichloroethylene, PERC) and hydrocarbon fuel components (gasoline, MTBE). Such observations are pertinent to different regions of Canada, which may be subject to both snowfall and rapid fluctuations in temperature about the freezing point. For more northerly communities, snow may accumulate all winter, cumulating with a thaw in the spring months. For other locations in temperate climatic zones, snowfalls followed by rain may result in a more frequent flushing of pollutants.

Table 21. Urban Stormwater Pollution Control Best Management Practices (from EPA 1993b)

Urban Runoff Controls		Combined Sewer Overflow Controls	
Regulatory Controls	Land use regulations	Source Control	Water conservation programs
	Comprehensive runoff control regulations		Pretreatment programs
	Land acquisition	Collection system controls	Sewer separation
Source controls	Street sweeping		Infiltration control
	Proper construction activities		Inflow control
	Cross-connection identification and removal		Regulator and system maintenance Insystem modifications
	Catch basin clearing		Sewer flushing
	Industrial/commercial runoff control	Storage	Inline storage
	Animal waste removal		Offline storage
	Toxic and hazardous pollution prevention		Flow balance method
	Reduced fertilizer and pesticide use	Physical treatment	Bar racks and screens
	Reduced roadway sanding and salting		Swirl concentrators and vortex solids separators
Detention facilities	Extended detention dry ponds		Dissolved air flotation
	Wet ponds		Fine screens and microstrainers
	Constructed wetlands		Filtration
Infiltration facilities	Infiltration trenches and dry wells	Chemical precipitation	
	Infiltration basins	Biological treatment	
	Porous pavement	Disinfection	Chlorine
Vegetative practices	Grassed swales		UV light radiation
	Filter strips		
Filtration practices	Filtration basins		
	Sand filters		
Other	Water quality inlets		

Table 22. Characteristics of Structural Best Management Practices (from EPA 1993b)

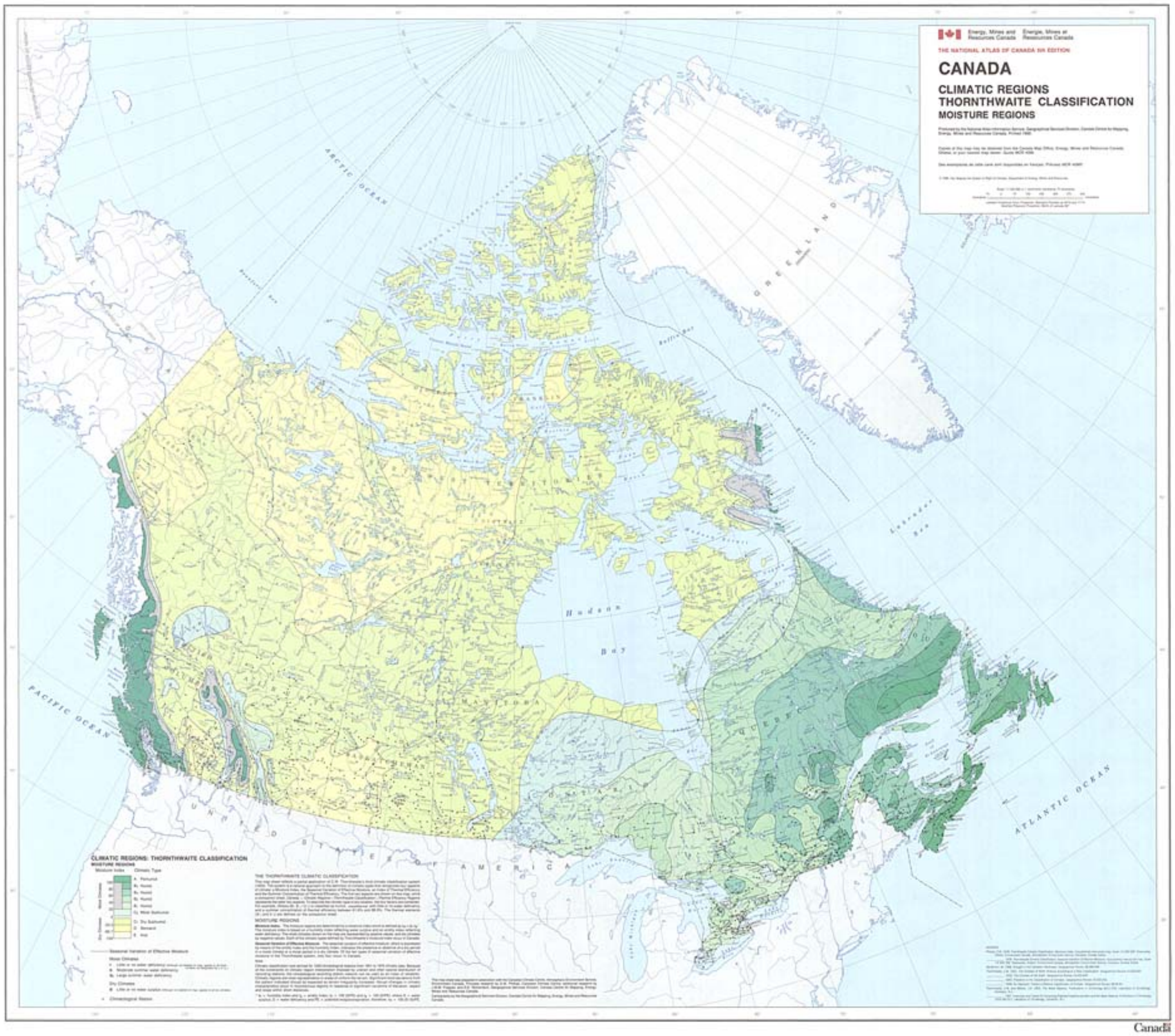
Structural BMPs	Typical Pollutant Removals, %[a]					Relative Land Require-ments	Drainage Area[b]	Desired Soil Conditions	Ground-water Elevation
	Suspended solids	Nitrogen	Phosphorus	Pathogens	Metals				
Detention Facilities									
Extended detention dry ponds	Medium	Low-medium	Low-medium	Low	Low-medium	Large	Medium-large	Permeable	Below facility
Wet ponds	Medium-high	Medium	Medium	Low	Medium-high	Large	Medium-large	Impermeable	Near surface
Constructed wetlands	Medium-high	Low	Low-medium	Low	Medium-high	Large	Large	Impermeable	Near surface
Infiltration Facilities									
Infiltration basins	Medium-high	Medium-high	Medium-high	High	Medium-high	Large	Small-medium	Permeable	Below facility
Infiltration trenches & dry wells	Medium-high	Medium-high	Low-medium	High	Medium-high	Small	Small	Permeable	Below facility
Porous pavement	High	High	Medium	High	High	Not applicable	Small-medium	Permeable	Below facility
Vegetative Practices									
Grassed swales	Medium	Low-medium	Low-medium	Low	Low-medium	Small	Small	Permeable	Below facility
Filter Strips	Medium-high	Medium-high	Medium-high	Low	Medium	Varies	Small	Depends on type	Depends on type
Filtration Practices									
Filtration basins	Medium-high	Low	Medium-high	Low	Medium-high	Large	Medium-large	Permeable	Below facility
Sand filters	High	Low-medium	Low	Low	Medium-high	Varies	Low-medium	Depends on type	Depends on type
Other									
Water quality inlets	Low-medium	Low	Low	Low	Low	Not applicable	Small	Not applicable	Not applicable

[a] Low = < 30 %; medium = 30 – 65 %; high = 65 – 100 %
[b] Small = < 4 hectares; medium = 4 – 16 hectares; large = > 16 hectares

3.2.3 Summary

The Best Management Practices outlined in Table 21 for control of I/I are generally applicable to all regions of Canada, although harsh winter conditions in Northern Canada may preclude the implementation of some practices such as constructed wetlands or grassed swales.

Figure 1. Moisture Zones of Canada (Natural Resources Canada, 2005)



3.3 Reduction and treatment of combined sewer overflows (CSOs)

3.3.1 CSO Reduction

Combined sewer systems were installed to reduce construction costs by using one collection system instead of two separate ones for sanitary sewage and stormwater. Subsequently, society has learned that periodic overflows from combined sewers can have a major negative effect on receiving water quality. Major efforts are now in progress in North America to reduce and treat combined sewer overflows (CSOs). The U.S. EPA (1993) indicates why reduction and treatment of CSOs is different than designing a standard wastewater treatment facility. Reasons include (a) the performance goals for CSO control are not uniform; (b) collection system characteristics are site-specific, leading to site-specific mitigation alternatives; (c) the design basis is not standard with the frequency, rate and duration of precipitation governing system design; (d) CSO flows are intermittent and highly variable; (e) CSO quality and treatability are site-specific; and (f) performance data in CSO controls is limited, (although since the timing of the EPA report, more performance data have been collected).

Control practices for CSO reduction include: restriction of the rate and/or volume of stormwater runoff entering the combined sewer system (inflow); adoption of pollution prevention practices that reduce the quantity of pollutants entering the combined sewer system; and operation and maintenance practices for the combined sewer system that improve its ability to contain wet weather flows and deliver them to the treatment plant. Redirection of stormwater from hard surfaces to more pervious surfaces such as gravel, soil or grass/vegetation result in seepage to the ground. Transfer of stormwater from one drainage area to another point in the combined sewer system is also possible. Removal of roof leaders, roof drainpipes or sump pump discharges from the collection system also reduces the quantity of stormwater entering the collection system (EPA, 1993).

Lau and Stenstrom (2002) found the catch basin inserts were effective in reducing total suspended solids, oil and grease, and turbidity in urban stormwater by 30 to 50 % on average. The mechanisms were excellent at preventing litter and debris, such as plastic bags or branches.

3.3.2 CSO Treatment

Major technologies involved in CSO control include (EPA 1993):

- In-system controls/in-line storage;
- Near-surface off-line storage/sedimentation;
- Deep tunnel storage;
- Coarse screening;
- Swirl/vortex technologies (now also called continuous deflective separation (CDS)); and
- Disinfection.

Flow in the combined sewer system may also be retarded by flow restriction devices such as vortex valves (EPA 1993).

The City of Hamilton has installed 5 off-line stormwater detention tanks as part of the remedial action plant to restore Hamilton Harbour, a designated “hot spot” by the International Joint Commission (Jordan et al., 2004). The purpose of the tanks is to temporarily hold the combined storm and wastewater, and then slowly bleed the combined stormwater/wastewater to the sewer system for treatment at the treatment facility when flows have returned to normal. Hamilton also makes use of real-time control in its collection system to maximize storage capacity (Jordan et al., 2004). Protection of Halifax Harbour is similarly planned with 22 CSO detention chambers, including screens that will remove larger materials from discharge to the Harbour, and return the solids to the collection system for downstream treatment at the treatment facility (Anon. 2005a).

