CANADA'S CHALLENGES AND OPPORTUNITIES TO ADDRESS CONTAMINANTS IN WASTEWATER

National Expert Panel Report

March 2018

Canadian Water Network

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This report was prepared by a national expert panel, which was convened to conduct a national review of contaminants in municipal wastewater and Canada's options to deal with them. The report is based on information gathered through a series of expert working sessions from October 2017 to February 2018 and a national questionnaire.

Canadian Water Network thanks the panelists for this important work and for generously contributing their time, expertise and leadership.

Donald Mavinic (Chair), Professor, Civil Engineering, University of British Columbia

Susheel Arora, Director of Wastewater and Stormwater Services, Halifax Water

Cecelia Brooks, Director of Research and Indigenous Knowledge, Mi'gmawe'l Tplu'taqnn; Water Grandmother, Canadian Rivers Institute

Yves Comeau, Professor, Civil, Geological and Mining Engineering, Polytechnique Montréal

Mike Darbyshire, General Manager, Alberta Capital Region Wastewater Commission

Karen Kidd, Steven A. Jarislowsky Chair in Environment and Health, McMaster University

Theresa McClenaghan, Executive Director, Canadian Environmental Law Association

Mark Servos, Canada Research Chair in Water Quality Protection, University of Waterloo

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Acronyms and Abbreviations

AOP	Advanced oxidation process
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
$CBOD_5$	Carbonaceous biochemical oxygen-demand, based on 5-day test
CCME	Canadian Council of Ministers of the Environment
CEC	Contaminant of emerging concern
CEPA	Canadian Environmental Protection Act
CSO	Combined sewer overflow
E.U.	European Union
GHG	Greenhouse gas
IFAS	Integrated fixed-film activated sludge
MBR	Membrane bioreactor
NPRI	National Pollutant Release Inventory
PAH	Polycyclic aromatic hydrocarbon
PBDE	Polybrominated diphenyl ether
PCB	Polychlorinated biphenyl
PCDD	Polychlorinated dibenzo-p-dioxin
PPCPs	Pharmaceuticals and personal care products
TSS	Total suspended solids
U.S.	United States
UV	Ultraviolet
WRRF	Water resource recovery facility
WSER	Wastewater Systems Effluent Regulations
WWTP	Wastewater treatment plant

Preface

Canadian Water Network and Environment and Climate Change Canada share a common objective of advancing knowledge that contributes to the management of harmful substances in wastewater, including identifying the most effective wastewater treatment investments, policies and practices. In October 2017, with $400,000 in financial support from Environment and Climate Change Canada, Canadian Water Network embarked on a national review of contaminants in municipal wastewater and Canada's options to deal with them. The project leveraged its national network of research and practitioner communities to consider the following critical questions:

- Which wastewater contaminants do we need to worry about most, now and in the future?
- What are the options for Canadian communities to address these contaminants through wastewater treatment?
- What are the important opportunities and trade-offs involved in treatment choices, including resource recovery, cost implications, socio-economic and cultural fit, and related issues like greenhouse gas emissions?

A national expert panel, with a strong collective understanding of the knowledge and practice base in wastewater treatment and impacts, was established to guide the process. The panel's deliberations were augmented with information and case studies from other Canadian experts with knowledge of municipal wastewater practice, environmental impacts and assessments associated with wastewater, and legal and community perspectives through a series of expert working sessions and a national questionnaire.

This report was prepared by the expert panel to provide critical insights that can inform and empower decision makers and stakeholders to choose the most effective wastewater treatment investments, policies and practices. In this culminating report, the expert panel:

- Identifies where wastewater treatment represents a particularly effective approach to protecting human health and the environment
- Articulates key opportunities and implications for future wastewater treatment in Canada
- Provides a blueprint to inform government policy, regulations and funding

Within the report, the term *contaminant* has been used to capture pathogens, nutrients, metals, chemicals and physical constituents generated or concentrated by society, which can potentially pose adverse effects on receiving environments and public health.

C*ontaminants of emerging concern* refers to non-conventional contaminants that have been, or will be, detected in wastewater effluents, and for which the potential risks to public and environmental health are not yet fully understood. These contaminants have also been referred to in various sources as emerging contaminants, emerging substances of concern, trace contaminants, micropollutants or microcontaminants.

Trace organic contaminants refers to the diverse array of organic substances found in wastewater effluents at low concentrations, including endocrine disrupting compounds, pharmaceuticals and personal care products. Although some trace organic contaminants may be contaminants of emerging concern, the latter group also captures other new and uncertain substances, such as microplastics and nanoparticles.

Wastewater treatment plant (WWTP) is used in this report, although this term is being replaced in some jurisdictions with *water resource recovery facility (WRRF)*, in recognition of a more holistic approach to urban water management. Municipal WWTP refers to a local or regional government or utility, or provincial or Indigenous-owned facility which receives collected wastewater for treatment and release into the environment.

For additional definitions of terminology used in this report, please refer to the glossary in Appendix 1.

Executive Summary

Effective management of our wastewater is critical for Canadians across the country, in both large and small communities. The advances that Canada has made in wastewater management are part of an important success story in protecting human health and the environment. The challenge moving forward is to meet the growing complexity of wastes generated by our society. Canada must consider how to make strategic investments that maximize the benefits to society and the environment and prepare our wastewater systems to address the uncertainties of the future.

The current picture of wastewater management in Canada is highly varied. It reflects more than a century of developing solutions to local waste management needs in very different settings. Moving forward, we are faced with an increasingly complex array of chemicals that find their way into wastewater, raising both concerns and uncertainty about the nature of their impacts. Despite our incomplete knowledge about the current and future risks confronting us with respect to wastewater, we cannot suspend decision making. Decision makers need to act now.

As municipalities and utilities invest in wastewater systems that will be locked-in for decades, the questions being asked are not only, "What are we required to do?" but also, "What makes sense to do now?" Moving forward involves making the best evidence-informed decisions we can, weighing the costs and benefits of those choices to our communities and the environment, and continuing to adapt as science and our understanding advances. To support decision makers in addressing the questions and concerns that Canadians have about the adequacy of our wastewater systems, Canadian Water Network convened a national expert panel. The panel's task was to assess where we are and how Canada can maximize benefits and minimize the risks to society and the environment through investments in wastewater infrastructure.

Key Findings

Through its research, discussions and outreach to national experts across Canada, the panel identified several important key messages related to Canada's wastewater treatment needs:

- A risk-based management approach, based on a commitment to environmental monitoring and adaptive management, is required to address the multiple concerns and uncertainties now being faced by the wastewater industry.

- Wastewater management should be embedded in an integrated watershed approach that considers source control as an important component, within a multi-barrier approach to addressing risk.

- Although regulatory standards provide a base to build from, policies, practices, technologies and other solutions that make sense for a community and provide additional benefits for society and the environment should be incented and rewarded.

- Canada needs to develop a clearer picture of its national wastewater sector, including sewer separation practices.

- Selection of best wastewater management solutions that protect human health and environmental services must be driven by Canada's diversity of geographic and cultural settings.

- Innovations that help to reduce multiple or uncertain risks, while improving overall societal and environmental outcomes by delivering co-benefits, should be encouraged and incented.

- There is a need for active and integrated research and technology transfer to support science-informed decision making in wastewater management. Environmental monitoring is needed to assess effects, as well as to determine whether management actions are achieving sustainable environmental benefits.

Answering the Big Questions

Which wastewater contaminants do we need to worry about most, now and in the future?

Removal of organic matter and pathogens remains a critical objective of wastewater treatment and vigilance is needed to ensure we address this in all locations and not just in large urban centers. Nutrients are a known issue and require monitoring to determine where additional reductions from wastewater sources are needed. The science is sufficient to indicate that some contaminants of emerging concern (CECs), such as estrogens (endocrine disruptors), may represent a meaningful risk to the environment and that well-operated, conventional treatment can help reduce environmental exposures. For the majority of the long list of CECs, the reality is that science has not yet established which CECs are the "most important" contaminants. As a result, informed decisions on actions need to be guided by a risk-based framework.

What are the options for our diverse Canadian communities to address these contaminants through wastewater treatment?

There are established and evolving technologies to address conventional and known contaminants. It makes sense to leverage what we know about these technologies to identify where optimizing their use will also likely provide risk reduction of CECs. When making upgrade investments to meet stricter effluent standards or increase capacity, there are strong opportunities to optimize existing processes and retrofit with improved technologies that can achieve co-benefits. Treatment represents only one element of wastewater management and the effectiveness of other options like source control, sewer separation and the use of non-technology options should also be given strong consideration.

What are the important opportunities and trade-offs involved in the treatment choices, including resource recovery, costs, socio-economic and cultural fit, and implications for related issues like greenhouse gas emissions?

Increased treatment incurs not only greater financial costs, but can also involve other trade-offs through increased energy footprint, or the transfer of risk through residuals management. This heightens the importance of capturing a broader set of societal and environmental considerations. Such considerations include adaptability, applications of the precautionary principle, resilience, socio-economics, cultural needs and emerging risks, as well as opportunities to achieve important co-benefits (e.g., resource recovery). The environmental benefits of reductions in energy use and GHG emissions through optimizing existing processes, using innovative technologies or solutions, should be prioritized and incentivized. Inevitably, the "future-ready" approach that should be encouraged is the one that will make the most sense for each unique geographic, cultural and environmental setting and is cost-effective and sustainable.

A Blueprint for Federal Action

Given that major infrastructure expenditures have long-term implications, we need to make smart and strategic investment decisions now. Sufficiently stringent regulatory requirements that establish minimum standards must be combined with conditions that support on-site innovations to ensure that our systems can meet the needs of the future as well as today. The following recommendations to the federal government provide a blueprint for how Canada can move forward effectively:

1. Work with all stakeholders (provincial, territorial, local and Indigenous rights holders) to continue to apply and further develop an effective risk management approach to deal with the complexity and changing nature of chemical mixtures in wastewater and their observed effects in the environment and on human health. The precautionary principle approach, based on best science and Indigenous knowledge, and inclusive of uncertainty and adaptive management, would be core to this work.

2. Establish a coordinated and meaningful national system of collecting, assessing and sharing data on wastewater treatment among municipalities and utilities in Canada. Consider re-establishing something similar to the Municipal Water and Wastewater Survey, with Indigenous input, as well as a nationally accessible database. Effective collaboration between provinces, territories, Indigenous and the federal government is required to build this database.

3. Incent and reward innovation to move beyond current minimum regulatory standards, thus continuing to minimize risk and maximize benefits for society and the environment. Encourage an assessment of new or amended treatment technologies, using research and pilot testing, to generate a menu of solutions to guide investment decisions. This would

include a compendium of key examples focused on how co-benefits can be derived from optimization and innovation in wastewater management. These actions would support Canada's infrastructure program for wastewater system upgrades, including resource recovery.

4. Support a site-specific, risk-based receiving environment approach to regulations, monitoring and water quality objectives. This would also incentivize jurisdictions to develop source water protection programs that include sewershed protection plans and prioritize options for source control. Recognize where keeping contaminants out of systems is more effective than trying to remove them from wastewater through treatment.

5. Embed wastewater management considerations, wherever possible, within an integrated watershed approach to water management and governance, including the possibility of water quality trading. In addition to source control, other non-technical opportunities could be considered to address and reduce risk to local communities and the environment.

6. Coordinate investment in science and Indigenous knowledge-based research and technology transfer to improve the understanding of risks and recognize meaningful co-benefits (e.g., Centres of excellence, data dissemination, success/failure case studies, pilot plant studies, coordination of research, process certification). This initiative will be challenging, but is much needed, and must be spearheaded by the federal government and Indigenous governments across Canada.

7. Develop a federal initiative to require a future-ready strategic planning document as a condition for immediate and long-term funding, with input from all stakeholders as well as consideration of resource recovery and implementation timelines. This will support the funding of proven and promising technology and the flexibility to choose community-tailored solutions that are appropriate, robust and will have the greatest beneficial impact.

1. Introduction

> Canada must consider how to maximize benefits and minimize risks to society through its investments in wastewater treatment.

As a nation, we are facing complex challenges in addressing the wastewater generated by modern society. Our wastewater includes human organic wastes, as well as a multitude of chemicals that make their way into Canada's waterways and may negatively impact the environment, public health and the economy. The challenges of addressing these potential threats will continue to grow, and meeting these challenges will require municipal, provincial and federal governments to carefully consider how to minimize harm, while also leveraging opportunities to achieve benefits and maximize investment in public systems.

Many experts involved in the design, management, research and regulation of wastewater systems are questioning whether current treatment practices, and the existing regulations and water quality standards that shape them, are adequate to meet future environmental and public health needs. Across Canada, wastewater treatment conditions and performance differ considerably, even with regard to addressing conventional pollutants. Although major treatment advances have been made in many communities, there are still places in Canada that are practicing only minimal treatment and are in need of upgrades to meet upcoming deadlines for new national minimum standards.

Large planned and future investments provide a catalyst to carefully consider how to address Canada's changing needs and equip communities to meet future demands and challenges. Our communities are very different than they were when most wastewater systems were initially designed and built. These public systems must now address a broader set of contaminant concerns, as well as issues beyond contaminant risks, such as the increasing importance of energy conservation, greenhouse gas emissions, and resource recovery.

Canadian Water Network and Environment and Climate Change Canada share a common objective of advancing knowledge that contributes to the management of harmful substances in wastewater, including identifying the most effective wastewater treatment investments, policies and practices. Supported by a $400,000 contribution from Environment and Climate Change Canada, Canadian Water Network undertook an expert panel process to provide a forward-looking consideration of how Canada can maximize investment and benefits while minimizing risks to society and the environment.

2. Project Methodology

> To make effective decisions, we need a clear picture of Canada's management of contaminants in wastewater that includes what we know and don't know, and the best options to move forward.