Thompson et al. (1989) demonstrated that step feed operation of an activated sludge plant was a viable strategy for reducing the need to bypass excessive wastewater flow due to storm events. Use of step feed operation was adopted by the City of Hamilton to reduce the number of bypass events. Excessive flow through wastewater activated sludge treatment facilities can cause ”washout” of the mixed liquor, resulting in high effluent suspended solids concentrations and inadequate treatment for BOD_5 and nitrogen. The step feed process, in which the front end of the aeration tank serves as a reservoir for the mixed liquor, helps to restrict the loss of mixed liquor solids during high flow periods.

3.3.3 Summary

The technologies for CSO reduction and treatment are applicable to most regions of Canada. Remedial plans to eliminate bacterial contamination of recreational swimming often include some form of stormwater detention. Permafrost in northern Canada may prevent the adoption of technologies where below-grade construction is required.

3.4 Reduction and Control of Sanitary Sewer Overflows (SSOs)

3.4.1 Causes of SSOs

Occasionally, sanitary sewer lines may crack, break, or become blocked or clogged with dirt, grease, or foreign objects, including tree roots. As well, excessive quantities of stormwater, or mechanical or electrical failures may cause pumps to shut down at pumping stations or at the treatment plant itself. When any of these events occurs, sanitary sewers may leak or overflow, resulting in discharge of sewage into home basements, streets and waterways.

SSOs occur as a result of either extraneous flow in the system, or because the pipes surcharge excessively. Surcharges are predominantly caused by a lack of downstream capacity (96% of surcharges), while only 4 % are due to a hydraulic overload of the pipe (Petroff, 1996). Limited downstream capacity was the result of hydraulic restrictions or "bottlenecks". From most common to least common, hydraulic restrictions can be present as (a) accidental bottlenecks, such as from debris accumulation or vandalism; (b) maintenance bottlenecks, as from roots and grease; (c) construction bottlenecks, as from sags in the line and offset pipe joints; and (d) design bottlenecks, as from throttling of pipe diameters or bends of greater than 90 degrees. Removal of hydraulic bottlenecks is proposed as a cheaper solution than building extra hydraulic capacity in the collection system (Petroff, 1996). I/I is the other principal cause of SSOs, and Petroff (1996) suggests that I/I represents almost half of all flow in U.S. wastewater treatment plants. In addition, he notes that a 1-year storm event generally results in wastewater peak flow factors of 4 to 10 in small systems, which are not designed to carry this volume. Limitation of I/I is thus a critical component of SSO reduction.

SSOs may also occur on private property due to tree root damage, joint expansion, and cracked pipes leading to infiltration and inflow (I/I), blocked lines, and sanitary sewer overflows. According to the Water Environment Foundation (2005), a nationwide survey of 316 American municipalities found that nearly 70% have problems with I/I from leaking laterals on private property. As a result, many municipalities are attempting to identify the sources and extent of private-property I/I and create programs to minimize it. Elements of public awareness programs combating SSOs on private property may include (Scanlan et al. 2001):

- Keeping heavy vehicles and plant roots away from house laterals;
- Avoiding in-sink garbage disposal units that add solids and grease to the system;
- Restricting entry of the following to the house laterals: oils, fats, and grease; coffee grounds; cigarettes; facial tissues and paper towels; sanitary napkins, tampons, and disposable diapers.

While SSOs exhibit many similarities with CSOs, there are a number of differences that make SSO control difficult to implement. Table 23 summarizes the main differences between SSOs and CSOs.

Table 23. Major Differences Between SSOs and CSOs (Graham, 1996).

Sanitary Sewers	Combined Sewers
Designed to carry only sanitary wastes	Designed to convey sanitary wastes and stormwater
Not designed with diversion and outlet structures except to protect some pump stations from flooding	Designed with diversion and overflow outlet structures
Designed to discharge wastewater to a treatment plant during wet weather	Designed to discharge a significant portion of combined flow to a waterway during wet weather
During wet weather, systems may contain overflows at uncontrolled locations	During wet weather, overflows occur at controlled points
SSOs occur through manholes and broken lines, at pump stations and inside buildings; discharges occur throughout the system	CSOs occur through overflow outlet structures discharging directly to a receiving stream

The Charlotte-Mecklenburg (NC) Utility Department investigated causes of SSOs as originating from four general conditions, including maintenance, structural, private and other. The predominant cause of SSOs was maintenance-related issues (100% of all events), with structural problems and private property problems each being flagged for another 6.3 % each (Gallaher and Brown, 1996). [Note that more than one cause could be attributed to the SSO, resulting totals greater than 100 %]. The category “other” had no entries. Within the predominant maintenance category, causes of SSOs included roots (49 % of events), grease (70 %), sand/silt (40 %) and rags/paper/plastics (15 %) (Gallaher and Brown, 1996).

Rae (1996) noted that collection systems with relatively flat slopes may have slow water velocities which allow sediment to accumulate and hydrogen sulphide to form. The hydrogen sulphide leads to corrosion of concrete and iron pipes, ultimately resulting in the crown of the sewer to fail structurally, and the street above to collapse. With the failure, the sewer line is blocked and SSOs result.

Problems related to SSOs include public health due to direct contact with wastewater high in pathogen levels, potential impact on drinking water supplies, adverse effects on receiving waters from toxins, pathogens, oxygen-depleting substances and floatable materials including plastics and oil. Beach closures may occur as a result of SSOs, leading to loss of recreational and tourist spending (Golden, 1996). Gallaher and Brown (1996) report that SSOs contributed to statistically significant increases in fecal coliforms, ammonia and biochemical oxygen demand (BOD) in local streams receiving SSOs from the Charlotte-Mecklenburg (NC) district.

Difficulties related to remediating SSOs from laterals on private property include the logistical and financial implications from inspecting so many potential sources, as well as the political and legal issues involved with accessing private properties. In a major review of I/I sources, the City of Edmonton determined that 70 % of I/I could be traced to on-lot (private property) sources, with only 30 % derived from on-street sources (Hodgson et al. 1996).

3.4.2 Reduction of Sanitary Sewer Overflows

Among the means available for curbing SSOs are: sewer system maintenance, reduced peak flows by reduction of inflow and infiltration (I/I); increased conveyance and treatment capacity and wet weather storage and treatment facilities (Golden, 1996). Sewer system maintenance is more often a response to an emergency than to planned preventive maintenance. Preventative maintenance programs can involve regular hydraulic, mechanical or chemical cleaning and root removal, and line replacement to eliminate hydraulic restrictions (Golden, 1996).

Computerized SSO management plans can incorporate maintenance records, complaint databases, computer-aided design (CAD) or geographical information system (GIS) overlays, hydraulic models and more (Crawford and Adderley, 1996).

Peak flow reduction is accomplished by reduction of inflow and infiltration. Methods identified by Jeyapalan and Jurgens (1996) for peak flow reduction include hydraulic or mechanical cleaning, chemical root control, trenchless technologies and less-trench technologies. Trenchless technologies include cured-in-place pipes, fold and formed plastic pipes, coatings such as shotcrete, cast-in-place concrete or chemical grouts, directional drilling, robotic repairs, fill and drain involving mixing of two chemicals as a sealant. Less-trench technologies involve some excavation, and are used to introduce new pipe into a system, and to reactivate laterals. Methods in this type of rehabilitation include sliplining, in which a new pipe is inserted into an older pipe, swaged and rolled down pipes, pipe bursting, microtunneling, pipe ramming and manhole rehabilitation technologies (Jeyapalan and Jurgens, 1996).

The appropriate maintenance program for prevention of SSOs proposed by the Charlotte-Mecklenburg Utility Department includes a targeted, rather than universal approach for the sanitary sewer system, based on different land uses and natural conditions above the system. Other elements of the preventive maintenance program there include flow monitoring stations to determine abnormal flow patterns at different locations; flow modeling to assess system capacity, bottlenecks, and planning for capital improvements; and a comprehensive complaint history database including SSO location and cause to identify recurring problematic geographical areas and contributing factors (Gallaher and Brown, 1996). The need for maintenance programs to be supported by integrated software programs linking facility inventories and historical condition and maintenance databases to mapping and geographical information systems was noted by Knott and Singleterry (1996).

3.4.3 Treatment of SSOs

Scheible (2002) investigated several technologies for treatment of SSO-type wastewaters, including continuous deflection separation (CDS, also known as swirl concentrator or vortex separator), a high-rate fibre-based media filter and UV light disinfection. A 1200 μm screen in the CDS reduced the total suspended solids (TSS) concentration by only 10 %, but was able to maintain self-cleaning action. A screen with smaller 600 μm openings was able to reduce TSS by 30 % but suffered blinding of the pores. The fibre filter downstream of the CDS effectively removed particles of greater than 50 μm size, resulting in approximately 40 % reduction of TSS at hydraulic loadings of 400 to 600 L/min-m^2.

For maximizing flow of wet weather-augmented sanitary wastewater, Field and O'Connor (1996) recommend utilizing storage facilities, either at the treatment plant site or off-site, and by increasing the interceptor flow-carrying capacity. Storage permits the accumulation of excessive flow during a precipitation event, with subsequent feeding back to the treatment plant during dry weather conditions, when the plant is not hydraulically limited. Land requirements for storage may be difficult to accommodate for some municipalities. Flow capacity of interceptors can be increased by cleaning interceptors blocked with silt, grease and debris; by increasing the pumping capacity for surcharged interceptors; by installing larger or parallel interceptors; and by injecting polymer or lining to reduce pipe roughness (Field and O'Connor, 1996).

The Best Management Practices for SSOs include elements of reduction of both infiltration and inflow, and treatment of the SSOs. Techniques described above for reducing peak flows, such as disconnection of roof leaders and foundations drains, preventive maintenance in local areas where low velocity flows contribute to hydrogen sulphide formation are appropriate across the country.

3.4.4 Summary

SSOs can result from many causes including aging infrastructure, poor design, blockages by grease, and obstruction from large solids (branches and roots). Most Canadian municipalities are faced with aging infrastructure. Implementation of sewer use programs will reduce blockages due to grease accumulation, and sewer maintenance programs, involving television cameras and maintenance records can identify blockages due to roots. The programs needed to prevent these problems can be implemented across Canada.

3.5 Cross-connection Systems

3.5.1 Problem Identification

Cross-connections exist when sanitary wastewater enters the stormwater collection system either unintentionally or by illegal intent. Cross-connections are common in municipalities that have undergone sewer separation, and they may have been overlooked when sanitary connections were to be removed from the existing storm water system and re-connected to a newer sanitary sewer (EPA 1993b). Accidental connection between house sewer laterals and the stormwater collection system may also occur in new housing construction. In other cases, illegal connections are made deliberately. Illegal industrial connections may have been attempted to avoid sewer use assessment costs, and may lead to increases in loadings of many types of pollutants including metals, organic waste and solids and pathogens.

Cross-connections typically can be identified by monitoring dry-weather discharges from storm sewers. If substantial concentrations of pollutants are found in the dry-weather stormwater, sources of the substances need to be identified by sewer sampling campaigns or by television camera monitoring programs. Other procedures include dye testing and personal visual inspections of the storm sewers.

The City of Edmonton implemented a cross-connection remediation program in three steps including an initial identification and classification of cross-connections, definition of geographical areas of the connections (often clustered in areas), and development of prioritization rules for remediation (Hodgson et al., 1996). Primary ranking criteria used in prioritizing the remediation of cross-connections included: (a) proximity to water intake; (b) type of interconnection; (c) fecal coliform count at the outfall; (d) receiving water type at the outfall; (e) sewage characteristics or strength; (f) past upgrading of sanitary or combined sewer system in the area; (g) combined, partially separated or separate sanitary sewer categorization; (h) accessibility of the outfall; and (i) age of the sewer infrastructure in the area. Weightings were applied to these various factors, ranging from 200 for proximity to the water treatment plant intake to 10 for age of the interconnection itself. The rankings for each cross-connection within geographical areas were entered in a database, and totaled to identify the areas in greatest need of remediation. The rankings led to an analysis of those interconnections most frequently activated to those rarely overflowed, if at all. Immediate action focused on those most frequently activated.

3.5.2 Summary

Review of the literature did not reveal any specific Best Management Practice for identification and removal of cross-connections. Monitoring of dry weather flows in storm sewers for evidence of sewage contamination is a common sense first step. Ranking of areas for removal of cross-connections as applied by the City of Edmonton is a practical approach for prioritizing areas of a municipality for reducing extraneous flows. The techniques appear to be applicable Canada-wide.

3.6 Trucked or Hauled Wastewater

3.6.1 Septage

3.6.1.1 Septage Characteristics

Septage is defined as a liquid or solid material removed and hauled from a septic tank, holding tank, pit toilet, or similar system that receives only domestic waste (Alberta Environment, 2004). Consequently, the characteristics of septage can be highly variable. Components of septage include water, human waste, grease, hair, grit rags, plastics, stones, food preparation, and sanitary hygiene products. Because of the human waste component, septage contains elevated levels of pathogenic organisms, including bacteria, viruses and parasites. Wastes from recreational vehicle (RV) holding tanks and portable toilets may contain de-odorizers, fragrances, and antibacterial or disinfection agents. The latter group, which includes substances such as quaternary ammonium-based compounds, formaldehyde or paraformaldehyde, may inhibit the biological wastewater treatment processes at a wastewater treatment plant. Septage may exert a heavy loading on wastewater treatment processes if discharged rapidly, because septage strength may be as much as 6 to 80 times that of conventional municipal sewage (Alberta Environment, 2004). Septage concentrations may vary considerably; characteristics of septage components are provided in Table 24.

3.6.1.2 Estimates of Septage Quantities

Estimates of annual septage production in Alberta is 4,000,000 m^3 from holding tanks, and 300,000 m^3 from septic tanks (Alberta Environment, 2004). In Ontario, the estimated annual volume of septage generated is similar. The total quantity of hauled wastewaters (holding tanks, septic tanks and portable toilets is 4,200,000 m^3 (XCG, 2004). In Ontario, the hauled wastewater discharged to municipal wastewater treatment plants represented 0.47 % of the average dry weather flow, as a median value over the 32 geographical regions evaluated (XCG, 2004).

Although the flow of septage is small compared to plant flow, it can have a significant effect on loading to the plant if discharged over a short time period.

3.6.1.3 Effect of Septage Addition on Treatment Plant Operation

Modeling with the Hydromantis GPS-X wastewater simulator was used to assess the effect of septage addition on a nitrifying conventional activated sludge plant, an extended aeration facility and a conventional facultative lagoon under winter conditions, as they were the processes most representative of Ontario facilities (XCG, 2004). Winter conditions were selected as the most challenging. The simulation results determined that co-treatment of septage at the nitrifying CAS and extended aeration plants, was able to meet MOE effluent criteria for BOD, solids, nitrogen and phosphorus. Simulation of the conventional lagoon effluent indicated an ammonia-nitrogen concentration ranging from 23 to 25 mg/L, in excess of the 5 mg/L criterion value. Consequently, the use of intermittent sand filters for nitrification of the effluent was deemed required as a polishing step after facultative lagoon treatment.

Other effects anticipated for co-treatment of septage included higher sludge production rates and higher biosolids handling costs for the CAS and EA plants, and more frequent sludge removal from the lagoon process (XCG, 2004). On-site costs related to co-treatment of septage included an equalization/holding tank, installation of mixers, and odour control equipment.

Treatment of septage prior to discharge to municipal sewers has been reported for Vernon, B.C. and the Capital Regional District (Victoria) B.C. At the CRD facility, screens remove larger objects for deposit in the landfill, while the screened liquid portion is subjected to integrated film and suspended growth activated sludge treatment, followed by dissolved air flotation treatment to reduce the BOD and TSS to 300 mg/L each prior to discharge to the municipal sewer (Alberta, 2004). The Vernon system is similar, with target BOD and TSS concentrations of 500 mg/L each for discharge to the municipal sewer (Alberta, 2004).

Table 24. Septage Characteristics (Alberta Environment, 2004).

Parameter	Septic Tank	Holding Tanks	Pit Toilets
Total Solids, mg/L	34100	720	78140
Total Volatile Solids, mg/L	23100	365	60582
Total Suspended Solids, mg/L	12900	220	No data
Volatile suspended Solids, mg/L	9000	165	No data
Biochemical Oxygen Demand, mg/L	6500	220	No data
Chemical Oxygen Demand, mg/L	31900	500	110360
Total Kjeldahl Nitrogen, mg/L	590	40	8070
Ammonia-Nitrogen, mg/L	97	25	3920
Total Phosphorus, mg/L	210	31	3730
Alkalinity, mg/L as CaCO3	970	100	14990
Oil and Grease, mg/L	5600	100	No data
PH, standard units	5.2-9.0	No data	No data
Total coliforms, No./100 mL	10^7-10^9	10^7-10^8	10^8-10^9
Fecal coliforms, No./100 mL	10^6-10^8	10^6-10^7	10^7-10^8
Fecal Streptococci, No./100 mL	10^6-10^7	No data	No data
Pseudomonas aeruginosa, No./100 mL	10^1-10^3	No data	No data
Salmonella sp., No./100 mL	1-10^2	No data	No data
Parasites	Present	No data	No data
Helminths	Present	No data	No data
Aluminum, mg/L	48		
Arsenic, mg/L	0.16		
Cadmium, mg/L	0.27		
Chromium, mg/L	0.92		
Copper, mg/L	8.27		
Iron, mg/L	191		
Mercury, mg/L	0.23		
Manganese, mg/L	3.97		
Nickel, mg/L	0.75		
Lead, mg/L	52		
Selenium, mg/L	0.076		
Zinc, mg/L	27.4		
Methanol, mg/L	11		
Isopropanol, mg/L	1		
Acetone, mg/L	0		
Methyl ethyl ketone, mg/L	1		
Toluene, mg/L	0.005		
Ethylbenzene, mg/L	0.005		
Benzene, mg/L	0.005		
Xylene, mg/L	0.005		

Although septage quantity may be slight compared to the average dry weather flow, the pollutant loading to the facility can be significant. Use of equalization facilities to bleed septage to the wastewater at a controlled rate is recommended, otherwise the treatment facility may receive an organic shock loading. Optimal management of loadings to the treatment facility may dictate the introduction of the septage during off-peak loading periods, such as later at night. Pretreatment of septage is recommended to remove hair grit, fibres and plastic materials. For this reason, addition of septage just prior to the wastewater plant headworks is suitable, providing there is sufficient flow to prevent the septage from settling.

If septage is held in unlined treatment pits in some Canadian locations, either as a form of treatment or prior to treatment in a wastewater treatment facility, the impact on the subsurface may need to be examined.

While treatment of septage may cause some operational problems because of its strength, co-treatment of septage with domestic wastewater in Canada is likely to continue. Trucking of septage in the Canadian North is a practical solution where it would not be cost-effective to provide piped infrastructure to small dispersed communities.

3.6.2 Municipal Landfill Leachate

3.6.2.1 Characteristics of Landfill Leachate

A survey for the Ontario Ministry of the Environment in 2003 found that for municipal treatment plants accepting landfill leachate, 30 facilities received only piped-in leachate, while 17 facilities received only vehicle-hauled leachate. Another 5 plants accepted both piped and hauled leachate. One other treatment plant receiving hauled leachate received a second type of leachate for which the method of transport was not determined (XCG, 2004). Most facilities accepting leachate (approximately 2/3 of 53 facilities) were conventional activated sludge plants, while lagoons and extended aeration plants each comprised approximately 10 % of the leachate-accepting facilities. Another 7 % of the plants accepting leachate were primary treatment plants, with the balance comprised of other processes.

Municipal landfill leachate characteristics vary with the age of the landfill. Younger leachates with active higher anaerobic decomposition have higher organic waste strength in terms of BOD than do older landfills. Landfill ages were given an age classification as follows:

Young – from solid wastes less than 5 years old
Medium – from solid wastes between 5 and 10 years old
Old – from solid wastes greater than 10 years old.

Based on an extensive literature search, parameter values for leachates of differing ages were found as reported in Table 25.

Table 25. Characteristics for Landfill Leachates of Differing Ages (after XCG, 2004)

Parameter	Concentration (mg/L) in Leachate Age Type		
	Young	Medium	Old
BOD	15,419	2,342	98
COD	22,624	5,348	1367
Ammonia –N	1,328	1,088	476
TKN	1,416	1,296	567
TSS	1,438	143	17

The overall leachate characteristics including all leachate age groups from the XCG literature review are provided in Table 26.

A literature review of leachates for concentrations of Tier I and Tier II trace substances from the Canada-Ontario Agreement respecting Great Lakes Water Quality was also completed as part of the leachate review. The results of the review are provided in Table 27.