In October 2017, Canadian Water Network convened a national expert panel. The panel was chaired by Dr. Donald Mavinic from the University of British Columbia and included eight leading experts in municipal wastewater treatment, the impacts of wastewater contaminants, environmental and ecosystem impacts, wastewater resource recovery, and the broader legal and socio-economic implications of wastewater effluent discharges (Appendix 2). In order to develop insights to inform strategic wastewater investments and future policies and practices regarding contaminants in wastewater, the panel considered the following core questions:

- Which wastewater contaminants do we need to worry about most, now and in the future?
- What are the options for Canadian communities to address these contaminants through wastewater treatment?
- What are the important opportunities and trade-offs involved in treatment choices, including resource recovery, cost implications, socio-economic and cultural fit, and related issues like greenhouse gas emissions?

Eighteen additional experts participated in working sessions with the national panel on October 25, 2017 in Vancouver; December 11-12, 2017 in Toronto; January 16-17, 2018 in Winnipeg; and January 31 to February 1, 2018 in Montreal (Appendix 3). The experts were asked to share their perspectives on a wide range of geographic and topic areas, including regulations, municipal wastewater practice, contaminants of emerging concern (CECs) in wastewater, environmental impacts associated with wastewater, legal and community perspectives, and treatment technologies.

Broader input was obtained through an online questionnaire that was completed by 78 experts representing a broad range of perspectives and sectors from all geographic regions of Canada. Canadian Water Network worked with the expert panel to develop the questionnaire, which was structured to provide input on the core questions being considered.

In addition to the four working sessions and national questionnaire, the expert panel was supported in its work through the preparation of high-level literature scans in key areas of relevance for their discussion, which are summarized in four supporting documents:

- Supporting Document 1 – National Questionnaire Results Summary
- Supporting Document 2 – Wastewater Treatment Practice and Regulations in Canada
- Supporting Document 3 – Contaminants in Municipal Wastewater Effluents
- Supporting Document 4 – Technology Scan for Wastewater Treatment

This culminating report was prepared by the panel based on this collective knowledge and presents a blueprint for moving forward.

3. Wastewater Treatment in Canada

Municipal wastewater treatment plants (WWTPs) serve as a core element of public systems that protect human health and the environment from the contaminants we produce. They were initially designed to deal primarily with human organic wastes, but in recent years, there has been an expansion in focus to include additional contaminants that are introduced to the environment through wastewater.

> Municipal wastewater management is critical to all Canadians, and overall it represents a success story on which Canada should build.

In the past, domestic wastes were collected and conveyed to nearby rivers, lakes or oceans to be flushed away. Separating our communities from waste, with water as the vehicle, is a sanitary engineering paradigm that remains entrenched in modern municipal wastewater management. Treatment of municipal wastewater began in the 20th century, primarily in response to the impairment of aquatic ecosystems by organics or acutely toxic impacts. The removal of much of the organic load introduced the need for solids (sludge) management that remains a core element of wastewater engineering. Treatment approaches were further refined in response to identified public or environmental threats, such as pathogens and metals, or the need to further reduce nutrients. In recent decades, as a result of significant urbanization and advancements in analytical capabilities, many additional chemical, microbial and physical elements have been identified in domestic wastewaters. This has significantly widened the considerations of what wastewater management should address and what approach is needed to deal effectively with a rapidly lengthening list of potential concerns.

3.1 A brief history of wastewater treatment

> The current paradigm of wastewater management reflects more than a century of development of engineered systems to safely convey wastes away from our communities and treat problems that resulted from adding human wastes to surface waters.

The advent of municipal wastewater management was driven by the need to address the problem of human and domestic waste in communities. Sanitation improvements through wastewater management and treatment, along with the treatment and disinfection of drinking water supplies, played a key role in public health protection. These improvements are widely regarded as two of the most successful public health interventions in the last century.

1800s: Introduction of the Sanitary Sewer and Municipal Wastewater Management

- The rapid growth of industrialized cities led to the accumulation and disposal of human, domestic and other wastes via gutters and drains.
- Pollution in nearby water bodies led to untenable living conditions (e.g., "The Great Stink" of 1858 in the Thames River in London).
- Cities began to build sanitary sewage collection systems, using water as the main vehicle to remove wastes and discharge them into nearby surface water.
- Louis Pasteur's germ theory (i.e., recognition that exposure to pathogens, such as those in human wastes and waste-impacted water, spread diseases like typhoid, dysentery and cholera) became widely accepted.

Early 20th Century: The Advent of Municipal Wastewater Treatment

- Cities around the world were coming to terms with the need to develop both sanitary systems and drinking water treatment to address health risks.
- Growing populations and the increasing use of flush toilets further enabled direct delivery of human waste to receiving waters in larger quantities, causing major oxygen depletion and impairment of aquatic systems.
- Gravity settling (primary treatment) was used to physically remove solids from wastewater prior to discharge. This created sludge as a by-product of treatment.

- The partial removal of organics did not restore environmental health in areas where dilution by receiving waters was insufficient to deal with the remaining dissolved and suspended organic load.
- Recommendations from a Royal Commission in the United Kingdom led to the concept of measuring biochemical oxygen demand (BOD) of wastewater effluents.
- Biological activated sludge (secondary treatment) was developed in the United Kingdom and represented a major milestone in the evolution of wastewater treatment. Microorganisms were used to degrade organic material that was dissolved or suspended in wastewater.
- The addition of activated sludge treatment introduced the need for aeration (i.e., the addition of air to wastewater and sludge) to encourage microbes to degrade dissolved and organic materials.

Mid-20th Century: Recognition of Additional Chemical Issues + Increasing Focus on Nutrients

- Although secondary treatment was adopted by some cities in Canada as early as the 1920s (City of Guelph, 2003), by mid-century many systems were still relying on dilution in receiving waters as a principle method, discharging directly into water bodies with little or no treatment. In 1951, 80% of all wastewater in Canada was discharged into receiving waters without any treatment (Society Notes, 2017).
- In the second half of the 20th century, upgrades to secondary treatment became common in areas discharging to inland waters. For example, Winnipeg upgraded to secondary treatment in 1964 (City of Winnipeg, 2016), Calgary and Hamilton upgraded in the early 1970s (City of Calgary, 2010; Hamilton Public Works, n.d.), and Ottawa performed upgrades between 1988 and 1993 (City of Ottawa, n.d.).
- In the early 1970s, phosphorus was identified as the key limiting nutrient causing eutrophication (Schindler, 1974), which led to the reformulation of laundry detergents.
- Following the Great Lakes Water Quality Agreement in 1972, Ontario began upgrading all wastewater plants. WWTPs in eastern Canada began to implement chemical precipitation methods to achieve phosphorus reductions.
- In the 1980s, biological nutrient removal (BNR), which increases the removal of nutrients beyond conventional secondary treatment, was imported to British Columbia (Case Study #1).
- Disinfection of final effluents to address persisting pathogens via chlorine-based compounds, or more recently using ozone or ultraviolet (UV) light, was also applied to some treatment systems to reduce pathogen risks.

Late-20th Century to Today: Emergence of New Concerns & Technologies + Resource Recovery

- Concurrent with a rapid growth in analytical capabilities, numerous individual contaminants have been detected in wastewater, receiving waters, and aquatic organisms and sediments.
- The introduction of federal regulations for wastewater effluents will result in continued upgrades to secondary treatment, especially in small communities and coastal locations.
- Advanced treatment technologies have been adopted in several WWTPs across Canada, such as cogeneration (e.g., Vancouver, Lethbridge, and Hamilton), phosphorus recovery (e.g., Saskatoon), anaerobic ammonia oxidation (e.g., Guelph) and MBRs (e.g., London).

Wastewater management in Canada initially focused on separating wastewater from people, and then on conventional targets such as the removal of debris, organic carbon compounds, and acute threats to human or ecosystem health. With the identification of significant risks from other wastewater constituents such as nutrients, metals, legacy contaminants and endocrine disruptors, more advanced treatment processes have been developed, with varied adoption across Canada and at the discretion of provincial authorities. More recent considerations include a long list of contaminants, often detected at trace levels. These potential concerns, combined with an increasing focus on resource recovery, are driving discussion on whether augmenting existing treatment systems or the application of new technologies or approaches can sustainably address Canada's environmental and public health needs.

CASE STUDY #1

The Advent of Biological Nutrient Removal in Canada's West

In the early 1980s, an advanced wastewater treatment plant (WWTP) was designed and constructed in Kelowna, British Columbia. This was the first plant in North America to employ a biological nutrient removal (BNR) process, especially phosphorus and nitrogen, under varying liquid temperatures. The technology was pioneered by James Barnard from South Africa. Bill Oldham, Professor Emeritus at the University of British Columbia (UBC), joined forces with Dr. Barnard, and with the help of the federal government, they built the first BNR pilot plant in North America on the UBC campus. Oldham's research team focused heavily on nitrogen and phosphorus removal under cold liquid temperature. Their database became the design criteria for the Kelowna WWTP. Following the WWTP's operational success, especially low effluent nitrogen and phosphorus levels, and concomitant with the Okanagan Basin Watershed Study (which confirmed the sensitivity of the Okanagan Basin to excess phosphorus loading) BNR technology expanded from British Columbia's Shuswap region down to the Canada-U.S. border. Eventually, this approach to nutrient control also spread to Alberta, Saskatchewan and Manitoba.

Contributed by Dr. Donald Mavinic, University of British Columbia.

3.2 Wastewater treatment approaches and regulations

In Canada, the evolution of wastewater treatment has resulted in a wide range of approaches across the country — from little to no treatment, to advanced systems.

Canada's approach to wastewater, similar to that in most countries, uses water to flush human excreta, domestic and some commercial wastes, resulting in a bulk liquid waste that is collected, treated and discharged into receiving waters. Depending on location, this may be fresh, brackish or marine waters. Wastewater treatment processes are generally designed as a single-pass process for managing discharged effluent and the sludge produced through treatment, although recovery of water or other resources (such as energy and nutrients) may be practiced in some advanced systems. There is considerable variation in the levels of treatment applied across the country.

According to the most recent Municipal Water and Wastewater Survey (MWWS; based on data from 2009), approximately 87% of Canada's population is served by sewerage connected to some type of wastewater treatment, and this proportion has remained stable since the late 1980s (Environment Canada, 2011). The remaining population is served by septic systems (12%) or sewage haulage (0.5%). The most common form of treatment is secondary mechanical (~55%) and 7% of the population receive secondary treatment in waste stabilization ponds (WSPs), also known as lagoons (Figure 1). Approximately 17% of the population receives tertiary-level treatment; 18% receives primary treatment; and 3% receives no or preliminary wastewater treatment, such as screening and grit removal. In the MWWS survey, treatment levels are self-reported, and therefore some variation exists within broad treatment categories. Recent federal legislation requires most wastewater treatment systems in Canada to achieve secondary treatment, so existing levels of wastewater treatment are likely higher than those recorded in 2009. The MWWS survey did not include data on Indigenous communities, but other assessments have indicated that many of these wastewater treatment systems discharge effluent that is insufficiently treated and poses health and safety concerns (Department of Indian and Northern Affairs, 2011).

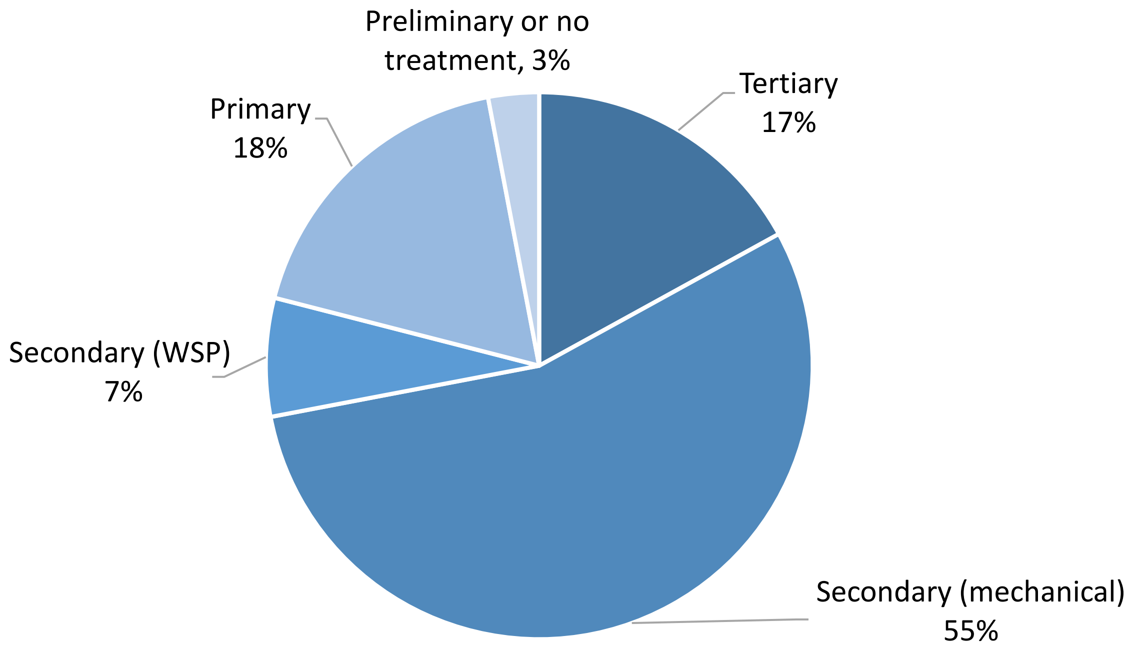

Figure 1. Levels of wastewater treatment across Canada for the population served by sewers. Data were obtained from the 2011 Municipal Water Use Report (Environment Canada, 2011), based on 2009 data collected in the Municipal Water and Wastewater Survey.

In Canada, large and densely populated areas tend to have higher levels of treatment than sparsely populated regions, and areas discharging wastewater effluent to inland waters typically have higher levels of wastewater treatment than those discharging to marine waters or large rivers flowing directly to the coast (Environment Canada, 2011; Holeton et al., 2011). For example, <50% of the population is served with secondary treatment in Québec and the Atlantic provinces, while >90% are served with at least secondary wastewater treatment in Ontario and Manitoba. Moreover, where access to large bodies of water is limited and demands on water resources are highest, there is typically a high level of wastewater treatment. For example, the Prairie provinces have the highest water use per unit of streamflow (Statistics Canada, 2009) and most major cities in the prairies provide tertiary treatment of wastewater effluents using BNR technology. Across Canada, lagoon systems are used by smaller communities (e.g., <3000 residents) and are numerically more abundant than mechanical treatment systems (Oleszkiewicz et al., 2015).