Table 26. Range of Concentrations of Landfill Leachate Constituents (XCG, 2004)

Parameter	Concentration in Leachate (mg/L unless otherwise indicated)	
	Minimum	Maximum
Alkalinity	0	2,900
Ammonia-N	0	2,455
Biochemical oxygen demand (BOD)	2	73,950
Chemical Oxygen Demand (COD)	9	90,000
Chloride	1	47,000
Fluorides	0.18	4.2
Hardness	57	25,000
Hydrogen sulphide	10.7	16
Nitrate and nitrite	0.1	1,900
pH (standard units)	3.7	9.6
Phosphates	0	150
Sulphates	1	6,960
Sulphide	3.1	130
Total Kjeldahl nitrogen (TKN)	0.94	2,730
Total organic carbon (TOC)	10	20,000
Total Phosphates	0	155
Total solids (TS)	4,815	32,685
Suspended Solids (TSS)	907	19,956
Total volatile solids (TVS)	5	33,616
Volatile suspended solids (VSS)	7	1,367

The volume of leachate discharged to the treatment plants as a fraction of the average daily wastewater flow ranged between 0.001 and 4.4 %, with a median value of 0.3 %. The loading exerted by leachate on a receiving treatment plant is clearly dependent on the age of leachate, as indicated by Table 25. For the same volume of leachate treated, a young leachate will have a more negative impact than will an old leachate. The effect of the contaminant loading from leachate on treatment plant performance is discussed in the following section.

Table 27. Concentration of COA Tier I and II Substances in Leachates (after XCG, 2004)

Parameters	Concentrations (µg/L)	
	Minimum	Maximum
Tier I Substances		
Aldrin	0.01	23
Benzo(a)pyrene	<0.5	12.5
Chlordane	<0.002	0.34
DDT and metabolites	<0.005	0.21
Hexachlorobenzene	<0.001	110
Mercury	0.05	200
Mirex (dechlorane)	<0.005	0.045
Total PCBs	<0.002	0.81
PCDDs (chlorinated dioxins)	<0.0077	<0.0077
PCDFs (chlorinated furans)	<0.0069	<0.0069
Tier II Substances		
Anthracene	<0.2	4.6
Cadmium	<1	17,000
1,4-Dichlorobenzene	<0.9	24
Lindane (γ- hexachlorocyclohexane)	<0.001	700
Pentachlorophenol	0.24	1.3
Benzo(a)anthracene	<0.2	37.6
7,12-Dimethylbenz(a)anthracene	<0.4	14
Benzo(b)fluoranthene	<0.4	7.6
Benzo(g,h,i)perylene	<0.4	10.1
Benzo(j)fluoranthene	<0.3	10.3
Benzo(k)fluoranthene	<0.22	2
Fluoranthene	<0.2	36.6
Indeno(1,2,3-c,d)pyrene	<0.6	7
Perylene	<0.3	3
Phenanthrene	<0.3	39.3
Pyrene	<0.3	15

3.6.2.2 Co-Treatment of Municipal Landfill Leachate with Domestic Wastewater

Based on simulations of treatment plant performance with GPS-X software (Hydromantis, Inc.), nitrifying conventional activated sludge treatment facilities accepting landfill leachate required no additional treatment to be able to achieve target treated effluent qualities of 25 mg/L each of BOD_5 and TSS, 1.0 mg/L of total phosphorus and 5 mg/L of ammonia-N during winter operation (XCG, 2004). Simulations of leachate co-treatment with facultative lagoons indicated that, because effluent concentrations of ammonia-N exceeded the target value of 5 mg/L, application of intermittent sand filtration was recommended. With respect to COA toxic substances, only cadmium was found to be of potential concern, domestic wastewater rather than leachate, was noted to be the primary source of cadmium, due to the relatively low contribution of leachate to the daily wastewater flow (0.3 %). No additional treatment for cadmium as a result of the mass loading from leachate was considered necessary.

Depending on the means of transporting leachate to the wastewater treatment plant, required upgrades would be a holding tank at the headworks to equalize the flow, and associated odour control facilities (XCG, 2004). As well, as noted above, lagoon facilities would require installation of intermittent sand filters for ammonia reduction.

Higher concentrations of landfill leachate may exert negative effects on activated sludge treatment of municipal wastewater without some additional treatment. Landfill leachate added to batch and semi-continuous activated sludge units at proportions of 5 to 25 % by volume resulted in deterioration of effluent quality (COD and ammonia-N). Addition of powdered activated carbon (PAC) at doses ranging between 100 and 3500 mg/L was found to have a positive effect on reducing effluent concentrations of the ammonia and COD (Cecen and Aktas, 2004). The author recommended PAC when leachate flow exceeded 10 % of the wastewater flow, or when shock loadings occurred.

3.6.3 Summary

Discharge of septage to municipal wastewater treatment plants appears to have the potential for greater impact than does landfill leachate for mechanical plants such as conventional activated sludge or extended aeration processes. The elements of a best management practice for septage treatment at wastewater treatment facilities include construction of an equalization storage facility at the reception site, equipped with an odour control device. Coarse screening of the septage prior to discharge to the treatment facility, as practiced by the Capital Regional District, may be advantageous.

The contribution of municipal landfill leachate to daily wastewater treatment plant flow is very small. Nitrifying wastewater treatment facilities were deemed capable of meeting target effluent concentrations in winter operation. Facultative lagoons were similarly deemed capable of meeting effluent quality target with the exception of ammonia-N. Intermittent sand filtration was recommended as a polishing step to achieve ammonia-N target concentrations in lagoon effluents. The best management practice for municipal treatment facilities accepting landfill leachate appears to be provision of a holding tank for flow equalization, and installation of odour control equipment.

3.7 Small/remote and Northern Community Wastewater Issues

3.7.1 Technical Issues

The technical issues facing small/remote and northern Canadian communities are often similar. In the North, lagoons are one of the most common forms of treatment. Because of the harsh climate, lagoons may discharge their effluents infrequently, typically on an annual basis, or perhaps even every other year (Environment Canada, 1987). Biological treatment processes, other than facultative lagoons, usually require a favourable temperature environment, substantial energy requirements for pumps and blowers, and skilled, trained operators to run them (Ferguson Simek, Clark, 2003). In the north especially, mechanically-operated biological treatment systems need to be housed in heated buildings to operate properly. In addition, the operating and maintenance costs for mechanical treatment systems in the North are substantially higher than in Southern Canada, due to higher costs for shipping chemicals, fuel, replacements and generation of electricity. Such considerations make these treatment processes less acceptable to small/remote and northern communities. Facultative lagoons, and wetlands and overland flow treatment systems, are more appropriate technologies for these communities. Because they are situated in more remote areas, the communities are often able to acquire the large land area required for these types of treatment. In the Yukon, some communities have installed oversized lagoon cells, including unlined long term storage cells. The unlined storage cells permit some exfiltration to occur, while seasonal discharge to wetlands is also used. The design of some of the unlined storage ponds has resulted in some ponds never discharging an effluent to a surface water, with seepage and evaporation as the only loss mechanisms.

Training and retention of trained operating staff is a major concern for small and rural communities, particularly in isolated northern areas. Because of the small population size and potential inability to hire or retain skilled operational staff, low maintenance technologies may be appropriate. Small and remote northern communities may need to consider risk assessment for determining the optimum treatment alternative

3.7.2 Technical Resources

The U.S. EPA has made significant efforts in assisting smaller communities to meet the requirements of 1972's Clean Water Act. The manual "Process Design Manual - Wastewater Treatment and Disposal for Small Communities" (EPA, 1992) provides a useful guide to treatment processes for both suspended growth and fixed film processes (such as trickling filters and rotating biological contactors (RBCs)), package treatment facilities and lagoons. Besides the process descriptions, a financing discussion is provided to assist in a cost-effectiveness decision. Considerations in treatment level required include:

- Minimum quality criteria for receiving water or land as set by the provincial and/or other regulatory agency;
- Effluent quality requirements
- Possibility of some form of land disposal of residual solids;
- Area and regional master plans;
- Financial capabilities of the community to meet initial and annual wastewater costs;
- Available energy resources in short and long term;
- Local capabilities for operation and maintenance of wastewater facilities
- Habits, attitudes and social patterns of the residents of the community.

Similarly, Environment Canada published a manual for Design and Selection of Small Wastewater Treatment systems (Ross et al., 1980). In addition to many of the topics covered by the EPA manual, the manual discusses land-based treatment systems, and the discussion of all topics reflects Canadian geographical considerations.

Since the EPA and Environment Canada published their manuals for small systems, other technologies for small communities have become available, such as membrane bioreactors and constructed wetlands. Advantages of membrane bioreactors include very high quality, low maintenance and operator attention, reduced number of pumps, and small footprint (Bernal et al., 2002). A community in the State of Louisiana constructed a wetland treatment facility following their aerated lagoon. The wetland effectively reduced BOS, TSS and fecal coliforms in the lagoon effluent (Barrilleaux, 2003).

The U.S. EPA has also established a National Small Flows Clearinghouse (NSFC) to provide technical assistance and information services about "small flows" wastewater treatment systems, which is defined by the EPA as those that have (3,780 m^3/d (one million gallons per day, 1 MGD) or less of wastewater, ranging from septic systems to small sewage treatment plants. The NSFC provides information about innovative, low-cost wastewater treatments for small communities(with populations less than 10,000). Topics addressed include treatment technologies, planning and financial issues (EPA, 2005). A number of databases are available that may be accessed for a nominal fee.

Wade (1996) described the efforts of 2 small central U.S. municipalities to comply with government requirements for controlling SSOs. In one case, a municipality in Oklahoma would have been completely unable to fund the estimated cost of $13.3 million (US) required for system rehabilitation. The recommendations proposed by the consultant were applicable to smaller U.S. communities faced with mandated improvements to sanitary sewer systems. A number of the recommendations are pertinent to smaller Canadian communities as well, and include:

- make inflow reduction a first priority;
- develop in-house training for sanitary sewer evaluation studies;
- purchase equipment and materials to perform most of the rehabilitation work;
- review and update sewer use ordinances to control private sector I/I;
- Develop a financial capability and financing plan;
- Investigate all potential financing alternatives;
- Form partnerships with larger regional cities;
- Stayed informed through professional associations [in Canada, such as the Canadian Water and Wastewater Association, the Federation of Canadian Municipalities and the Water Environment Federation sections];
- Pursue I/I in the private sector organize and maintain a systematic database that will help to monitor the remediation program; and
- Implement modest but consistent rate increases.

Value Engineering (VE) is a systematic analysis of a project with objectives of improving the function and quality of a project, while at the same time trying to reduce project costs. A Value Engineering Coordinator is required to ensure balance and impartiality of all input ideas. Typically Value Engineering proceeds in three steps: a pre-workshop preparation, a value engineering study workshop; and lastly a post-study summary. The Workshop itself provides an organized approach to identifying high initial capital, energy and life cycle costs of wastewater treatment. The requirements needed to operate and maintain the treatment facilities are analyzed to assure performance. Where the essential functions are not being furnished by the design, there is a lack of “value”. The VE team identifies alternative approaches that will provide the needed value. Portions of the project not functionally required or carrying major parts of project costs are likely targets for team evaluation. Developing recommendations to reduce these high cost areas is an important aspect of the workshop. A workshop is conducted in six phases in this specific order: (a) Orientation Phase; (b) Information Phase; (c) Creative Phase; (d) Judgment Phase; (e) Development Phase; and (f) Presentation Phase. The *Final VE Report* identifies which VE Recommendations are to be implemented without change, which are to be implemented after improvement, and which are not to be implemented.