3.2.1 Federal legislation

The Fisheries Act is the primary federal tool to control the environmental impacts of wastewater release. The pollution prevention provisions of the Fisheries Act, which are administered and enforced by Environment and Climate Change Canada, prohibit the deposition of deleterious substances in water frequented by fish, unless authorized by regulations. Under this Act, the first national standards for wastewater treatment were established. The Wastewater Systems Effluent Regulations (WSER; SOR/2012-139; Government of Canada, 2012) establish baseline municipal effluent quality standards and include limits for:

- Suspended solids
- Carbonaceous biochemical oxygen-demand
- Total residual chlorine
- Un-ionized ammonia

In addition, wastewater effluents must not be acutely toxic at the point of discharge based on a 96-hour acute toxicity test for rainbow trout. Specific requirements for effluent monitoring, record-keeping and reporting are specified in the WSER. These federal regulations do not apply to wastewater systems that collect an average daily volume of <100 m^3, or to wastewater systems located in the Northwest Territories, Nunavut, and north of the 54th parallel in Québec or Newfoundland and Labrador.

The WSER came into force in June 2012, with the effluent quality standards coming into force on January 1, 2015 (Government of Canada, 2012). Wastewater treatment systems not meeting the standards could apply for a transitional authorization to continue discharging effluent, but must upgrade by the end of 2020, 2030, or 2040, depending on the risk imposed on receiving waters by effluent. In cases where provincial or territorial wastewater regulations are deemed to be equivalent to the WSER, a bilateral equivalency agreement may be established. Bilateral administrative agreements may also be established under WSER, which establish a single window approach for the administration of the regulations.

Federal implementation of the WSER arose from recommendations that were part of a national strategy designed and endorsed by the Canadian Council of Ministers of the Environment (CCME). The CCME strategy was intended to create a standardized approach to municipal wastewater management across Canada, to both harmonize wastewater reporting into a one-window approach, and to ensure a baseline level of environmental protection (CCME, 2009). In addition to establishing National Performance Standards and timelines for achieving them, the CCME strategy recommended compliance monitoring and reporting, and discussed an economic plan for associated upgrades. The strategy also encouraged reduction of pollutants at the source, and indicated that environmental monitoring at the watershed level was important to confirm that the environment was protected.

In addition to the Fisheries Act, the Canadian Environmental Protection Act (CEPA) is used to manage toxic substances, and can contribute to improved wastewater effluent quality by controlling the use of substances that are difficult to treat. CEPA requires wastewater treatment facilities that meet reporting requirements based on size and pollutant loads, to report certain discharges to the National Pollutant Release Inventory (NPRI), which tracks releases of several toxic substances associated with municipal wastewater (e.g., ammonia, chlorine and phosphorus). Data from the NPRI include pollutant releases for specified chemicals above certain thresholds to air, land and water (i.e., it is not specific to wastewater effluents) and is accessible to the public (Environment and Climate Change Canada, 2016). In addition, a federal Chemicals Management Plan (CMP) has been established under CEPA (Government of Canada, 2017a), which includes monitoring and surveillance of certain chemicals in wastewater in addition to a variety of environmental matrices, such as air, sediment and water. Twenty municipalities across Canada representing a range of WWTP facilities and geographic regions are involved in the CMP sampling program. The samples of wastewater and solids at various treatment stages are tested for conventional parameters and CMP priority substances, metals and trace organics. The results provide insight on the removal of various substances through a variety of treatment processes.

3.2.2 Regional perspectives

Provinces and devolved territories (i.e., Yukon and Northwest Territories) have the power to implement additional or more stringent requirements pertaining to wastewater effluents. As a result, there are varying wastewater regulations and practices across Canada. For example, Manitoba regulates total nitrogen loads, and British Columbia, Alberta, Manitoba and Ontario have requirements for total phosphorus on a province-wide or site-specific basis (Oleszkiewicz et al., 2015). Additional regulations may also apply to sensitive waters, such as stringent phosphorus limits (0.1 mg/L) for WWTPs discharging effluent to the Lake Simcoe watershed in Ontario. Details of provincial regulations are outlined in Supporting Document 2, with a focus on regulations that are supplementary to federal WSER requirements.

British Columbia

A wide variety of wastewater treatment levels exist in British Columbia, largely depending on the discharge location. BNR plants are common across the interior of British Columbia, but wastewater treatment levels tend to be lower along the coast. For example, Vancouver has three secondary-level plants and two primary-level plants. Metro Vancouver is upgrading the North Shore WWTP (formerly called Lion's Gate) from primary to conventional secondary. The Capital Regional District in Victoria currently has no treatment and discharges untreated wastewater via a deep ocean outfall, but is currently undertaking construction of a single advanced WWTP (with resource recovery).

Prairie Provinces

In Alberta, Saskatchewan and Manitoba, the majority of mid- to large-sized municipal WWTPs utilize BNR technology. Post-treatment also occurs in phosphorus resource recovery facilities in Saskatoon. Alberta regulations require a minimum of tertiary treatment (including phosphorus removal) for facilities serving populations >20,000 (Government of Alberta, 2013). Manitoba is the only province with province-wide regulations for total nitrogen (Manitoba, 2017). Across the prairies, facultative lagoons are common for small systems and numerically outnumber mechanical systems. Most of the wastewater effluent from Alberta, Saskatchewan and Manitoba ultimately drains to Lake Winnipeg, which has suffered significant eutrophication and algal blooms in recent years.

Ontario

In Ontario, most WWTPs use extended aeration with chemical precipitation of phosphorus using aluminum or iron salts. Nitrification is common, but most WWTPs do not attempt to remove total nitrogen. Phosphorus levels are regulated depending on the sensitivity of the receiving water, as assessed by an Environmental Compliance Approval process. Wastewater treatment facilities discharging to sensitive water bodies such as the Great Lakes and Lake Simcoe have more stringent limits. For example, WWTPs discharging effluent in the Lake Simcoe Watershed have phosphorus limits of 0.1 mg/L, which are the most stringent in the country (Oleszkiewicz et al., 2015).

Québec

In Québec, most small communities are served by aerated facultative lagoons for wastewater treatment. The introduction of the WSER resulted in stricter standards for several parameters, including carbonaceous biochemical oxygen-demand ($CBOD_5$) and total suspended solids (TSS), which will result in the need for significant upgrades to existing plants to achieve compliance. The Jean-R. Marcotte plant in Montreal is the second largest wastewater treatment plant in the world and receives 40% of all wastewater treated in the province of Québec. This plant currently uses alum or ferric salts for its chemically-enhanced primary treatment and is in the process of upgrading to include ozonation for disinfection and destruction of other trace organic contaminants.

Atlantic Provinces

The Atlantic Provinces primarily discharge wastewater effluents to marine waters and have traditionally had lower levels of secondary treatment than inland regions of Canada. For example, in 2009 approximately 50% of the population of Nova Scotia was connected to central treatment facilities, 45% were served by septic tanks, and 5% discharged untreated wastewater (Government of Nova Scotia, 2015). Several Atlantic communities have been issued transitional authorizations to extend the timeframe for meeting national standards. Because these communities have access to marine waters for effluent discharge, several are considered low-risk, although there are a few clusters that are considered medium- or high-risk. As a result of the WSER, New Brunswick has a bilateral administrative agreement in place with the federal government.

Northern Regions

Northern communities face several unique challenges in wastewater treatment because of the cold climate and the small size and remoteness of settlements (Case Study #2). Most employ lagoons or oxidation ponds for wastewater treatment, and some also use wetlands for seasonal polishing of effluents before discharge. WSER criteria are met in the Yukon, which has a bilateral equivalency agreement with the federal government (Government of Canada, 2016). However, the WSER do not currently apply to Nunavut, Northwest Territories or communities in Québec, Newfoundland and Labrador above the 54th parallel. These regions are excluded because the CCME strategy determined that careful consideration is needed to produce a viable means of improving the protection of human and environmental health through wastewater treatment (CCME, 2014). A Northern Working Group has been established to undertake research into factors that affect performance of wastewater facilities in northern conditions. In the interim, effluent quality requirements in existing water board authorizations continue to apply, in addition to the general prohibition of depositing deleterious substances in accordance with the federal Fisheries Act.

Indigenous Communities

Responsibilities for wastewater management in Indigenous communities south of 60 degrees are shared by Indigenous communities and the federal government, and wastewater systems that collect more than 100 m^3 are subject to the WSER. North of 60 degrees, some responsibilities have been devolved to territorial governments or Inuit and First Nations as part of land-claims settlements in the North (Government of Canada, 2018). In general, a wide disparity has existed in local governance capacity, regulatory framework, funding per capita and methods of wastewater treatment from one community to another. In a 2011 national assessment, the most common types of treatment methods were facultative lagoons, which are commonly employed in Ontario, Saskatchewan and Alberta, and municipal-type agreement systems, which are commonly employed in British Columbia, Yukon and Atlantic regions (INAC, 2011). Out of 532 wastewater systems across 418 First Nations communities (representing 112,836 homes), 54% of homes are connected to sewers, 8% are on a truck haul, 36% have individual wastewater systems (septic tanks) and 2% of homes (1,777) have no service at all (INAC, 2011). The 36% of homes with individual wastewater systems represents 40,803 homes, approximately 47% of which had operational concerns, and 20% of which had inappropriately-installed leaching beds, leading to surface discharge of septic waste (INAC, 2011). The absence of adequate wastewater infrastructure impedes the development of housing that is needed to address shortfall in First Nations, Metis and Inuit communities.

CASE STUDY #2

Evolving Wastewater Management in the North

Wastewater treatment in the North has evolved significantly over the last few decades. In the 1960s, Northerners began moving into more permanent centralized communities. Early on, basic approaches were employed for wastewater treatment, such as outhouses and "honey buckets." Any wastewater that was collected was dumped into designated ponds away from the community and treated passively through natural processes. Gradually, toilets and indoor plumbing were introduced and wastewater was collected in storage tanks below homes. Trucks were used to transport the waste from these tanks to centralized dumping areas. As communities grew, basic engineered wastewater facilities (typically lagoons) became more widely adopted. These basic facilities now comprise the majority of wastewater treatment technology used today.

A typical lagoon facility in the North has engineered gravel berms. The interior of some lagoons are lined with clay/plastic liners, while others make use of existing permafrost as an impervious layer. In some communities, natural wetlands are also used as a component of the wastewater treatment train. The window for treatment is fairly small, and mainly occurs over a few short months (i.e., June-August). At the end of the treatment season, lagoons are decanted, and wastewater is discharged to the receiving environment over the course of several weeks. Communities have largely adopted these passive systems because of challenges like extreme weather, lack of basic/supporting infrastructure and a limited number of trained operators. These challenges present substantial barriers for implementing many treatment technologies that are routinely used in southern jurisdictions. For this reason, overly stringent or prescriptive regulations that require mechanical treatment can hold significant impact and risk. In the past, mechanical treatment plants were used in some communities (e.g., Iqaluit), but numerous mechanical breakdowns and inconsistent operation led to system by-passes with little more than primary treatment before discharge.

Lagoons and wetlands have predominantly been seen as the technologies that are best-aligned with the realities of the North. There is a need for innovative approaches — both technological and regulatory — that are also socio-economically and culturally appropriate for Northern communities.

This case study is based on Christensen, 2015; Daley, 2017; Inuit Tapiriit Kanatami, 2008; Jamieson et al., 2015; Lam & Livingston, 2011; Rohner, 2016.

3.3 Comparing Canada to other jurisdictions

Canada's WSER standards regulate conventional wastewater contaminants and are intended to be achievable through secondary wastewater treatment or equivalent (Government of Canada, 2012, 2017b). The United States (U.S.) and the European Union (E.U.) also use secondary treatment as a minimum baseline for wastewater effluent, with similar concentrations for their BOD and TSS standards. Secondary treatment has been the minimum acceptable technology in the E.U. for 27 years, since the introduction of the Urban Waste Water Directive in 1991, while in the U.S., secondary treatment has been the minimum acceptable technology for 46 years, since the enactment of the Clean Water Act in 1972. Given that the WSER have only been in place in Canada since 2012 (with an implementation date of 2015), the advent of national standards in Canada requiring secondary treatment is very recent compared to the U.S. and E.U. Some of Canada's WWTPs have until 2030 or 2040 to meet federal regulations.

Requiring all communities in Canada to meet a baseline of secondary treatment or equivalent will improve conditions in some waterways, but will not address all risks, such as those associated with the discharge of nutrients and trace contaminants. Canada does not regulate nutrients on a nationwide basis, and in this respect, the regulations are less comprehensive than those of the E.U., which regulate nitrogen and phosphorus in wastewater effluents. In the U.S., there are no national effluent limits for nutrients, but the Clean Water Act requires creation of Water Quality Based Effluent Standards for each water body (supplemental to minimum regulated levels), which assess the impact of effluents on the receiving environment and set maximal loading criteria for nutrients and other compounds accordingly. The U.S. assigns total maximum daily loads (TMDLs) to wastewater treatment facilities that stipulate the maximum amount of a given pollutant that can be discharged per day. This system necessitates consideration of the multiple discharge sources and their cumulative impact on the ecosystem. The E.U.'s Water Framework Directive specifies that the watershed scale must be used for water management, regardless of administrative boundaries.

In Canada, wastewater treatment levels and nutrient management practices vary widely among provinces and territories, with some regions having treatment well beyond the WSER requirements. More advanced wastewater treatment has been implemented largely as a matter of necessity due to high pressures on water resources (e.g., the Prairies) or international commitments such as the Great Lakes Water Quality Agreement. Canada is a large and diverse country that may benefit from solutions tailored to the local context, but under the current framework, water management decisions beyond the WSER fall entirely to the provinces, with no national standards, incentives or guidance.