In a similar vein, municipalities may also be faced with choices with respect to monitoring or control of non-regulated pollutants that may be of a social or other environmental issue. In such cases, it may be necessary to derive monetary values for the issues, thus permitting the ranking and prioritization of the various issues that different social elements of a community may deem of conflicting value. A useful guide in this respect is provided by Infraguide Canada (2003b) on "Accounting for Environmental and Social Outcomes in Decision Making". For example, a decision might be made as to whether it is better to disinfect a lagoon effluent if not required, remove additional phosphorus loading to a receiving water, or to reduce levels of metals in the effluent. Each action could affect different end uses for activities such as bathing, fishing, recreational boating, or others. The Infraguide Canada manual describes the cost-benefit analysis approach for identifying, quantifying and monetizing the various economic, environmental and social costs and benefits associated with investment in the infrastructure investment (which also applies to trade-offs for pollutant management).

Smaller and rural communities may have difficulty in attracting and employing dedicated wastewater treatment operators or superintendents. Use of low maintenance facultative lagoons, requiring minimum operator attention, may help to alleviate this situation. Otherwise it may be possible to retain private firms to offer operating and maintenance services. The operating firm is responsible for achieving effluent quality and complying with all other regulations, personnel issues and plant upkeep in exchange for remuneration. Prior to acceptance of any contract, municipalities should be aware of responsibilities and liabilities assumed by both contracting parties, and requirements and conditions for the state of the facility at the time the contracting firm is released or replaced by another.

Membership in technical associations is another resource available to small or rural municipalities to assist them in decision-making. These communities should actively pursue involvement in the Provincial/Territorial Associations to receive training and access to technical specialists. The Water Environment Federation (www.wef.org) is one of the largest technical associations involving members of the wastewater treatment community. A number of Canadian Associations are members association of WEF, including the British Columbia Water and Waste Association (http://www.bcwwa.org), the Western Canada Water Environment Association (http://www.wcwwa.ca), the Water Environment Association of Ontario (http://www.weao.org), RÉSEAU Environnement Inc. (http://www.reseau-environnement.com), and the Atlantic Canada Water Works Association (www.acwwa.ns.ca), and an Operators' Association, the Maritime Provinces Water and Wastewater Association (http://www.mpwwa.ca**).** The main WEF site also has a Technical Information Center in which questions may be posted under a variety of major topics, with answers provided on a voluntary basis by other members of WEF (http://www.wef.org/TechInfoCtr/).

The Water Environment Research Foundation (WERF) (www.werf.org) is the research foundation set up by the Water Environment Federation. Utility members and private sector companies may become subscribers, helping to fund the research programs conducted for WERF by quality research teams. Non-members can access the research reports prepared by WERF, but pay a higher price for them than the subscribers do.

The Canadian Water and Wastewater Association (http://www.cwwa.ca/) is an organization mainly for municipal agencies, but with some private sector associate members as well. The Association is a clearinghouse of information and facilitates discussion between members. It highlights issues of concern to municipal wastewater and water treatment providers, and serves as a mechanism for communication with Canadian legislators.

The Federation of Canadian Municipalities (http://fcm.ca/) represents the interests of all municipalities on policy and program matters within federal jurisdiction. FCM members include Canada's largest cities, small urban and rural communities and the 17 major provincial and territorial municipal associations. Municipal leaders from all parts of Canada meet annually to establish FCM policy on key issues.

The National Association of Clean Water Agencies (NACWA) is a new name of an association formerly known as the Association of Metropolitan Sewerage Agencies (AMSA) (http://www.amsa-cleanwater.org/). NACWA represents the interests of over 300 public agencies and organizations. NACWA members serve the majority of the sewered population in the United States and collectively treat and reclaim more than 18 billion gallons of wastewater daily. A major objective of NACWA is as a lobbying organization to influence the development of environmental legislation, and to work with federal regulatory agencies in the implementation of environmental programs. A number of technical publications and resources are available from the AMSA web site (http://www.amsa-cleanwater.org/) and are either free or available for purchase.

3.7.3 Funding

For municipalities that are capital-deficient, the Green Municipal Funds may be available to help with wastewater treatment improvements. The Government of Canada endowed the Federation of Canadian Municipalities with $250 million to establish the Green Municipal Funds and support actions by municipal governments to reduce pollution, reduce greenhouse gas emissions and improve quality of life. Applications for projects are being accepted in Autumn, 2005.

The Water Environment Research Foundation (WERF) often funds projects with collaboration by individual or groups of municipalities. As well, WERF projects may need demonstration sites to accomplish a specific test program. In such cases, municipalities may become part of the technology demonstration and end up with significant technology advancement. For example, a recent notice from WERF seeks a wastewater treatment facility that will serve as a test site for a new research project that develops and demonstrates a model-based control strategy to improve biological nutrient removal (BNR) at a full-scale wastewater treatment facility. WERF is seeking a utility partner that would like to participate in the project and implement model-based control at one of their BNR facilities (WERF, 2005).

3.7.4 Summary

Small and remote municipalities across Canada face the problems of obtaining funding needed for required treatment levels, hiring and maintaining staff, and understanding the technicalities of wastewater treatment. These problems are especially acute in the Canadian North. Best management practices for these communities appear to be the adoption of lower technology and lower maintenance processes such as lagoons and wetland or overland treatment. Large storage cells that are shallow (e.g. less than 1 m) would maximize UV light penetration to promote photo-oxidation and biological utilization of organic substrates.

Many technical resources are available through technical associations, government agencies and internet portals. Funding opportunities may be available to help offset some or all costs by participating in technology demonstration projects.

3.8 MWWE Discharging to Marine Receivers

3.8.1 The Global Situation

Most major developed countries around the globe recognize the impact of nutrients in the nearshore marine environment, with nitrogen being the nutrient of primary concern in most cases. For this review of best management practices, municipal wastewater treatment will be examined for representative countries. It will not be a comprehensive review of all nations with treatment plants discharging to marine environments.

In Europe, the Council of Ministers developed 7 legislative initiatives to deal with water issues, and include: (a) the Integrated Pollution Prevention and Control (IPPC) directive for harmonization of programs between member countries; (b) the directive on nitrates from agricultural sources; (c) the urban wastewater treatment directive; (d) the shellfish waters directive; (e) the dangerous substances directive; (f) the bathing waters directive; (g) the Water Policy Framework directive (UK Marine CAS, 2005).

The urban wastewater treatment (UWWT) directive governs most issues with respect to municipal wastewater effluents. The main objective of this Directive is to ensure that all significant discharges of sewage are treated before they are discharged, either to inland surface waters, groundwaters, estuaries or coastal waters. Municipal wastewater is to be treated to secondary treatment standards, which normally involves a biological process. Where effluents are discharged into receiving waters identified as “sensitive” due to the risk of eutrophication, more stringent treatment is required, which will typically include nitrogen removal in coastal waters and phosphorus removal in freshwaters (UK Marine CAS, 2005).

The provisions of the UWWT Directive were embedded in UK legislation by the Urban Waste Water Treatment Regulations 1994 in England, Wales and Scotland. Initially, the Directive and the UK Regulations allowed for the designation of High Natural Dispersion Areas (HNDAs) in coastal waters. In which only primary treatment of sewage was required. Eighty-five such HNDAs were identified in the UK: 58 in England and Wales, 24 in Scotland and 3 in Northern Ireland. Subsequently, however, the UK decided to withdraw all HNDAs, thereby requiring all discharges covered by UWWT Regulations to undergo secondary treatment as a minimum.

Dischargers affected by this change of policy were allowed longer to comply with the secondary treatment requirements (UK Marine CAS, 2005).

Most European countries adhere to the Water Policy Framework Directive (WFD) adopted by members of the European Union on 26 February 1997. The overall aim of the Directive is to establish a framework for the protection and management of surface waters, including estuaries, coastal waters and groundwaters in the EU. The main objectives of the Directive are to:

- prevent further deterioration and to protect and enhance the aquatic environment;
- achieve "good" water quality for all surface waters and groundwaters unless it is impossible or prohibitively expensive;
- promote sustainable water management based on long-term protection of water resources.

In the more northerly EU countries, Scandinavian countries such as Denmark and Sweden already have very high levels of municipal effluent treatment. From about 1970, most of Sweden's municipal wastewater treatment plants installed *chemical* or *advanced treatment*, which can eliminate 90 per cent or more of the phosphorus content of unprocessed wastewater. Since the mid-1970s, approximately 95 % of all Swedish urban wastewater is treated both chemically and biologically (Swedish EPA, 2005). Most of the Baltic and the North Seas are nitrogen-limited, and nitrate from point and non-point sources contribute to eutrophication, not only of coastal inlets and archipelagos, but also for more open stretches of the Swedish coastline. Municipal wastewater treatment in the larger coastal towns and cities of Central and Southern Sweden have recently been made to include *nitrogen removal*, such that nearly 75 % of all treatment plants discharging to marine waters have biological treatment with nitrogen removal, including both nitrification and denitrification processes (Sweden, 2003).

Similarly in Denmark, effluents from all the approximately 1500 wastewater municipal wastewater treatment facilities undergo treatment. Sensitivity of the receiving body of water is taken into consideration for effluent limits. Municipal facilities now treat almost all the wastewater both mechanically and biologically, and 86% of the wastewater further undergoes nitrogen and phosphorus removal. Nitrogen is removed using biological methods while phosphorus is removed using biological and/or chemical methods (Danish EPA, 2005).

Gabrielides (1995) outlined the many types of pollutant concerns in the Mediterranean Sea, including the metals mercury and cadmium, chlorinated hydrocarbons (principally PCBs and DDT-type pesticides), organotin compounds, several organophosphorus compounds, herbicides, fungicides, and floatable litter. Pollutant groups of highest priority in sensitive coastal areas were nutrients, pathogens and toxic organic chemicals. Select heavy metals, other hazardous materials (oil and chlorine) and plastic floatables were considered substances of intermediate priority. The generic substances BOD and TSS were ranked as low priority (Orhon et al, 2002).

A remedial plan known as the Mediterranean Action Plan (MAP) has been developed for the Mediterranean Sea under the auspices of the United Nations. The "Convention for the Protection of the Mediterranean Sea against Pollution" (Barcelona Convention), which was adopted in 1976, became effective in 1978. It was amended by the Contracting Parties in 1995 and recorded as the "Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean". The Convention entered into force on 9 July 2004. The objectives of the MAP and its Contracting Parties are to meet the challenges of protecting the marine and coastal environment while boosting regional and national plans to achieve sustainable development. The 22 Contracting Parties to the Barcelona Convention are: Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, the European Community, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Morocco, Serbia and Montenegro, Slovenia, Spain, Syria, Tunisia, Turkey.

The Convention and six Protocols constitute what is known as the Barcelona System, the MAP's Legal Framework. The six protocols include:

- Dumping Protocol “Protocol for the Prevention and Elimination of Pollution in the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea” adopted on June 10, 1995, with an effective date of implementation pending.
- Prevention Protocol “Protocol Concerning Cooperation in Preventing Pollution from Ships and, in Cases of Emergency, Combating Pollution of the Mediterranean Sea”, adopted in 25 January 2002 and in force as of 17 March 2004.
- LBS Protocol “Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources and Activities”, adopted on 7 March 1996with an effective date of implementation pending. [This protocol governs municipal wastewater effluent discharges to the Mediterranean Sea. No effluent concentrations limits are set out in the Protocol.
- SPA and Biodiversity Protocol “Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean,” adopted on 10 June 1995, and in force as of 12 December 1999.
- Offshore Protocol “Protocol for the Protection of the Mediterranean Sea against Pollution Resulting from Exploration and Exploitation of the Continental Shelf and the Seabed and its Subsoil”, adopted on 14 October 1994, with an effective date of implementation pending.
- Hazardous Wastes Protocol “Protocol on the Prevention of Pollution of the Mediterranean Sea by Transboundary Movements of Hazardous Wastes and their Disposal”, adopted on 1 October 1996, with an effective date of implementation pending.

At the 13th meeting of the Barcelona Convention’s Contracting Parties in Catania, Italy in 2003, the Parties decided to prepare a new Protocol to deal with Integrated Coastal Areas Management (ICAM). This Protocol is currently under development.

With respect to the land-based sources, Annex I of the LBS Protocol defines the different industrial and municipal categories of wastewater that can adversely affect the Sea, as well as classes of contaminants that are restricted due to properties such as persistence, toxicity, bioaccumulative, radioactive, etc. While no numerical limits are set out in the Protocol or its Annexes, Annex IV discusses implementation of best available technology and best environmental practices for limiting discharge of contaminants in wastewater discharged to the Sea.

Cape Town in South Africa supports 20 wastewater treatment facilities which collectively produce 567,000 m^3/d of treated effluent. 3 marine outfalls discharge 32,500 m^3/d of treated effluent (City of Cape Town, 2005). The waters of Table Bay and False Bay are subjected to pressures from sediments, nutrients, heavy metals and solid waste (floatables) from municipal effluents, combined sewer overflows, and other non-point sources (City of Cape Town, 2005).

The City of Yokohama operates eight (8) municipal wastewater treatment plants that discharge to Tokyo Bay. The Bay is subject to excessive eutrophication from nitrogen and phosphorus, which contribute to low dissolved oxygen concentrations and algal blooms called "red tides" which produce toxins harmful to aquatic life. As a result the Yokohama treatment facilities have implemented biological nutrient removal, which reduces total nitrogen from 29 to 8.9 mg/L, and total phosphorus from 4.0 to 0.7 mg/L (Kirihara, 2001).

Nitrogen in wastewater effluents is reportedly causing hypoxia (low dissolved oxygen) in coastal waters of the U.S., specifically in Long Island Sound, the Gulf of Mexico, Chesapeake Bay, Florida coastal waters southern New England and Cape Cod (Lombardo and Robertson, 2003). Most large American coastal facilities have completed extensive upgrades of wastewater treatment facilities to at least secondary treatment levels, as mandated by Section 301 of the Federal Water Pollution Control Act (a.k.a. Clean Water Act) of 1972. In the Clean Water Act, however, Subsection (h) provides for a 'waiver' for secondary treatment for marine water discharges under certain conditions, including requirements by the discharger to address the impact on the receiving water,, to perform enhanced monitoring, to apply and enforce pretreatment and source pollution control, and to apply a minimum of primary treatment level of 30% removal of BOD and SS (U.S. EPA, 2006, from Briggins, 2006). The timetable for implementation has resulted in most of these major upgrading projects being completed in the 1998-2000 time period. The upgraded facilities are often accompanied by long marine outfall pipes to ensure the effluent is discharged away from shallow nearshore waters to deeper zones.

Massachusetts Water Resources Authority has essentially completed a new sewage treatment system under the federally mandated 11-year, $3.8 billion Boston Harbor Project. The project included the Deer Island Treatment Plant with primary and secondary treatment capabilities; a new sludge-to-fertilizer facility and the 9.5-mile Effluent Outfall Tunnel to discharge treated wastewater away from shallow Boston Harbor waters and into the deeper waters and stronger currents of Massachusetts Bay. Secondary treated effluent is disinfected with sodium hypochlorite, followed by dechlorination to remove whole effluent toxicity due to the hypochlorite (MWRA, 2005).

The Metro Seattle Area is served by King County wastewater treatment facilities (King County, 2005). Both the West Point (Seattle) and South (Renton) plants have secondary treatment plus disinfection prior to discharge to Puget Sound. The West Point treats and discharges approximately 449,800 m^3/d (119 MGD (US)) through a 1.1 km (3,600 ft) outfall at a depth of 73 m (240 ft). The South plant treats and discharges 306,200 m^3/d (81 MGD) via a 3.05 km (10,000 ft) outfall at a depth of 191 m (625 ft). Disinfection is accomplished with either chlorine gas or sodium hypochlorite, followed by dechlorination with sodium bisulfate (Phillips, 2005).

In the Los Angeles Region of Southern California, three wastewater treatment plants discharge into Santa Monica Bay, two of which are very large capacity treatment facilities. The Hyperion plant operated by the City of Los Angeles, treats approximately 1,368,400 m^3/d (362 MGD) by secondary treatment. Effluent is discharged via a 8.1 km (5 mile) outfall to the Bay. The Joint

Water Pollution Control Plant, operated by Los Angeles County Sanitation Districts in Carson discharges approximately 1,247,400 m^3/d (330 MGD) of secondary effluent to Santa Monica Bay. The Terminal Island facility of the City of Los Angeles produces extremely high quality tertiary effluent, including reverse osmosis (RO) added in 2002, for discharge to Los Angeles Harbour. The RO unit was implemented by the City of Los Angeles rather than constructing a new deep-water ocean outfall to carry the effluent outside of the Harbour (South Bay Cities COG, 2005).

In Canada, most coastal cities discharging to marine waters generally have treatment systems consisting of advanced/chemically assisted primary treatment or less. In Vancouver, plants discharging to the Fraser River use secondary (biological) treatment, while the two facilities discharging to marine waters (Lions Gate and Iona Island) are primary treatment only without disinfection. The Iona Island facility discharges to the Strait of Georgia via a 7.5 km outfall, while the Lions Gate plant discharges to First Narrows. The Iona Island facility has a permit limit of 72,600 tonne/yr of BOD and 55,580 tonne/yr of total suspended solids (TSS), while the Lions Gate plant has loading limits of 5770 tonne/yr each of BOD and TSS. The primary treatment plants may be required to upgrade to chemically enhanced primary treatment to maintain base levels of treatment as defined by the Provincial policy P4, with further upgrading to secondary treatment if necessary to comply with concerns of Policy P2, or to maintain effluent concentrations and loadings beyond the capabilities of enhanced primary treatment (GVRD, 2005b).

The Capital Regional District serves municipalities in the Victoria, B.C. area with two main outfalls. The Macaulay Point outfall uses fine screening (6 mm) of the wastewater to remove larger suspended solids, plastic and other floatable materials prior to discharge through a 1.7 km outfall. The Clover Point outfall also uses 6 mm screens to remove solids from the wastewater prior to discharge from a 1.1 km long outfall pipe at a depth of 67 m (CRD 2005a). The CRD has in place a plan to upgrade to primary treatment in the event that receiving water quality or aquatic testing triggers the need (CRD, 2005b).

The Halifax Regional Municipality (HRM) serves the communities of Halifax, Dartmouth, Bedford and Halifax County. HRM operates three wastewater treatment facilities, of which two are secondary treatment or better (Mill Cove on the Bedford Basin, and the Lakeside/Timberlea plant, which discharges to Nine Mile River). The Eastern Passage facility has primary treatment only (HRM, 2006).

In Newfoundland and Labrador, the City of St. John’s, the City of Mount Pearl and the Town of Paradise have a combined population of 130,000 people. Municipal wastewater from these municipalities is currently discharged, untreated, into St. John’s Harbour. As a result, the harbour exhibits problems such as high bacterial levels, floatable materials, nutrient levels above recommended levels and localized areas of dissolved oxygen depletion (St. John’s 2003). The Riverhead Wastewater Treatment Facility, to be completed in early 2008, will be located on Southside Road. As the central element of the St. John’s Harbour Project, the treatment plant will treat 120,000 m^3/d of raw sewage and storm water run-off that presently enters the Harbour every day. In the initial phase, wastewater will be screened before discharge. The second phase will implement primary treatment, followed by disinfection using chlorination and dechlorination (St. John's, 2005).

Charlottetown and Summerside in PEI have recently received funding to provide secondary treatment with disinfection (PEI, 2005). Currently both plants have primary treatment, but the provincial standard is secondary treatment.

Relative to southern Canada, there are no large municipalities in Northern Canada located on marine coasts. Iqaluit is the largest northern community on a marine coast, with a comparatively small population of approximately 6500. Organic substances discharged in municipal wastewater to Arctic marine environments (the Arctic Ocean, Hudson Bay) would tend to persist for long periods because both biodegradation and volatilization to the atmosphere are slow under cold conditions (relative to southern Canada). Prevailing currents off southern Canada's east and west coasts, where the larger coastal cities are located, tend to bring colder Arctic waters down, and so effluents from the larger coastal cities are generally discharged into cold marine waters as well.

3.8.2 Effluent Treatment Issues

Treatment of municipal effluents discharging to marine waters is of sufficient concern to warrant symposia dedicated to the topic, particularly by the International Water Association, and its forerunner organizations, the International Association on Water Quality, and the International Association on Water Pollution Research and Control. Symposia on Marine Disposal Systems (IAWPRC, 1992a and IAWQ, 1994), wastewater management in coastal areas (IAWPRC, 1992b), pollution of the Mediterranean Sea (IAWQ, 1995a), the Black Seas and Bosporus (IAWQ 1995b and IWA, 2002) outline the concerns of municipal wastewater and its effects on coastal waters.