3.4 Major contaminant concerns in Canadian wastewater

> Known contaminants (pathogens, nutrients, chemicals) require continued vigilance. An expanding list of contaminants of emerging concern is demanding additional consideration of the risks they pose and how these effects can be minimized.

Currently, Canada's focus is on ensuring that all treatment plants sufficiently address the conventional concerns posed by oxygen-demanding material, pathogens, nutrients and acute toxicity (see Supporting Document 3 for an overview of major contaminant groups found in wastewater). However, there are also concerns about many other contaminants contained in municipal wastewater effluent that will ultimately be discharged to receiving waters, which include a wide variety of industrial and household chemicals, pharmaceuticals and personal care products (PPCP), endocrine disruptors and other chemicals that were previously not recognized as a threat to public health or the environment. The need to address CECs, which are mostly unregulated from an effluent perspective, was one of the leading issues of concern expressed by the questionnaire respondents (Figure 13, Supporting Document 1).

Contaminants in wastewater effluent discharges can be of concern due to acute or chronic impacts on human or aquatic ecosystem health, reduced ecosystem services, or the deterioration of socio-cultural value (e.g., recreation). Impacts can be exacerbated in the receiving environment by other factors, such as periodic overflows of untreated wastewater (e.g., from combined sewer overflows (CSOs)), additional contaminant inputs from other sources (e.g., urban runoff and agriculture), water extraction for irrigation, industrial processes or drinking water, and climate change. Determining what wastewater treatment should achieve requires an assessment of the relative risks posed by these contaminants and an understanding of how they can be minimized effectively and reasonably.

3.4.1 Impacts on human health

From a public health perspective, WWTPs have been successful at reducing pathogens, but potential risks remain and new risks continue to emerge. Human health concerns from wastewater are first and foremost related to exposure to pathogenic viruses, bacteria and parasites. Pathogens of concern identified in wastewater originate primarily from human feces, and include bacteria (e.g., *Salmonella*, *Vibrio cholera*, *Legionella* and some strains of *Escherichia coli*), viruses (e.g., adenoviruses, enteroviruses), parasites (e.g., *Cryptosporidium*) and helminths (i.e., parasitic worms). As many pathogens, particularly viruses, are host specific, municipal wastewater represents a potentially important pathway for exposure through drinking water, contaminated food, ingestion via recreation and other uses. Many pathogens originating from other animals can also infect humans and may be present in wastewater or other sources across watersheds (e.g., agriculture).

In addition to pathogens, some chemicals may represent a risk to humans. For example, fish and shellfish can accumulate toxins such as mercury, which pose health threats to those consuming them. Risks from contaminants concentrated in aquatic organisms and magnified in food webs may be particularly problematic in communities where fish and shellfish are a major part of the diet, such as some Indigenous communities. Nutrient enrichment of surface waters may lead to harmful algal blooms that pose a health threat to humans that drink the water or consume fish from the water. Contaminants can also be transferred to biosolids during wastewater treatment, and exposure may occur through food consumption as a result of the application of biosolids to agricultural lands.

In addition to health risks traditionally associated with wastewater, there are many emerging concerns. One example is the potential for enhanced exposure to antibiotic-resistance genes or antibiotic-resistant organisms. Although antibiotic-resistance genes are produced naturally by microorganisms, they are selected for in tissues and environments that are enriched with antibiotic compounds. Given that these genes can be transferred among many types of microorganisms, and may be enriched during wastewater treatment, there is growing concern regarding their release from wastewaters. Potential human health impacts associated with PPCPs in wastewater effluents have also been raised. The presence of PPCPs in effluent was one of the highest ranked concerns identified in the project's questionnaire (Figures 11 & 13, Supporting Document 1). Given the low concentrations detected in drinking water sources, the risk to humans is thought to be minimal, although some uncertainty remains due to the wide diversity of chemical structures and the potential interactions among mixtures of chemicals.

3.4.2 Eutrophication

The excessive input of nutrients (primarily phosphorus and nitrogen) from wastewater is a major contributor to eutrophication of aquatic environments. Eutrophication is an increase in the nutrient status of a lake, stream, or river, and results in increased growth of aquatic plants, algae and biofilms. Blooms of nuisance and toxic algae (e.g., cyanobacteria) can result in oxygen depletion and fish kills, in addition to degrading the quality of drinking and recreational waters. Phosphorus has been well-established as a limiting nutrient in freshwater environments, while nitrogen may play an important limiting role in marine and coastal environments. Although the degradation of water quality caused by nutrient overloading has been known for decades, these issues continue to plague many Canadian waters, including the Great Lakes, Lake Winnipeg and the Okanagan Basin. Although wastewater nutrient loading is an important component, reducing eutrophication of surface waters is complicated by many factors, such as changes in ecosystem conditions, legacy phosphorus in sediments, and contributions from non-point urban and agricultural sources or CSOs. Control of phosphorus was noted as the third most common wastewater-associated concern in the questionnaire (Figure 13, Supporting Document 1).

3.4.3 Impacts on aquatic ecosystems

Fish and other aquatic organisms can be impacted by the discharge of wastewater-associated contaminants. Un-ionized ammonia (which is a breakdown product of urea in urine and protein in feces) and chlorine (which is used by some WWTPs to disinfect effluents before their release) are major contaminants in wastewater that are a concern for acute toxicity and a target for control in the WSER. There are also a large number of legacy contaminants in wastewater such as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs; additives in flame retardants) and polycyclic aromatic hydrocarbons (PAHs) that have been recognized for decades because of their persistent, toxic and bioaccumulative nature. Although many have been banned from use or have undergone risk management, they are still found in wastewater effluents because of their previous widespread release and persistence in the environment. Metals are also present in municipal wastes and have well-documented toxicities. Wastewater treatment processes tend to partition metals and insoluble organic compounds into solids streams, which can limit the use of biosolids on agricultural lands.

A wide variety of recently identified substances in wastewater effluents that are typically more water-soluble, such as endocrine disruptors (e.g., estrogens) and many pharmaceuticals. These compounds may have chronic effects on aquatic organisms such as impaired survival growth, development and reproduction, which is leading to changes in species diversity and composition of aquatic communities. Some of these compounds have relatively well-documented adverse impacts (e.g., estrogens) and may represent a risk to the environment where exposure is elevated (e.g., poorly-treated effluents, low dilution, sensitive populations). The majority of individual PCPPs are thought to pose minimal risks due to their relatively low concentrations in effluents and surface waters, but these compounds can be bioactive, exist in effluents as complex mixtures and act through diverse mechanisms, making it difficult to assess their risk to the environment.

New contaminant-related concerns are constantly arising and may have significance for future decisions about wastewater management. For example, recent research in freshwater and marine environments has suggested that wastewater-derived microplastics may have negative impacts on aquatic life (Case Study #6). Research is also examining the diversity and impacts of novel engineered substances that may enter the environment in wastewater effluents, such as nanomedicines and nanoparticles. More research will be needed before the fate and risks from these contaminants can be established sufficiently to determine how to address them, but they are generating considerable public and scientific concern.

3.5 What will future contaminant management require?

> Canada's approach cannot assume that all threats can be systematically identified, characterized and minimized, and must recognize wastewater treatment as part of a comprehensive management strategy addressing complex risks and multiple uncertainties.

Municipal wastewater effluents contain a wide variety of substances, including conventional and established contaminants and a long list of CECs. The risks associated with conventional contaminants are generally well-understood and management actions have been taken to address them. The number of CECs that can be detected in wastewater effluents is growing, but the impacts of these substances are highly uncertain. As a result, these substances may require a different management strategy. CECs may need to be assessed and managed as complex mixtures, rather than through a contaminant-by-contaminant risk assessment approach.

3.5.1 Conventional and established contaminants

Many priority conventional and established contaminants have been managed through source control programs (e.g., CEPA), which has reduced their entry into wastewater treatment systems. Recent examples include triclosan and microbeads. Conventional contaminants (including those regulated under the WSER), nutrients, pathogens and additional established contaminants (such as metals) are generally managed under provincial permits or standards on a site-specific basis. Treatment processes that can address many of these contaminants (Supporting Document 4) are well-established although not always applied. The respondents to the questionnaire felt that WSER-regulated substances are generally adequately managed (although there were some concerns about ammonia), but that pathogen and nutrient management, particularly phosphorus, remains a concern that requires further attention (Figures 7 & 9, Supporting Document 1). Achieving additional treatment for nutrients or pathogens will require implementation of more refined federal, provincial or local guidelines/standards, as well as permits that are based on an assessment of receiving-water conditions. Determination of treatment requirements needs to include consideration of receiving water characteristics, multiple stressors, cumulative effects at the watershed scale, and local environmental and community goals.

3.5.2 Contaminants of emerging concern

Recently recognized contaminants in effluents pose a different type of management challenge. When identifying priorities for effective treatment strategies, decisions are confounded by lower confidence in the cause-and-effect relationship between detected constituents and negative impacts. It is clear that some concerns warrant action, but determining which contaminants represent the most significant health or environmental risks and where investments in treatment should be targeted is less clear. Furthermore, wastewater is a complex mixture containing a suite of chemicals that can vary from one time to another. Measuring and regulating a comprehensive list of contaminants is not practical in any jurisdiction. Instead, there is a need for a complementary method to prioritize risk to the receiving environment and feasibility for removal, both of which take into account uncertainty, as well as consideration of source control.

CECs present in municipal wastewater have received increased attention and study in recent decades. While the risk to humans from the trace levels of these contaminants introduced through wastewater is thought to be minimal, this diverse group of chemicals is raising new concerns as additional research is conducted. A limited number of these chemicals may represent a significant environmental risk where precaution is warranted. A lack of clear linkages between exposure and adverse outcomes in receiving environments makes it difficult to establish the level of environmental risk and treatment/control options and priorities. Additional research is needed to better assess these complex mixtures and the risks they represent and identify viable remediation options.

3.5.3 Risk-based management of contaminants

In the face of uncertainty about potential risks, the consideration of options should be informed by how serious the potential impact may be, as well as how technically, economically and socially feasible it is remove the contaminants. The ability to successfully remove or degrade different groups of contaminants in wastewater will vary according to their chemical and physical properties and susceptibility to biological or physical degradation and/or sorption potential. For example, triclosan (a common antimicrobial agent), is degraded rapidly in the environment as a result of photolysis, whereas triclocarban (another antimicrobial agent) does not readily degrade and will likely remain in the biosolids after treatment. Venlaflaxine, an anti-depressant, is relatively water soluble but not easily degraded, and as such, remains in the effluent and is discharged to the receiving environment. Persistent contaminants merit special consideration in the mitigation of risks from wastewater effluents. In addition, the risk and feasibility to remediate specific chemicals or effects may be dependent on local considerations.

In general, once a level of potential risk is assigned to a contaminant or group of contaminants, a consideration of ability to feasibly reduce risks through treatment can be taken into account when deciding on best management approaches. For example, consider Figure 2 below, where risk is high and treatment feasibility is low. This contaminant is a higher priority that would call for options such as source control or the development and implementation of new treatment technologies. Alternatively, where risk is low and treatment feasibility is high, less attention is needed for this contaminant if appropriate treatment is already being used and the CEC is already being removed or can be easily removed. For many chemicals the risk will be uncertain and remedial action may depend on the feasibility of removal and economic and social considerations. For example, medically important drugs that do not have alternatives may be important for human health and wellbeing making source control a difficult or undesirable option. In these cases, research may lead to socially-acceptable treatment alternatives. Alternately, where uncertainty exists, monitoring on occurrence and investigations into impacts, feasibility of treatment, or other source control options can be initiated to gain greater clarity on relative priorities and mitigation options (Case Study #3).

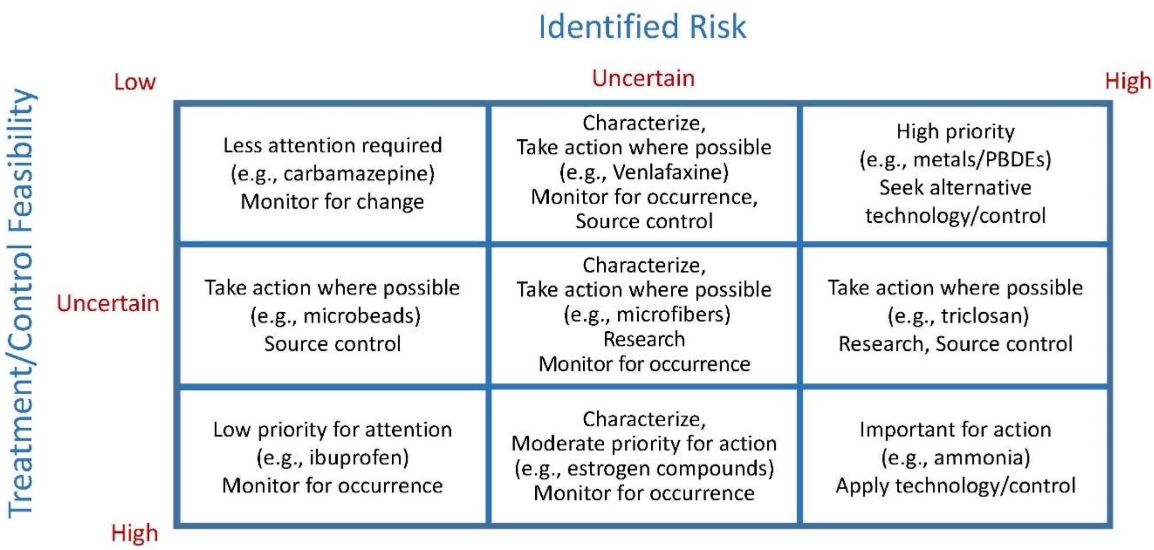

Figure 2: A general framework for consideration of risk management, with examples demonstrating some of the complexity around removal of contaminants in municipal wastewaters.