One of the main concerns in temperate and tropical marine zones is the rapid change in the volume of wastewater to be treated in tourist-dominated areas. Orhon et al. (2002) recommended the use of existing baseline treatment systems augmented with innovative treatment processes, such as sequencing batch reactors, intermittent aeration, moving bed reactors and Biofilm-filter-sequencing batch reactors (BFSBR) to handle high tourist-related loadings. The BFSBR operates in stages as a moving bed, a fixed bed and a filter. During the SBR stages of filling and reacting, the moving bed is fluidized. In the settling and draw-down stages, the reactor becomes a fixed bed and filter.

Application of membrane microfiltration to chemically-enhanced primary treatment appears to offer significant advantages for discharging municipal wastewater to marine waters. The Orange County Sanitation District of California (near Los Angeles) operated a pilot plant of 200 gal/min (0.76 m^3/min) for nine months and reported excellent solids and bacterial removals with negligible evidence of long-term fouling of the membranes. The authors indicated the combination of chemically assisted primary treatment with microfiltration was more cost-effective than conventional activated sludge followed by chemical disinfection (Juby et al., 2003).

3.8.3 Summary

Most developed nations have implemented either long outfalls to deep water and/or secondary treatment to deal with common problems of bacterial levels, elevated nutrient concentrations, depleted dissolved oxygen levels, plastic floatable materials, and sediments with elevated levels of heavy metals, pesticides and other substances. Treatment of wastewater to secondary levels or higher offers environmental improvements in nutrient removal and reduced levels of potentially toxic substances, either dissolved or associated with suspended solids. Canadian coastal cities have not generally matched the tendency of other developed nations to move to secondary treatment, although there is some indication, such as with Charlottetown and Summerside in PEI, that this is changing.

3.9 Lagoon Systems

3.9.1 Lagoon Operation

An excellent resource for optimization of lagoon performance has been prepared by the National Guide to Sustainable Municipal Infrastructure (NGSMI, 2004). The manual discusses different types of lagoon facilities used in Canada, and discusses the methods for process optimization, including: operational and minor design changes that may improve mixing and flow patterns in lagoon cells; modifying the flow scheme of multi-cell lagoons; adding mechanical aeration equipment to augment natural oxygenation of the lagoon; adding chemicals to the lagoon to enhance settling and to remove phosphorus; and adding pre- or post-treatment processes to reduce lagoon loadings or to improve lagoon effluent quality.

The lagoon optimization manual recognizes that consistent ammonia removal on a year round basis may be the most significant challenges of lagoon operators, particularly facultative ponds. Among techniques recommended for optimization, addition of mechanical aeration equipment offers several advantages. Additional transfer of oxygen can help to maintain dissolved oxygen levels needed for nitrification to proceed, especially in warmer months when the solubility of dissolved oxygen in waters is lowest, and when biodegradation of organic carbon and nitrogen is fastest. Moreover, the mechanical aerators may help to prevent the water surface of lagoons from completely freezing over in winter, thus avoiding the common problem of hydrogen sulphide accumulation and release when the ice cover breaks up in spring. Mechanical aeration is not likely to significantly reduce ammonia concentrations in winter operation, however (NGSMI, 2004).

While continuously discharging lagoon effluents in summer may approach secondary effluent quality, lagoon effluents in mid-winter are reported to be of little better efficiency than primary treatment plants. Formation of an ice cover on lagoons results in deterioration of lagoon performance. The ice cover contributes to: (a) onset of anaerobic conditions within 2 to 3 days in an aerobic facultative system; (b) reduction in biological removal of organic material; (c) loss of disinfecting capability of sunlight (Townshend and Knoll, 1987). At break-up of the ice cover in spring, gases accumulated under the ice cover, especially hydrogen sulphide, are released. Installation and operation of static-tube aerators in winter has been demonstrated as an effective technology to prevent the formation of hydrogen sulphide by keeping the water surface above the aerators free of ice (Townshend and Knoll, 1987).

To overcome the above-noted limitations of lagoon operation, some municipalities in the Yukon have adopted over-sized lagoon cells followed by a large long-term unlined holding cell that percolates or is discharged to wetlands seasonally. The long-term cells are large and shallow to promote evaporation and maximize sunlight penetration (Truelson, 2006).

3.9.2 Lagoon Effluent Treatment

Removal of ammonia-nitrogen and other pollutants in lagoon effluents may also be accomplished using intermittent sand filtration (Melcer et al., 1995). The New Hamburg, ON facility uses aerated and polishing cells prior to the intermittent sand filters. The filters do not operate through the winter months but are typically started in early March. Development of nitrifying conditions is rapid, even at ambient March temperatures. For the filter operating period from March to December of 1990, the average ammonia-N concentration was 1.2 mg/L (Melcer et al., 1995), compared to the polishing cell ammonia concentration of 15 mg/L. In Canada, this polishing step would typically applied to batch discharge or semi-continuous discharge lagoons, as the filters are unable to operate when frozen it may not be applicable or restricted in northern operations. In addition to the reduction of ammonia-N, BOD and TSS concentrations are reduced to less than 2 mg/L, and effluent total phosphorus to 0.5 mg/L.

Use of intermittent sand filters for lagoon effluent in South Carolina has also resulted in high quality effluents. Concentrations of ammonia-N at two sites were reduced to 1.2 and 4.1 mg/L, when raw wastewater concentrations were approximately 52 mg/L at the two sites (Rich et al., 1995). Total suspended solids in the sand filter effluent were 6 and 4 mg/L at the two sites. Covering of filters to extend winter operation has been suggested. Covering of the filter may also reduce plant growth on the filter surface, thus reducing maintenance efforts (EPA, 1983). Because removal of ammonia in winter operation may be curtailed due to slower biological kinetic rates, upgrading of lagoon processes to mechanical treatment may become necessary if regulations require a reduced effluent ammonia-N concentration.

Removal of phosphorus in lagoons may be accomplished by continuous dosing (at the forcemain of the pumping station before the lagoon), or by batch chemical treatment with coagulants such as alum or iron salts (Townshend and Knoll, 1987). Batch treatment is conducted by metering the coagulant into the propeller wash of a motorboat equipped with coagulant storage tanks. Reduction of total phosphorus below 1 mg/L in lagoon effluents are achieved. With seasonal discharge lagoons, the coagulant treatment must take place after the ice cover has left the lagoon, and discharge must be extended over a period of 10 – 14 days to prevent excess discharge of BOD and TSS due to hydraulic turbulence.

Another technique suggested for upgrading lagoon effluents is aquaculture, primarily through algae or other vegetative biomass. Duckweed is one type of plant considered; water hyacinths have also been suggested, but because they are an invasive species, widespread application is discouraged (EPA, 1983). In northern Canada, natural wetlands treatment and harvesting of biomass such as duckweed have been suggested (Townshend and Knoll, 1987). Micro-strainers and dissolved air flotation units have been suggested for removal of algae from lagoon effluent (EPA, 1983). Land treatment (overland flow) of lagoon effluents has also been discussed (EPA, 1983).

De-sludging of lagoons is recommended to maintain sufficient volume for treatment and to prevent the development of foul odours from anaerobic decomposition on the lagoon bottom. Although the period between de-sludging operations may be less than 5 years, often it may be greater than 10 years. Use of chemical addition for phosphorus removal or solids settling will increase settled sludge volumes and hence increase the frequency of de-sludging operations (NGSMI, 2004).

3.9.3 Summary

Lagoon treatment is one of the most common methods of treatment for small communities across Canada. Most of the problems experienced in lagoon treatment are common to all locales. Toxic gases such as hydrogen sulphide accumulate under ice cover, and produce foul odours and potentially toxic effluents when the ice cover breaks up in spring. In winter, biological removal of ammonia is curtailed and may exceed regulatory limits. Technologies such as intermittent sand filters and static aerators may reduce some of these ammonia-related concerns. Long retention times and wetland treatment are also able to improve lagoon effluent quality.

3.10 Use of Alternative Technologies and Source Control Plans for Reduction of Flow Volumes to the Municipal Wastewater Treatment Facility

3.10.1 Source Control

Roof leaders and foundation drains or sump pumps can contribute significant quantities of extraneous water to sanitary sewers. The City of San Luis Obispo in California implemented a voluntary house lateral correction program in an attempt to reduce the quantity of I/I in the collection system. During wet weather events, the peak wet weather flow can reach 8 times the dry weather flow (Hix and Nance, 2001). Through a rebate program of 50 % of the cost up to a ceiling price of $1,000, the City had over 900 applications from homeowners seeking to participate in the program. No reduction in the rate of I/I as a result of the program was detectable. Another house lateral replacement program was implemented in Mobile, AL, where in certain older areas of the City, I/I contributed up to 70 % of the wastewater flow. Rather than a rebate incentive, financial penalties were imposed in Mobile for non-compliance when leaking sanitary laterals were discovered (O'Sullivan et al., 2001). The program has resulted in replacement of over 20,000 linear feet of private sewer laterals with an additional 10,000 ft identified for replacement.

3.10.2 New Technology

Implementation of new technology can significantly reduce the quantity of wastewater produced daily in homes, apartments and hotels. Low flush toilets were mandated in the U.S. in 1992 to produce a water volume of 1.6 gallons (6 L) per flush, rather than the standard volume of 3.5 gallons (EPA, 2000). The resulting volume of water saved for a household of four was 15,000 to 20,000 gallons per year. At one time, the City of Olympia Washington provided the low flush toilets free, but no longer does so (City of Olympia, 2005). During the giveaway program, however, over 6800 of the devices were distributed. As a result, Olympia estimates that the City saves over 50 million gallons of water produced and discharged as wastewater per year.

3.10.3 Water Reclamation and Reuse

Water reclamation and reuse is now a fact in water-deprived areas of the globe. To date only Windhoek in Namibia uses direct potable reuse of reclaimed wastewater (Lahnsteiner et al., 2002). The highly treated effluent is blended with other premium water sources for the finished product. For reduction of pathogens such as *Cryptosporidium* in the wastewater, multiple barriers are used, including ozonation, chlorination, enhanced coagulation, dissolved air flotation and membrane ultrafiltration. Dissolved organic substances are removed by the enhanced coagulation, ozonation, biologically active carbon, granular carbon adsorption and ultrafiltration processes.

Singapore is pursuing indirect potable reuse with the establishment of its NEWater (sic) facility, a 10,000 m^3/d advanced water reclamation plant using a dual–membrane (microfiltration and reverse osmosis) and UV light disinfection system (Singapore Expert Panel Review, 2002). The report notes that a number of facilities for indirect potable water reuse have been in operation in the U.S. for a number of years, including the facility known as Water Factory 21 in Orange County, CA, and at the Upper Occoquan Sewage Authority in Virginia, the 16,500 m^3/d Jackson Creek facility in Gwinnett County, GA and in Scottsdale, AZ.