There are three main approaches to removing contaminants from wastewater, including:

(i) Source control (i.e., keep the contaminant out of the wastewater system)

(ii) Diverting the substance to another part of the waste stream (e.g., effluent to sludge)

(iii) Degrading the substance during treatment

For all compounds, monitoring for the presence of a substance and assessing environmental impacts can be used in conjunction with treatment to facilitate adaptive management and modification of risk minimization strategy as appropriate. For low-risk compounds that are difficult to treat, monitoring for change may represent the most reasonable strategy.

When considering treatment options, the whole system needs to be considered, as risks might be transferred from the water to land or air. A particular challenge for making decisions on best investments in wastewater management is the long list of CECs for which considerable uncertainty exists about serious and potentially irreversible risk. For these cases, socio-economic considerations factor into whether to address uncertain risk. Taking an environmental risk-based approach has been studied previously in a Canadian context, and previous work in this area should be considered when establishing an approach (e.g., the CCME supporting document on *Environmental risk-based approaches for managing municipal wastewater effluent*; CCME, 2005)).

CASE STUDY #3

Characterizing Contaminants of Emerging Concern in Calgary's Wastewater

The City of Calgary takes a proactive approach to contaminants of emerging concern (CECs). A strategy was developed in 2007 to track CECs in surface water, wastewater effluent and wastewater biosolids. The strategy includes a monitoring program and joint collaborations with other government and university partners to advance the state-of-the-science and ensure that public health and the environment are protected.

The City's monitoring program consistently detects CECs in wastewater effluent and downstream surface water, generally at parts per trillion concentrations. The majority of these compounds are detected less frequently in surface water than in wastewater effluents and at concentrations typically 1 to 2 orders of magnitude lower. The City has invested in expanding its in-house analytical capabilities to gather data on 60 chemical compounds, including flame retardants, hormones, perfluorinated substances, pharmaceuticals, personal care products, plasticizers and surfactants. This prioritized contaminant list is based on existing guidelines, potential future regulations, relevance to Calgary, relative toxicity and persistence, analytical capabilities, and interest from the public, media and researchers.

Calgary has been a long-term participant in Environment and Climate Change Canada's chemicals monitoring program and continues to support a number of academic research projects related to CECs. In addition, the City has invested in Advancing Canadian Wastewater Assets, an innovative partnership with the University of Calgary to advance wastewater treatment technologies. Calgary is positioning itself as an industry leader through the acquisition of data which can inform future decisions with respect to CECs in wastewater and the environment.

Contributed by Dr. Norma Ruecker, Leader Microbiology and Watershed Assessment, City of Calgary.

3.5.4 The role of a precautionary approach

BOX #1 — Precautionary Principle

The precautionary principle is meant to be an evidence-based decision making tool. Accordingly, decisions should be made that can be adapted over time as additional information becomes available through monitoring or future developments in science, therefore reducing uncertainty of the risk. The precautionary principle assists in considering co-benefits and trade-offs of investment in improved treatment or source control.

Canada has committed to the precautionary principle in a number of international legal instruments and in domestic law. For example, the preamble to the Canadian Environmental Protection Act states:

> *Whereas the Government of Canada is committed to implementing the precautionary principle that, where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation;*

The federal government's proposed revisions to the Fisheries Act, introduced as Bill C-68 in February 2018, also includes the precautionary principle (referred to as "precautionary approach") as follows:

> *2.5 Except as otherwise provided in this Act, when making a decision under this Act, the Minister may consider, among other things,*
>
> *(a) the application of a precautionary approach and an ecosystem approach.*

Contributed by Theresa McClenaghan, Executive Director and Counsel, Canadian Environmental Law Association.

Decision making often relies on scientific evidence to suggest whether there is risk of significant or irreversible harm arising from various groups of contaminants in wastewater components; a conundrum that is faced by jurisdictions around the world. If there is reasonable evidence, then reasonable measures are justified to avoid or reduce the risk through wastewater treatment, as compared to source control, which may or may not represent the best approach to dealing with them (Box #1). When considering co-benefits of a treatment technology, the fact that other risks may be reduced should be included in the cost-benefit calculation.

4. Opportunities in Wastewater Treatment

> Canada has an opportunity to do more through wastewater treatment by considering how planned investments can address uncertain risks, accrue additional benefits, incent progress and innovation, and be situated in a watershed approach.

Ensuring that all communities in Canada (which vary widely in setting and needs) can meet minimum standards for wastewater treatment created through national regulations is an important foundation. Given the increasing complexity and uncertainty of current and future risks, our communities will need to build on that foundation to ensure they are future-ready and focused on achieving public and environmental health objectives. Selecting best approaches to meet and exceed minimum standards to ensure future-readiness will require careful consideration of the costs and benefits of available options.

A new global paradigm is emerging that has broadened the thinking about the risks that can be mitigated and the societal benefits accrued through wastewater treatment. We now have the ability to improve the benefits realized from our systems by recovering beneficial resources and minimizing energy use and greenhouse gas (GHG) emissions, all while protecting public and environmental health. The need to address uncertainties facing management choices increases the importance of considering the co-benefits that solutions provide. Co-benefits arise when actions designed to achieve one objective (such as urban flood mitigation measures) also provide benefits to another objective (such as reducing contaminant loading to receiving waters).

Similarly, the "cost" side of cost-benefit analysis should include a broader consideration of human and environmental health and socio-economic impacts. Treating wastewater to increasingly stringent levels may involve trade-offs or collateral impacts such as increased energy use and GHG emissions, or shift risks elsewhere in the environment. Biosolids management, for example, can represent up to 50-55% of the cost of wastewater treatment and must take into account the eventual use or disposal of extracted contaminants (Metcalf and Eddy - AECOM, 2014). Another important trade-off to consider is the changing risk profile involved in the beneficial reuse of wastewater treatment resources. A review of available and innovative technologies in Supporting Document 4 identifies some co-benefits and trade-offs.

Municipalities and regional wastewater utilities who adopt new technologies bear the majority of the financial risk and are responsible for legal, social, political and environmental consequences of failure. Charged with delivering a critical public good, Canada's municipal water sector tends to be risk-averse and slow to adopt new wastewater technologies despite the potential for social, economic and environmental benefits. Going further with wastewater treatment requires doing more, but also thinking about the consequences of those choices and how effectively they address differing and sometimes competing risks to people and ecosystem services at both the local and larger, watershed scale. This brings better focus on the question of where wastewater treatment represents the best investment for protection within various watershed management options, such as source control.

4.1 Making the most of planned infrastructure investments

> Canadian communities have an opportunity to capitalize on current investment windows to consider best approaches to future-ready systems, including the consideration of co-benefits.

Large investments are currently being made to achieve the WSER standards (and updated provincial regulations) in some communities. It is estimated that 1 in 4 wastewater facilities in Canada will require substantial upgrades to meet the WSER requirements (Federation of Canadian Municipalities, 2017; Government of Canada, 2017b). The total cost of these upgrades is estimated at $5.5 billion, with an estimated $16.5 billion in associated benefits (Government of Canada, 2012). Additional investments will also be required as communities grow and receiving water protection requirements become stricter. Major upgrades to WWTPs are expensive, time-consuming, and potentially disruptive to local service delivery. As a result, the investments made during major upgrades essentially lock in the chosen wastewater technology and infrastructure for decades to come. Less expensive improvements in system performance may be made through optimization of existing systems and retrofitting of existing infrastructure, although in some cases more substantial upgrades will be required. For all upgrades, whether driven by wastewater regulations or other community needs, the consideration of co-benefits (e.g., Box #2) alongside standard decision making processes may provide added value for municipalities and utilities.

BOX #2 — An Opportunity for Co-Benefits

Reducing the impacts of estrogenic compounds through conventional technology

Wastewater technologies designed to remove conventional contaminants such as biochemical oxygen demand and ammonia may also enhance the removal of trace organic contaminants. Biological reactors host microbial communities with diverse metabolisms that are capable of exploiting a wide range of compounds as sources of energy and carbon, and as a result will break down compounds that may not be the primary target. It has been widely demonstrated that wastewater treatment infrastructure designed to facilitate nitrification (i.e., the conversion of ammonia to nitrate) is also effective at degrading estrogen compounds. This phenomenon has been demonstrated for a variety of technology types, including conventional activated sludge processes, biological nutrient removal and membrane bioreactors (Gaulke et al., 2009; Kasprzyk-Hordern et al., 2009; Vader et al., 2000; Yoshimoto et al., 2004). Both nitrifier co-metabolism and heterotrophic degradation have been suggested as possible mechanisms of estrogen degradation (Song et al., 2017; Yi & Harper, 2007).

Although questions remain regarding the mechanism of estrogen degradation, factors that increase microbial diversity appear to be associated with the removal of estrogenic compounds. In particular, operating parameters that increase solids and hydraulic retention times and promote biofilm formation are associated with a decrease in estrogenicity of wastewater effluents (Joss et al., 2004; Koh et al., 2008). In one study, nitrification upgrades in the Region of Waterloo's Kitchener Wastewater Treatment Plant (WWTP) in Ontario resulted in decreased estrogenicity in effluents and a decrease in the incidence of intersex fish downstream (Hicks et al., 2017).

The degradation of estrogens in nitrification bioreactors is well-established, and it is likely that other technologies using biological treatment also result in the degradation of trace organic contaminants. For example, technologies to remove phosphorus to ultra-low levels, such as membrane bioreactors and nanofiltration, have been shown to have concomitant removal of trace organic contaminants. This may help justify upgrades to reduce phosphorus in effluents, even in watersheds where phosphorus additions are dominated by non-point sources (Blair et al., 2015; Oulton et al., 2010).

As Canadian WWTPs upgrade to meet the WSER standards, the inclusion of nitrification infrastructure merits serious consideration. In many cases WWTPs will need to nitrify to meet the WSER acute toxicity requirements, but for some plants (such as those that heavily dilute wastewater with stormwater), nitrification will not be necessary. Upgrading to nitrification infrastructure mitigates the toxicity and oxygen-demand associated with ammonia, and also offers the co-benefits of simultaneously partly degrading estrogenic compounds.

4.1.1 Infrastructure and process optimization

Optimization of existing wastewater treatment infrastructure can be a cost-effective method to improve performance measures and potentially delay the need for major infrastructure investments. WWTP performance can be optimized with improved monitoring of facility parameters and staff training of operators and managers that results in improvements to operation, design, maintenance and administration (Federation of Canada Municipalities, 2003). An example of an optimization processes is the 2-stage Composite Correction Program developed by the United States Environmental Protection Agency (US EPA; Water Canada, 2015). The City of Brantford in Ontario followed this program and identified ways to re-rate design capacity, achieve higher effluent quality and defer significant infrastructure expansion capital costs (City of Brantford, 2015). Additional benefits included an increased understanding of treatment capability, improved communication between operations and city staff, confidence in troubleshooting issues, tools to address poor process conditions and the ability to nitrify when conditions were optimal. It should be noted that optimization requires investment in staff training and expertise, which can be difficult to access and retain in rural and remote communities.

4.1.2 Treatment technology retrofits

The need to upsize capacity can be challenging from a cost and footprint perspective. However, a variety of processes and technologies, such as aerobic granular sludge, integrated fixed-film activated sludge (IFAS) and membrane bioreactors (MBRs) can be incorporated within existing treatment systems and facility infrastructure to enhance water quality and delay or prevent more costly plant expansions (e.g., Case Study #4). Retrofitted technologies can target a variety of contaminants, such as ammonia, nutrients, microplastics and trace organic contaminants. To address its growing population and improve effluent quality for downstream communities, the City of London in Ontario retrofitted its Oxford Pollution Control Plant (which previously used conventional activated sludge) to include MBRs, making it one of the largest MBR plants in Canada (Stantec, 2011). Several structures were repurposed, including aspects of the headworks and aeration basins. This presented engineering challenges, but ultimately resulted in nearly doubling treatment capacity with minimal footprint expansion and higher effluent quality, including <0.5 mg/L phosphorus. These upgrades were found to be comparable to conventional treatment solutions on a 20-year lifecycle cost basis.

Trade-offs associated with implementing new technologies include the potential risks associated with unknown technology (discussed in Section 4.3), and the higher level of operator training and utility capabilities required, which may not be available in all municipalities and communities.

CASE STUDY #4

Retrofitting with New Technology to Attain Greater Water Quality

There are opportunities to achieve additional water quality objectives by retrofitting existing wastewater facilities with newer technology. These upgrades may also have co-benefits, such as removing trace contaminants. A CWN-funded research project (2015) noted that options are now available that retain more biomass in the existing system and achieve higher removal rates per volume. Membrane bioreactors (MBRs) can be retrofitted into existing reactors, reducing the required volume by up to 75% as compared to conventional biological nutrient removal (BNR) methods. MBRs require a complete change of membranes every eight years, and they are energy-intensive, but there have been significant improvements in MBR technology and membrane prices have decreased significantly. Due to extended biomass retention time, the process provides an opportunity for advanced removal of contaminants of emerging concern and generates reuse-quality effluent. Another technology increasing the amount of biomass and its residence time in reactors is an integrated fixed-film activated sludge (IFAS) process, which combines the features of suspended and attached biomass, providing up to 30% volume reduction compared to conventional activated sludge systems.

Other new technologies entering the Canadian market include aerobic granular sludge (AGS) processes, which use a sequencing batch process configuration that leads to the creation and maintenance of compact granules of bacteria that significantly reduce settling times compared to conventional BNR plants. With the specific distribution of different groups of bacteria within the granules, the process can simultaneously remove organic matter, nitrogen and phosphorus in one aerated tank. The granular biomass settles within minutes, significantly reducing volume as compared to conventional flocculent biomass, which must employ large secondary clarifiers. The process may also reduce energy demand by 40% due to lower aeration, mixing and pumping requirements. AGS technology already operates in a number of plants overseas. The first plant in the United States has been commissioned, which will provide performance measures for the design of full-scale reactors that promote granulation.

Many Canadian facilities currently have an opportunity to significantly decrease their nutrient load discharge through relatively low-cost changes to their process operations utilizing existing wastewater treatment infrastructure, particularly in plants practicing conventional activated sludge processes.