3.10.4 Summary

Source control is a policy that can be adopted across Canada to reduce total wastewater flow. Programs can be provided that are either incentives (grants) or disincentives (financial penalties and fines). Improvements in domestic plumbing devices, (low-flush toilets, low-flow shower-heads) in new developments can significantly reduce wastewater volumes. Water reclamation is not practiced to any extent at this time in Canada, but with the apparent onset of global warming, the need to practice water reclamation and reuse appears inevitable, as it has already become well-entrenched in the in the southern U.S.

3.11 Aging Collection System Infrastructure

3.11.1 Assessment Resources

Infraguide Canada has established many excellent technical publications regarding municipal infrastructure planning and financing. A number of them will be discussed herein.

"Planning and Defining Municipal Infrastructure Needs" (Infraguide Canada, 2003b) is one of the first in the series. The report outlines the steps that should be taken by municipalities to define their infrastructure needs once a clear corporate vision has been established. The steps include: (a) strategic planning, i.e., development of an integrated vision and strategy; (b) identification of information and asset management; (c) building of public support and acceptance; (d) exploring new and innovative methods for continuous improvement; (e) prioritization, which involves development of weighting and ranking systems, linking of capital with operating and maintenance budgets during planning, and use of business case approaches. Illustrative examples are provided for a number of communities across Canada, including New Glasgow, NS, Caledon, ON, Winnipeg, MB, Okotoks, AB and Surrey, BC.

The extent of infrastructure renewal is often dependent on the ability of a community to support the infrastructure initiatives. The manual "Developing Levels of Service" (Infraguide, 2003c) outlines five processes that need to be implemented to define the level of infrastructure renewal undertaken by a community. The steps include: (a) understanding of assets by identification of existing number and type of infrastructure assets; (b) consultation and communication, either formally (meetings and hearings) or informally (e.g. surveys) with identified key stakeholders; (c) strategic alignment of efforts with corporate goals or legislative or regulatory requirements; (d) determination of community's risk tolerance (e.g. level of potable water treatment); and (e) financial considerations, which are typically based on user willingness to pay, unless mandated by regulatory requirements.

Management of infrastructure assets involves maintaining, operating and upgrading of the asset components. An asset management plan, as outlined in "Municipal Infrastructure Asset Management" (Infraguide Canada,2003d) should include: (a) valuation of the assets; (b) life cycle costing; (c) sustainability; (d) integration of technical and financial plans; (e) risk assessment; (f) performance measurement; and (g) high-level (long-term) and detailed (short-term) planning. The asset management plan is constructed using the following set of questions:

1. how is the achievement assessed? (policy objectives);
2. how are funding limitations dealt with? (priorities);
3. what are the assets and where are they? (inventory);
4. what are the assets worth? (costs and replacement rates);
5. what is the condition of the assets and the expected remaining service life? (condition and capability analysis);
6. what is the level of service expectation and the work that needs to be done? (capital and operating plans);
7. when do you need to do it? (capital and operating plans);
8. how much will it cost and what is the acceptable level of risk? (short- and long-term financial plans);
9. how do you ensure long-term affordability? (short- and long-term financial plans).

Use of dedicated (or "earmarked" fees) for wastewater and water infrastructure renewal are discussed in the manual "Dedicated Funding" (Infraguide Canada, 2004). Methods discussed include: full cost recovery using any of base cost billing, a levy on the water bill or a surcharge on the water bill for wastewater or stormwater; dedicated tax increments or property tax surcharges; and other methods such as local improvement charges, development charges or public-private partnerships. Examples of municipalities across Canada using these various models are cited in the manual (Infraguide Canada, 2004).

The Report on Assessment and Evaluation of Storm and Wastewater Collection Systems (InfraGuide Canada, 2004) outlines five tasks, including: a detailed inventory of the system attributes; investigation by visual, geometric, mechanical or geophysical means; assessment for structural integrity, functional integrity (service condition) and hydraulic capacity; performance evaluation of sewer system components to prioritize areas for renewal locations and candidate technologies; and the development of a rehabilitation and replacement plan.

3.11.2 Funding

Financing of aging infrastructure is a major issue in many Western nations. In Canada, a report commissioned by FCM examines a number of procedures for funding infrastructure renewal

(Zuker and Associates, 2004). Methods proposed include use of the full accrual accounting procedure; wise use of debt financing, and equity financing methods. Equity financing can include greater funding from senior levels of government (including either contributions to investment financing or contributions to cost recovery), full cost recovery based on economic rather than financial costs; and implementation of public-private partnerships (P3).

There are a number of potential federal funding initiatives for wastewater infrastructure renewal, including the Infrastructure Canada Program (ICP) a $2.05 billon program for environmental and local transportation upgrading that runs from 2000 – 2007 (Infrastructure Canada, 2005), the Green Municipal Investment Fund (GMIF, $100 million) and the Green Municipal Enabling Fund (GMEF, $ 25million). The GMIF and GMEF programs are administered by the FCM.

3.11.3 Summary

Canadian municipalities need to maintain their infrastructure to provide safe drinking water and proper sanitation. In Ontario alone, the investment required to return Ontario's current water and wastewater systems to a state of good repair – and maintain that condition for the indefinite future – is estimated to be between $30 and $40 billion over the next 15 years (Water Strategy Expert Panel, 2005). Other provinces are faced with similar challenges. There are many best practices provided by Infraguide Canada that municipalities can use to understand the condition of their infrastructure and take the necessary measures to attack the problem.

3.12 Wastewater Treatment Facility Performance Monitoring and Quality Control Practices

3.12.1 Benchmarking Practices

A number of Canadian initiatives in benchmarking were discussed by Robertshaw and Himanen (2003). Programs of national interest discussed in their paper included the National Water and Wastewater Benchmarking Initiative, which involves quantitative performance measurement with exchange of information and networking between participating municipalities; and the National Guide to Municipal Infrastructure, a program funded by the Infrastructure Canada Program and implemented by the Federation of Canadian Municipalities in collaboration with the National Research Council. Best Practices are developed for wastewater and stormwater, along with other areas such as decision-making, potable water, and municipal roads and sidewalks. Many of these guides have been referenced in earlier discussions of this report.

Qualserve is a voluntary program developed by the American Water Works Association (2005) to promote continuous improvement in water and wastewater utilities. The three elements of the Qualserve program include an initial self-assessment, followed by a peer review, and lastly by benchmarking facility operations against the experiences and practices of other utilities.

The Water Environment Research Foundation (1997) has published a report on benchmarking practices in wastewater treatment. The report, titled "Benchmarking Wastewater Operations: Collection, Treatment, and Biosolids Management", describes the benchmarking process as a systematic process of searching for best practices, innovative ideas, and highly effective operating procedures that lead to superior performance and then applying those practices, ideas, and procedures to enhance the performance of one's own organization.

3.12.2 Quality Management and Performance

In Ontario, the Regional Municipality of Peel has a Total Water Quality Management Plan in place for drinking water quality and treatment. Peel Region's operating authority, the Ontario Clean Water Agency, was accredited to the ISO 14001 environmental management system at the Lakeview water treatment plant in May 1998 (OCWA, 2003). While the Lakeview plant produces potable water rather than treating wastewater, the procedures for certification in ISO 14001 are applicable to wastewater treatment facilities as well as potable water plants.

The O&M Division of the City of San Diego, CA's Metropolitan Wastewater Department was the first in the U.S. in 1999 to receive ISO 14001 certification. The City adopted the procedures of ISO 14001 to compete with private firms seeking to run the wastewater treatment facilities (Daigger et al., 2001). The certification applies to a water reclamation plant, wastewater treatment plant, biosolids center, and pumping stations.

The ISO 14001 requirements for continual improvement and internal education have resulted in improved operations and the cost-competitive edge that was initially responsible for adoption of the program. Reported benefits to San Diego's O&M Division include (Daigger et al., 2001):

- improved emergency preparedness,
- greater proof of responsibility toward the customers through improved record-keeping,
- transparency of procedures,
- mechanisms for identifying nonconformance and constructive change,
- avoided cost through risk reduction,
- plant process optimization, and
- reductions in energy use and miscellaneous chemicals.

The City of Shelby, NC attained ISO 14001 certification in June 2002 for its 6 MGD (23,000 m^3/d) wastewater treatment plant (NC DENR, 2003). Reported costs included approximately $25,000US for implementation of the program and $13,500US for actual certification. The estimate of labour to implement the program was 1,150 hours of staff time. Shelby also reported many benefits for moving to the environmental management system of ISO 14001, such as, (a) improved internal teamwork and communication; (b) improved public perception; (c) more effective training and documentation of training; (d) increased efficiency in managing environmental obligations; and (e) better focus on environmental objectives (NC DENR, 2003).

Other sites in the U.S. that have become certified in ISO 14001 include Lowell, MA, Gastonia, NC, Eugene, OR and Charleston, SC (EPA 2001). Funding for development of the Environmental Management System can be eligible for use of the State Revolving Fund for capital projects, provided that the EMS is part of the construction modification or expansion of the wastewater treatment facility.

3.12.3 Data Management

Treatment of municipal wastewater is one of many services provided by municipal governments for their citizens. Keeping track of various sources of municipal data is becoming a challenge, for making timely and informed decisions based on recovery of all information pertinent to an emergency response, a long-range project, study, a citizen request for information, or various other needs. InfraGuide Canada has published a Best Management Practices manual for Utility-Based Data (InfraGuide Canada, 2003e). The manual makes the case that the first step for managing utility data is to establish all the various business requirements of the municipal government, then to evaluate the types of software programs that are available to best handle the business requirements.

According to the Data management guide, the initial step is to establish a documented data model or data structure that can be used throughout the effort. This step is followed by collection of all the different types of data to be incorporated into the management system. Data categories include: (a) municipal assets, with information on number condition, location, performance, etc., (b) O&M data, (c) financial data, (d) meteorological data, (e) environmental data, and (e) customer data (InfraGuide Canada, 2003e). Wastewater treatment plant data in this organization would be included in the environmental data, and might include topics such as effluent quality requirements, raw wastewater and final treated effluent concentration data, biosolids quantity and concentration data, industrial discharge data and information on number of bypass events, volumes of bypasses and quality. When the various types of data for management have been identified, then the type of computer application to support the data uses, such as a geographical information system (GIS) or computerized maintenance management program (CMMP), may be selected.

3.12.4 Summary

Benchmarking is a procedure that Canadian municipalities can conduct on their own through voluntary programs such as Qualserve, offered by the American Water Works Association. Adoption of ISO Certification by Canadian wastewater treatment facilities is in its infancy. There is a growing trend in the U.S. for this level of environmental management. Municipalities that have become certified as ISO 14001 compliant indicate that many advantages result.

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