Contributed by Dr. Jan Oleszkiewicz, University of Manitoba
For more information, see Options for Improved Nutrient Removal and Recovery from Municipal Wastewater in the Canadian Context (Oleszkiewicz et al., 2015).

4.1.3 Treatment infrastructure upgrades and expansion

For communities across Canada requiring investments to accommodate growth or meet more stringent discharge requirements through new or expanded WWTPs, the consideration of co-benefits and balancing trade-offs is critical, given the high cost of new installations compared to optimization and retrofitting. Taking a long-term vision of different future scenarios and risk profiles, as well as community or environmental priorities, technology advancements and economic opportunities, is critical. For example, future-ready systems can include flexible modular or scalable designs, extra room in the hydraulic grade line for additional processes and resiliency to climate change, decentralized facilities to reduce the need to upsize centralized facilities, and innovative solutions to address contaminants, including upstream pollution prevention and watershed management, as discussed in Section 4.2.

4.1.4 Advanced treatment of trace organic contaminants

Some trace organic compounds are addressed in conventional secondary treatment processes, but others require advanced treatment technologies to be degraded or removed. Advanced oxidation processes (AOPs) such as ozonation and ultraviolet (UV) treatment were the most frequently cited treatment options for trace organics by the questionnaire respondents (Figure 14 & Table 2, Supporting Document 1). AOPs involve the generation of hydroxyl radicals, which are strong oxidants that can destroy a wide range of compounds. These processes are able to degrade organic contaminants, but come with considerable trade-offs, including increased costs, higher energy requirements and associated increases in GHG emissions. The Regional Municipality of York has conducted a pilot project to investigate AOP options (Regional Municipality of York, 2015). UV-based methods were evaluated instead of ozone because this is the preferred wastewater disinfection method in Ontario. The results demonstrated that some trace organic compounds (e.g., 17β-estradiol and diclofenac) were >90% removed by UV photolysis at doses 100-fold higher than those typically used for disinfection. Compounds such as caffeine and carbamazepine were more recalcitrant (i.e., <40% removal at the same UV dose) and required higher UV doses (~150-fold of typical UV disinfection doses) in combination with oxidants such as hydrogen peroxide. The pilot determined that targeting a 90% removal of carbemazepine with UV-only increased overall treatment plant costs by up to 16%, although inclusion of hydrogen peroxide resulted in a more modest 8% increase in overall costs. Given that carbamazepine is a recalcitrant compound that is considered low-risk (Section 3.5.3), alternative end-targets such as a 90% reduction in 17β-estradiol could result in environmental benefits at a lower overall cost. Alternative methods of treating trace organic contaminants also exist; for example, in Switzerland, ozonation and powdered activated carbon are favoured for trace organics removal (Eggen et al., 2014).

BOX #3 — Looking Forward

Resource recovery goes hand-in-hand with more advanced treatment

Historically, WWTPs have used energy-intensive processes and focused on removing conventional pollutants. However, as population growth and climate change place increasing demands on the world's limited freshwater, energy, and phosphorus resources, wastewater is increasingly viewed as a valuable source of resources. Resources that can be recovered from wastewater for beneficial reuse include:

- Water for non-potable or even potable applications.
- Nutrients phosphorus & nitrogen which can be used as fertilizers in biosolids application, agricultural irrigation water and commercial products following recovery. For example, it is now recognized globally that phosphorus is a non-renewable resource that is in short supply; it is a component of cell membranes and DNA and is therefore necessary for all life forms.
- Energy, which can be produced from organic carbon, heat and hydraulic dynamics of fluid flow. Examples include generating electrical power or combustible fuels such as biomethane and biomass for biofuels, and heating on-site at the plant and in the community.
- Biosolids (organic matter) that when stabilized can be used for land amendment and can be a source to recover other products, such as fibres, bioplastics and lipids.

Recovering resources from wastewater can also be an approach to further remove pollutants from wastewater, thereby contributing to the goal of reducing risks to the environment and public health. Simultaneously, resource recovery represents an opportunity to produce commercially valuable products while reducing carbon footprints and energy costs.

Contributed by Dr. Donald Mavinic, University of British Columbia.

4.1.5 Co-benefits through resource recovery

Municipal wastewater represents a threat to public and environmental health, and WWTPs provide a critical public service by mitigating these risks. Recently, there has been increased interest in maximizing the benefits of WWTPs by recovering resources while treating waste to protect public and environmental health (Box #3). For example, the U.S. Water Environment Federation (WEF) has stated:

"WEF believes that wastewater treatment plants are not waste disposal facilities, but rather resource recovery facilities that produce clean water, recover nutrients (such as phosphorus and nitrogen) and have the potential to reduce dependence on fossil fuel through the production and use of renewable energy." (Water Environment Federation, 2011)

WEF and other organizations have begun using the term water resource recovery facility (WRRF), instead of wastewater treatment plant. Although the position of this panel is that WWTPs are primarily responsible for protecting public and environmental health, resource recovery can maximize benefits to society by providing opportunities to treat wastewater at a higher level while simultaneously generating new revenue streams. Resource recovery is still in its infancy in Canada, but emerging drivers like climate change and resource scarcity will incentivize expansion. The business case for resource recovery is helped by the fact that wastewater treatment is a necessity, so the costs of recovery are incremental to that of treatment. There are also opportunities for generating revenues for partial or full cost recovery, such as selling methane back into the grid (Case Study #5) or commercial fertilizer products. Recouping costs may be attractive at the municipal level, while supporting a circular economy is likely to resonate with the general public.

Biosolids have commonly been recovered from wastewater and spread on land, which can contribute to soil fertility. However, there are also trade-offs associated with the application of biosolids, such as the potential impacts of pollutants, such as metals, which have partitioned into the solids. In many jurisdictions, land application or landfilling biosolids is becoming increasingly controlled, creating additional complexity. Similarly, although the reuse of treated wastewater effluent is commonly cited as a way to maximize water resources, it also has the potential to create new exposure pathways for public health risks.

Biogas production was frequently cited as a key opportunity for resource recovery by the questionnaire respondents (Figure 16, Supporting Document 1). Because wastewater systems represent a significant portion of municipal energy requirements, they represent a major opportunity to mitigate GHG emissions (Canadian Water Network, 2018).

CASE STUDY #5

Co-generation and Heat Recovery in Canadian Wastewater Treatment Plants

All five of Metro Vancouver's wastewater treatment plants recover and use biogas to generate heat for their plants. Two of the plants also co-generate enough electricity to meet roughly half of their needs. One treatment plant is also planning to sell excess biomethane to a local natural gas utility. Metro Vancouver has also established a liquid waste heat recovery policy that enables municipalities and businesses to use the heat from sewers to heat nearby buildings. The first project enabled by the policy is an effluent heat recovery project that will be built at the new wastewater treatment plant serving the North Shore of the region, opening in 2021. It will sell 5 megawatts of heat to the district energy system of the Lonsdale Energy Corporation, providing heat for approximately 3,000 homes. The renewably-sourced heat will displace natural gas and reduce greenhouse gas emissions.

Across the country, multiple examples of co-generation facilities using wastewater treatment plant biogas exist or are under consideration:

- The City of Hamilton has a 1.6 megawatt capacity co-generation plant at its Woodward wastewater treatment plant as well as a biogas purification unit. Having both facilities allows the City of Hamilton to choose between selling electricity or natural gas to energy distributors based on current market rates.
- The City of Ottawa's Robert O. Pickard Environmental Centre's co-generation facility produces 5 megawatts of heat and electricity, which provides 50% of the plant's annual energy needs, and in 2006 was saving approximately $1.6 million per year.
- The Regional District of Nanaimo's Greater Nanaimo Pollution Control Centre is a smaller system that produces 0.3 megawatts of electricity which is sold to BC Hydro and powers 325 homes.
- The Saint-Hyacinthe wastewater treatment plant in Quebec purifies its excess methane and supplies it to the Energir grid (formerly Gaz Métro). It also powers municipal vehicles with natural gas. New anaerobic digesters were also added to accommodate food residues sent by industries and supermarkets to generate methane for reuse.
- The Region of Waterloo has plans to add co-generation to three of its wastewater treatment plants, with a combined electrical capacity of 1.4 megawatts that is expected to offset electrical demands by 30-60%.

This case study is adapted from Balancing the Books: Financial Sustainability for Canadian Water Systems (Canadian Water Network, 2018).

4.2 Wastewater treatment as part of watershed protection

> Wastewater treatment is one component of a comprehensive waste management strategy to address the complex problem of human impacts on the environment.

A broader, watershed-based view of costs and benefits must consider whether treating certain contaminants in wastewater is always the most effective investment. A holistic approach considers available treatment options as well as other interventions, such as combined sewer separation, that may be more effective or complementary. Combining watershed management options with treatment is being adopted in Europe, particularly in Germany, where they are examining the needs of the receiving environment and controlling contaminants at the source as well as through treatment.

4.2.1 Source control

Reducing or eliminating contaminants through source control (i.e., keeping them out of wastewater systems) was one of the top priorities expressed by the expert panel and the expanded group of experts (Figures 14 & 15, Supporting Document 1). Source control (i.e., pollution prevention), represents an important complementary strategy to treatment, given that many contaminants are not treatable, or are only partially treatable by conventional treatment, or are expensive to treat. The contamination of recovered biosolids limits beneficial reuse or requires further treatment. Source control can be accomplished by restricting the presence or levels of certain contaminants in consumer products, or by removing or reducing contaminants prior to entering the wastewater system. Environment and Climate Change Canada and Health Canada assess and manage risks associated with existing and new substances in the marketplace that often end up at WWTPs through CEPA. Examples of source control in Canada include the recent ban on the use of microbeads in toiletries (Case Study #6), past regulation of phosphates in detergents, and the separation of dental waste that contains mercury.

In addition to banning or restricting chemicals in products through CEPA, controlling what goes down the drain and ends up at WWTPs is also an important component of source control. Municipal sewer-use bylaws can limit concentrations or loading of certain constituents and require certain industries or commercial operations to pre-treat their waste streams prior to discharge to the municipality's sewer collection system. Sewer-use bylaws can also limit substances that will not be adequately treated at the WWTP. For example, the U.S. Environmental Protection Agency issues industrial user permits through their national pretreatment program via industrial user permits. Site-specific or watershed-based environmental risk assessments can inform sewer-use bylaws about which contaminants are of concern for a particular WWTP or receiving environment. Customer education was also cited in the questionnaire responses (Figures 15 & 19, Supporting Document 1) as a component of source control to reduce the loading of CECs to WWTPs through proper disposal of certain products, such as expired or excess medication.

CASE STUDY #6
Microplastics in Canadian Wastewater

Microplastic pollution is rapidly emerging as a global environmental and policy concern for many. Research on the distribution and impacts of microplastics in the environment is very new, and the extent to which they present a conservation-level risk to aquatic biota remains unclear. However, a few things are evident: microplastics are everywhere — in the air, on land, in freshwater and marine environments; on the surface of waterways, in the water column and in sediments; and in virtually all species that have been examined, including invertebrates, fish, birds and marine mammals. The ubiquitous extent of microplastics in our ecosystems suggests a need to consider the potential for negative biological or ecological consequences.

Microplastics are defined as any plastic particle smaller than 5 mm, and comprise both primary microplastics (i.e., microbeads and nurdles) and secondary microplastics, which result from the breakdown of larger plastic items. Primary microplastics have faced regulatory actions under the Canadian Environmental Protection Act — notably the first non-chemical in Canada to be classified as 'toxic' — but secondary microplastics remain a more enigmatic concern.

Microplastic fibres appear to be the dominant microplastic found in water samples collected from the coastal regions of North America. It has been theorized that domestic wastewater may represent a significant source of textile fibres shed from synthetic clothing during home laundry. To date, a handful of studies have documented microplastic particles in wastewater treatment plants from different countries, as well as in the final effluent, which suggests that more research is warranted. However, significant methodological challenges have constrained the strength of these studies and led to difficulties in comparing results. A detailed study conducted by Ocean Wise is underway which involves Metro Vancouver's two largest wastewater treatment plants. The first results are expected to be published in mid-2018.

Contributed by Dr. Peter Ross and Dr. Anna Posacka, Ocean Wise Conservation Association

4.2.2 Reducing combined sewer overflows

A current area of increasing focus, particularly in the face of changing and more severe weather, is the contribution of sewer discharges that don't receive treatment or receive only partial treatment. This is particularly an issue in older systems with combined sewers that receive both raw wastewater (sewage) inputs as well as stormwater. CSOs release stormwater and raw wastewater when the collection system capacity is exceeded during heavy rain. This may occur when sewers overflow upstream of a WWTP, or when flows are intentionally by-passed or diverted around some or all WWTP processes if the system is unable to deal with the increased flow. As extreme weather events continue to increase as a result of climate change, CSOs have the potential to contribute significant quantities of untreated sewage into receiving water bodies. Under the WSER, municipalities are required to report monthly on the volume and number of days that effluent is discharged via CSOs. The CCME Strategy, which many (but not all) Canadian provinces and territories signed, set a target of no increase in CSO overflows for new development or redevelopment.

With growing cities and the impacts of climate change on the water cycle, upgrades to collection systems must follow. Reducing CSOs represents a particular opportunity to reduce wastewater risks to the environment and public health. In some municipalities, strategic investments in sewage networks may provide greater opportunity to mitigate environmental impacts than costly WWTP upgrades. Examples of upstream investments to reduce CSOs and bypass events include: separating stormwater and sanitary sewers; reducing inflow and infiltration of stormwater or groundwater into sanitary sewer collection pipes; disconnecting downspouts to sanitary sewers; strategically utilizing existing storm sewer capacity; real-time control; and incorporating overflow storage/surge tanks into systems. For example, the City of Ottawa has been implementing a series of measures to mitigate CSOs into the Ottawa River. Actions include real-time controls of overflow equipment and monitoring pipe flow data to maximize the capture of potential overflows, building storage facilities to temporarily hold additional flows, ongoing work to separate sewers and developing monitoring systems to alert staff of flows at the 13 different overflow locations (City of Ottawa, n.d.). Other Canadian cities such as Quebec City and Montreal have implemented similar measures.

4.2.3 Watershed management of non-point sources of nutrients

The management of more diffuse watershed issues does not fall within the dominant purview of any one department, group or sector, and requires coordination of decisions and actions by a variety of stakeholders. Therefore, the adoption of watershed-based policies and practices provides an opportunity to take a more holistic approach to assessing the relative impacts and cost-effectiveness of municipal wastewater treatment options in reducing the overall impact on the environment. A watershed-based approach to management decisions, by default, requires a multi-sectoral effort to capture the impacts and benefits of interventions for both large and small systems and point and non-point sources.

Significant gains have been made in Canada over the past 40 years to reduce the impairment of water quality from end-of-pipe sources, including municipal wastewater treatment effluent. However, water quality problems such as algal blooms persist, and our focus is now shifting to consider the more complex task of reducing non-point sources of nutrients throughout watersheds. For some contaminants, non-point sources make up the dominant contribution to a surface water body, and at a certain point, incremental reductions in loading from WWTPs may earn marginal benefits. For example, achieving a stringent phosphorus concentration of 0.05 mg/L in wastewater effluent at a WWTP would cost approximately $100,000 per kilogram of phosphorus removed. In comparison, reducing phosphorus loading from non-point sources, such as measures through urban stormwater management and agricultural best practices, would cost from $4 to $1,700 per kilogram of phosphorus removed (Environmental Commissioner of Ontario, 2017).

In addition to integrated watershed approaches, water quality trading or offsetting programs represent an opportunity to achieve overall reductions of pollutant discharges to aquatic environments. These programs allow dischargers to meet environmental objectives with more flexibility and lower cost than other types of regulations. They build on the fact that pollution sources that are generally located in the same watershed or subwatershed often face different costs to control. Basic criteria for a successful water quality trading or offsetting program include (adapted from IISD, 2009; Lake Simcoe Region Conservation Authority, n.d.):

- Well-defined sources and amounts of pollution
- Incentives (regulation or otherwise) that encourage offsetting, that includes the flexibility to meet regulatory requirements via offsetting
- Pollutant discharges that can be reduced more cost-effectively by working with other dischargers in the watershed
- Benefits are experienced within the sub-watershed
- Effective monitoring
- An entity to administer the program

Ontario has recently added legislation to provide a basis for water quality trading and offsetting (Ontario Water Resources Act, s.75 (1.7)). Successful examples of watershed-based management across Canada include Ontario Conservation Authorities supporting phosphorus offsetting and trading (i.e., Lake Simcoe Region Conservation Authority and South Nation Conservation Authority) (Case Study #7). Longer-term nutrient trading programs have been active in areas of the U.S., including Chesapeake Bay, which is an example of a program within a multi-jurisdictional watershed. In parallel to this, there is an approach known as Principle Nutrient Management now in place in some U.S. and E.U. watersheds which is intended to demonstrate the cost-effectiveness of nutrient recovery and nutrient-trading in watershed partnerships, where agricultural stakeholders are the recipients of any WWTP-recovered nutrients under a cap-and-trade approach. This is currently practiced in the Greater Miami River Watershed Water Quality Trading Program (NACWA, 2015).

CASE STUDY #7

Reducing Phosphorus in Lake Simcoe through Water Quality Trading and Offsetting

The Lake Simcoe Phosphorus Offset Program (LSPOP) is one part of a larger strategy to reduce phosphorus loading to Lake Simcoe. The program originated from a study that evaluated the feasibility of water quality trading within the watershed. Water quality trading recognizes that pollutant control costs can vary widely. For example, it is extremely costly and time-consuming to upgrade wastewater treatment infrastructure, whereas non-point sources of phosphorus from agriculture or urban runoff can be controlled more quickly and at much lower cost. Trading programs allow organizations facing higher pollution control costs to meet regulatory obligations by purchasing credits from another organization with lower pollution costs.

Although water quality trading is still being explored as a viable phosphorus control option within the Lake Simcoe watershed, LSPOP is not a trading program. LSPOP has a zero export target that requires new development to prevent 100% of phosphorus from leaving their site. Phosphorus loads must be controlled to the maximum extent possible within new developments, using the best available control technology, in compliance with Ontario Ministry of Environment and Climate Change (MOECC) Guidelines and Lake Simcoe Conservation Authority (LSRCA) Watershed Development Guidelines — whichever is most stringent. Remaining stormwater phosphorus loading that cannot be controlled triggers the need for an offset to achieve a zero export target. An offset ratio of 2.5 to 1 is applied, meaning that 2.5 kg of phosphorus per year would be removed for every 1 kg required to be offset. The offset measures would consist of phosphorus load reductions through low impact development and the retrofit of existing stormwater discharges elsewhere in the sub-watershed or adjacent sub-watersheds.

LSPOP is the product of more than 5 years of collaboration with the LSRCA, Chippewas of Georgina Island First Nation, MOECC, municipal partners, and the Building Industry and Land Development Association. Additional co-benefits include reduced flood risk, increased community resilience to climate change, enhanced groundwater recharge and the addition of "green" jobs to the local economy. The offsetting program has laid a foundation for a broader water quality trading program, which may include more players. Phosphorus credit buyers in the Lake Simcoe watershed could include municipalities, private developers, industrial operations and transportation authorities.

Contributed by Michael Walters, Chief Administrative Officer, Lake Simcoe and Region Conservation Authority.

4.2.4 Monitoring watersheds

Monitoring of the receiving environments to which WWTPs discharge, can help guide decisions about the need for both WWTP and watershed improvements. Addressing this need has largely been left to the discretion of each province or territory. Without a formal monitoring program, it is difficult to know if there are environmental problems or to identify potential new issues as they arise. As such, there is an excellent opportunity for the federal government to propose a more coordinated and cost-effective approach. A monitoring program to characterize which contaminants from municipal wastewater persist in downstream aquatic environments (such as in Calgary, Case Study #3) and to monitor environmental impacts would improve the ability to connect wastewater treatment actions with intended benefits. Sustained, long-term monitoring is needed to encompass both acute and chronic impacts and support a more holistic watershed approach to environmental protection.

Expanding the geographic scope to incorporate site-specific compliance monitoring within a larger watershed-scale environmental monitoring program provides an opportunity for broader stakeholder engagement (Case Study #8). It would also assist municipalities and utilities in their own cost-benefit considerations for investments. Effectively monitoring to assess the impacts of WWTP effluents on the receiving environment is complicated by the cumulative effects of multiple stressors in watersheds. There can be multiple sources of contaminants, and the effects observed may not have a clear connection to various actions (e.g., WWTP upgrades). In addition, the timeframe between mitigation measures taken and observable effects may vary greatly. Some changes occur relatively quickly, such as the observed reduction in intersex fish within a few years following upgrades to the Region of Waterloo's Kitchener WWTP (Hicks et al., 2017). On the other hand, phosphorus reduction strategies may require decades between implementation of management practices (such as WWTP upgrades and agricultural best management practices) and improvement in ecosystem health (Canadian Water Network, 2017).

Developing cumulative effects monitoring approaches represents a key opportunity and a daunting but important challenge faced by both federal and provincial/territorial governments, as well as other jurisdictions worldwide. Local Indigenous knowledge on land use activities in addition to Western science is needed to fully understand the risks to remote communities and the North. Environmental contaminants may have a greater impact on Indigenous populations who rely on food from wild sources. Indigenous monitoring in their own communities would increase understanding of environmental and human health impacts in remote indigenous communities and increase confidence in results.

CASE STUDY #8

North Saskatchewan River Water Management Framework

In 2007, the Province of Alberta was faced with the potential for unprecedented growth in the Edmonton Metropolitan Region, both in terms of industrial development and population. Realizing this could have a negative effect on the North Saskatchewan River, the province — in collaboration with a broad stakeholder group — created The Water Management Framework for the Industrial Heartland and Capital Region. This was the first application of Alberta's cumulative effects management approach. Initially, much of the focus was on quantity management and water recycling. However, it soon became apparent that there were opportunities to improve the use of water management tools and models to address potential water quality concerns. As a result, the initiative has focused on gathering information, commissioning studies, synthesizing knowledge and analyzing water quality trends. Using the data collected through an Effluent Characterization Program, the next steps are to assess effluent quality entering the North Saskatchewan River, set new standards for effluent levels if needed, and provide insight for the future management of the river using tools (e.g., models) that will help inform adaptive management solutions to manage loading to the river. This initiative is a good example of multi-stakeholder collaboration to understand the cumulative effects of discharges to the environment.

Contributed by Mike Darbyshire, General Manager, Alberta Capital Region Wastewater Commission.

4.3 Enabling and incenting progress and innovation

Meeting future needs for our wastewater systems requires that we can move beyond our existing minimum standards which are not completely protective of the environment. The complexity of those future needs requires using broader cost-benefit considerations, including co-benefits and trade-offs, with input and actions from a wide variety of players. New challenges require new ways of doing things, and innovations in governance and approaches will be as important as innovations in technology.

> Ensuring that Canada builds effectively from its current foundation requires strategies that engage the many players involved in determining costs and benefits, as well as recognizing where the risks are being borne, in order to incent innovation.

Establishing more effective regulations is an important opportunity, but strategies will also be needed to incent and support coordinated action and innovation. This requires recognition that each of the groups involved in watershed management bears different risks and costs in taking actions that contribute to a shared public goal.

4.3.1 Identifying and sharing the risks and costs

In Canada, the wastewater treatment sector is known for being risk averse, and generally adheres to conventional and established approaches. If a municipality or utility adopts a new approach or technology, they are primarily responsible for the costs of installing new systems. They are also responsible for absorbing significant costs incurred (which may be substantial) if the technology fails, such as fines, sanctions or related health, environmental or economic consequences (e.g. disease outbreak, impact on local water recreation). Provincial authorities also share the burden of responsibility and tend to exercise caution in approving new approaches.

Opportunities that explicitly identify and share the risks faced by municipalities and utilities could increase the uptake of innovative approaches and new systems which may yield a wider range of benefits, such as higher effluent water quality, reduced carbon footprint, or recovery of beneficial resources. This could be supported by higher levels of government through the provision of financial incentives or backing of financial safety nets, as well as the ability to waive or offer regulatory flexibility when the purpose is to incent worthwhile innovations and trials. Risk and cost-sharing can also be accomplished by partnerships among utilities (e.g., Water Services Association of Australia and United Kingdom Water Industry Research) or through public-private partnerships (P3s).

Ongoing and predictable funding programs for water and wastewater, and adequate support for remote, rural and Indigenous communities, are ongoing challenges in Canada. For some municipalities and utilities, there is a need to make major investments to achieve minimum standards, including many coastal communities, smaller systems, Northern communities and most Indigenous communities. An opportunity exists to take advantage of the investments needed to achieve minimum standards (or potentially modified targets in the North) to go beyond these minimum requirements to reduce more risks and achieve more benefits.

4.3.2 Combining regulatory and non-regulatory approaches

Regulatory options have a bearing on wastewater investment decisions. They are a command-and-control approach in which the government requires stakeholders to comply by law to attain a given objective. For example, federal and provincial water quality performance standards on individual contaminants or technology-based standards are regulatory tools. Additional non-regulatory approaches, such as taxes, charges/fees, tradeable permits, subsidies and monetary incentives such as grants or access to financing, can also be designed to complement regulatory efforts.

Combining incentives with regulatory approaches has the potential to promote more efficient or cost-effective solutions that satisfy regulatory requirements and achieve more environmental and societal benefits. For example, the Treasury Board of Canada's Cost-Benefit Analysis Guide provides guidance on assessing the use of regulatory and non-regulatory (e.g., financial or performance-based) instruments to maximize net benefits to society as a whole (Treasury Board of Canada Secretariat, 2007). Greater flexibility to achieve objectives and choose technologies that are appropriate to the local context are important considerations when selecting policy approaches. A broader consideration of a suite of policy options that can be combined to help move beyond minimum standards could include regulations, market instruments, incentives, capacity building, information and education, governance structures and financial incentives (Canadian Urban Institute et al., 2010). Some examples are discussed below.

4.3.3 Supporting the uptake of innovation

For technology-based innovations, incenting pilot and full-scale demonstrations has frequently been identified as a key need in the path to uptake of new, beneficial technologies that can achieve more than minimum standards. An opportunity exists to demonstrate the ability for proven technologies to meet regulatory requirements, achieve co-benefits and address future wastewater management challenges. Some examples of programs that support water-related innovation include: Showcasing Innovation (Ontario), Alberta Innovates, the Southern Ontario Water Consortium and the Federation of Canadian Municipalities Green Municipal Fund. Opportunities also exist to promote uptake and technology transfer by providing financial or regulatory incentives, such as expedited approvals processes. For example, Ontario has an innovative technology verification pilot project for market-ready municipal wastewater treatment technology that involves third-party verification of technology performance and streamlines the permit application process (Government of Ontario, 2018).

Financial tools are used in some jurisdictions to penalize non-compliance and reward performance that exceeds compliance limits. For example, in addition to effluent quality regulations, Germany has a federal Waste Water Charges Act which levies fees when contaminant-containing wastewater is discharged into water bodies (Federal Ministry for the Environment Nature Conservation and Building and Nuclear Safety, 2016). The charges vary according to the noxiousness of the wastewater, taking into account oxidizable substances, phosphorus, nitrogen, organohalogens, several heavy metals and the toxicity of the effluent to fish (German Law Archive, 1998). This polluter-pay based fee provides an economic incentive to reduce the impacts of effluents on receiving waters. Switzerland, on the other hand, has chosen a stronger regulatory approach to address trace organic contaminants by legislating nationwide an 80% reduction in trace organic contaminants for WWTPs serving large populations or discharging to sensitive waters (Eggen et al., 2014; The Federal Assembly of the Swiss Confederation, 2017). Upgrades are supported by a federal fund (which covers 75% of total costs) and a sewerage tax paid by wastewater producers, according to the polluter-pays principle (BAFU, 2012; Swiss Federal Institute of Aquatic Sciences and Technology, 2015).

Another opportunity that has been embraced by some jurisdictions to address the complexities of watershed management, is the move to regulations that use receiving-water conditions and cumulative impacts as the basis for setting performance goals. These types of regulatory approaches can address future needs for wastewater management in Canada by enabling the development of goals that provide the best overall benefits for a given region. This is an approach that is already being taken by some individual provinces, though to varying degrees and not as a legal requirement, similar to the approach used in the U.S. Clean Water Act. Monitoring and enforcement, although challenging, are critical within a watershed-based approach. Innovation in WWTP operations can also be encouraged by recognizing and rewarding leadership, as promoted in the PEX StaRRE program in Quebec (Case Study #9).

CASE STUDY #9

PEX StaRRE — Quebec's Wastewater Excellence Program

The province of Quebec has introduced programs to support and incentivize the use of performance evaluation tools to achieve water quality parameters that exceed provincial regulations. The PEXEP-Treatment (PEXEP-T) drinking water excellence program, coordinated by Réseau Environment, was introduced to municipalities in 1999. For more than a decade, this program has been funded by member participants. The program is an adaptation of the American Water Works Association's (AWWA) *Partnership for Safe Water* program. There is a certification process involved, and each step is subject to peer validation on the basis of established criteria.

Following the success of PEXEP-T, a new wastewater excellence program was developed by Réseau Environment in 2015. PEX StaRRE is a continuous improvement program that surpasses provincial regulatory requirements. The program aims to improve wastewater effluent quality, optimize operations and maximize resource recovery. Equipment, operational and administrative performance indicators encourage optimization, and utilities that demonstrate progress are recognized by their peers at an annual awards ceremony.

There are currently eight member municipalities participating, which serve a total population of 1.5 million people (out of 8.2 million in Quebec). The members have been reporting a yearly baseline of performance data for future referencing. On March 23, 2017, the Water Environment Federation (WEF) and AWWA signed a memorandum of understanding with Réseau Environnement to collaborate on the development of an equivalent program in the United States. The WEF has thus initiated its WATER STARRE (sustainable treatment and resource recovery excellence) program.

Contributed by Dr. Yves Comeau, Professor, Civil, Geological and Mining Engineering, Polytechnique Montréal and is based on information from CentrEau, 2017; Réseau Environnement, 2016a, 2016b.

4.3.4 Increasing confidence by building a better coordinated knowledge base

Other policy instruments that exist to support innovative solutions include capacity building and effectively using existing information. Addressing future wastewater challenges will require an ability to efficiently advance and disseminate knowledge about how wastewater and receiving environments are changing and their response to management approaches. This will empower us to make better decisions and ensure an adaptive management approach. A significant opportunity exists to build capacity and facilitate the sharing of research and practice knowledge across jurisdictions, not only of technology performance to support technology transfer, but of the efficacy of different governance structures and approaches (CCME, 2006). This may include connecting existing expertise and knowledge across Canada, including Indigenous knowledge on land use activities and research from Northern and remote communities, to make the most of existing resources, both infrastructure and expertise, to support innovation and progress. This is particularly important given reduced federal research capacity, as occurred with the closing of the Burlington Wastewater Technology Centre. Private companies often perform required research on an ad hoc basis, but this knowledge does not necessarily enter the public domain. Undertaking this opportunity requires knowledge compilation, as well as coordination, synthesis, interpretation and the dissemination of insights. This is critical to supporting development of management and operational capacity of wastewater policymakers and practitioners. The Intergovernmental Panel on Climate Change is one example of an effective model that directs and collates research on a complex topic and generates actionable recommendations.

5. Getting to Future-Ready Wastewater Systems

5.1 Summary of key messages

Through the course of the expert panel's consultations and deliberations, a number of key messages emerged:

A risk-based management approach, based on a commitment to environmental monitoring and adaptive management, is required to address the multiple concerns and uncertainties now being faced by the wastewater industry.

The list of contaminants of known or potential concern for humans and the environment is already long and will continue to grow. There will always be uncertainty. The current paradigm of contaminant-by-contaminant regulation needs to be augmented with adaptive risk management approaches that explicitly recognize the complex mixture and uncertainties that characterize wastewater, and a precautionary approach applied going forward. This must be coupled with an increased focus on environmental monitoring to detect potential risks, advance our understanding of them, and identify best approaches in an adaptive framework for subsequent use. This continuous improvement "feedback loop" of measuring, analyzing and incorporating the science as it advances, using adaptive management, is especially critical for on-site application.

Wastewater management should be embedded in an integrated watershed approach that considers source control as an equally important component within a multi-barrier approach to addressing risk.

Wastewater treatment is a critical element of managing our impacts on the environment, but is not always the only (or best) choice for dealing with particular contaminants. Wastewater management should be situated within the context of the watershed, and the approaches considered should include those that avoid adverse impacts and have the potential to improve the ecosystem. Monitoring allows the risk of cumulative impacts to be assessed and can also allow strategic and efficient responses (e.g., a multi-sectoral approach, source control, etc.). Within this broader picture, in situations where treatment feasibility is low and the potential risk is high, alternate approaches — such as source control or water quality trading — might be more effective and rational, as part of sewershed and watershed management.

Although regulatory standards provide a base to build from, policies, practices, technologies and other solutions that make sense for a community and provide additional benefits for society and the environment should be incented and rewarded.

Municipalities and utilities upgrading their wastewater infrastructure should view regulatory standards as a minimum baseline and should aim to achieve stricter targets as much as possible, to protect health and provide additional benefits to society and the environment. Given that the costs of technologies with co-benefits may be incremental over basic upgrade costs, facilities undergoing upgrades to meet and exceed regulatory requirements are well-poised to make progressive upgrades and advances. If infrastructure funds are available, incentives to make more progressive decisions, including those with co-benefits, could provide the maximum benefit to society and the environment. Incentives to achieve results beyond minimum compliance do not necessarily have to be financial in nature. Professional accreditation and peer-assessed benchmarking programs demonstrate responsible stewardship and effective management and are excellent motivators for municipalities and utilities.

Canada needs to develop a clearer picture of its national wastewater sector, including sewer separation practices.

There is a need for access to comprehensive and current data on wastewater operations, collection systems and effluent parameters across Canada. This would enable decision makers to determine, on a national level, the current state and progress toward targeted goals. The availability of operational and performance data nationwide would support more effective water management decisions. Curtailed regulatory capacity, excessive layers of reporting, the loss of municipal water and wastewater surveys, and reduced stakeholder engagement in many jurisdictions all need addressing. There is an opportunity to optimize and build on existing systems to provide these data. This can include mining what we already have in government-funded research databases, as well as bringing back the federal municipal wastewater survey. This would also include information sharing among wastewater operators. It should be noted that operational data does exist with the provinces, but it is not coordinated at the national level.

Selection of best wastewater management solutions that protect human health and environmental services must be driven by Canada's diversity of geographic and cultural settings.

There are diverse contexts for wastewater treatment and effluent discharges across the country, which dictate capacity, available technologies and effective solutions. For example, smaller remote Indigenous communities and remote communities in general may not have (or necessarily need) centralized wastewater systems; they would benefit from other approaches, like composting toilets or communal systems. Design of systems in the Far North must consider lengthy periods of frozen soils, ice cover and lower temperatures, which impact the performance of wetlands and lagoon systems. In the Prairies, free-flowing waterways are in short supply in many areas, and communities instead rely on facultative lagoons. In these situations, building and managing well-performing lagoon systems will benefit human and environmental health. If not already in place, some of these approaches could be pursued immediately with relatively minimal investments.

Innovations that help to reduce multiple or uncertain risks, while improving overall societal and environmental outcomes by delivering co-benefits, should be encouraged and incented.

In the face of uncertainty about contaminants of emerging concern, investment in primary removal targets for conventional contaminants that also recover resources and reduce GHG emissions can immediately result in water quality improvements and a reduced environmental footprint. Treatment processes to address regulated contaminants can also be optimized to achieve greater removal of some contaminants of emerging concern, providing a risk-reduction co-benefit. There are resources that can readily be recovered, like energy from improved solids digestion, heat recovery from waste streams themselves, and valuable nutrients (e.g., phosphorus) from the biosolids. Given growing considerations about GHG emissions and some resource scarcity, the definition of reducing environmental risks and maximizing benefits to society has expanded. The business case for some types of resource recovery and co-benefit values is still in its infancy in Canada, but is growing steadily. More stringent regulations, carbon pricing, targeted resource scarcity, optimized energy use and financial incentives are all likely to make these approaches more important in Canada.

There is a need for active and integrated research to support science-informed decision making and technology transfer in wastewater management. Environmental monitoring is needed to assess effects, as well as to determine whether management actions are achieving sustainable environmental benefits.

There is a need to support research that advances our knowledge of how various management options, including treatment, can help reduce risks. To better understand the potential for risks and impacts, we need a consistent monitoring program for wastewater contaminants and effects across the country. This program could be established through carefully planned pilot studies at selected sites to assess environmental risk. Canada can make the most of current infrastructure, professional expertise and operational performance. There are also opportunities to:

- Use and augment existing research excellence across Canada
- Continue re-building strength in government-funded research
- Build upon and improve Indigenous training programs and engagement
- Coordinate a compilation, synthesis and sharing of wastewater research and technology transfer case studies

The integration of knowledge, including Indigenous knowledge, with forward-thinking decision making supports innovation and progress, but will require mechanisms to coordinate, prioritize, synthesize and disseminate existing and future research and insights. In addition, funding the research and technology transfer itself is necessary.

5.2 Panel's response to the mandate from Canadian Water Network

The panel set out to address three core questions, which drove the subsequent work and findings in this report. What follows is an overarching summary of its findings within this context:

Which wastewater contaminants do we need to worry about most, now and in the future?

Vigilance is still needed to ensure we address conventional and known contaminants in all locations and not just in large urban centers. Removal of organic matter and elimination of pathogens remain critical objectives of wastewater treatment. Nutrients require continuous monitoring to determine where additional reductions from wastewater sources are needed. Some CECs, such as estrogens (endocrine disruptors), may represent a meaningful risk to the environment; however, evidence in the literature shows clearly that well-operated, conventional treatment can help reduce their exposure in the environment.

Within the long list of CECs, the reality is that science has not yet established which CECs are the "most important" contaminants. Informed decisions on what actions to take in the face of uncertainty need to be guided by a risk-based framework. Environmental monitoring for biological and other effects is necessary to understand and address these uncertainties, given the continual use and discharge of novel compounds and the diversity of receiving environments.

What are the options for our diverse Canadian communities to address these contaminants through wastewater treatment?

There are established and evolving technologies to address conventional and known contaminants, and it makes sense to leverage what we know to identify where optimizing their use will also likely provide risk reduction of CECs. When making upgrade investments to meet stricter effluent standards or increase capacity, there are strong opportunities to optimize existing processes and retrofit with improved technologies.

Treatment is only one element of wastewater management, and the effectiveness of other options like source control, sewer separation and the use of non-technology options should also be given strong consideration.

What are the important opportunities and trade-offs involved in those treatment choices, including resource recovery, costs, socio-economic and cultural fit, and implications for related issues like greenhouse gas emissions?

Increased treatment and associated costs may have greater impacts (e.g., energy footprint) and may transfer risk to other places, particularly through residuals management. This heightens the importance of broader cost-benefit considerations and potential opportunities for co-benefits. There is an increased global focus on the co-benefits provided by different approaches and the significant socio-economic benefits of resource recovery. The environmental benefits of reductions in energy use and GHG emissions should be prioritized and incentivized.

The best technology options can be unique to the geographic area, the receiving water requirements and the local cultural setting. Inevitably, the approach that makes the most sense from an environmental perspective, and is cost-effective and sustainable, should be encouraged. Recognizing the uncertainty associated with future conditions and priorities requires decision making today that captures a broader set of societal and environmental considerations, such as: adaptability, applications of the precautionary principle, resilience, socio-economics and emerging risks. All will support “future-ready” wastewater systems.

5.3 Moving forward

Controlling conventional contaminants remains a known and central challenge that must continue to be addressed and which drives much decision making, investment and technology evolution. Beyond managing conventional and established contaminants, we are now at a point of deciding what the biggest risks are from a long and growing list. Trying to deal with them all through treatment has tremendous costs and trade-offs (e.g., energy and resource use). We are making decisions now that involve major infrastructure expenditures and have long-term implications for what our systems will be able to do. However, we cannot suspend decision making until we are more certain. Therefore, there is a need to make investment decisions that make the most sense. Decision makers must act (and adapt) in the interest of human and environmental health, despite the uncertainties.

Strategic investments, in concert with forward-thinking and flexibility in final design, can advance the uptake of innovation that will support defensible, long-term investments in wastewater infrastructure. Sufficiently stringent regulatory requirements that establish minimum standards must be combined with conditions that support on-site innovations to reach beyond these minimums.

5.4 Blueprint for federal action

1. Work with all stakeholders (provincial, territorial, local and Indigenous rights holders) to continue to apply and further develop an effective risk management approach to deal with the complexity and changing nature of chemical mixtures in wastewater and their observed effects in the environment and on human health. The precautionary principle approach, based on best science and Indigenous knowledge, and inclusive of uncertainty and adaptive management, would be core to this work.

2. Establish a coordinated and meaningful national system of collecting, assessing and sharing data on wastewater treatment among municipalities and utilities in Canada. Consider re-establishing something similar to the Municipal Water and Wastewater Survey, with Indigenous input, as well as a nationally accessible database. Effective collaboration between provinces, territories, Indigenous and the federal government is required to build this database.

3. Incent and reward innovation to move beyond current minimum regulatory standards, thus continuing to minimize risk and maximize benefits for society and the environment. Encourage an assessment of new or amended treatment technologies, using research and pilot testing, to generate a menu of solutions to guide investment decisions. This would include a compendium of key examples focused on how co-benefits can be derived from optimization and innovation in wastewater management. These actions would support Canada's infrastructure program for wastewater system upgrades, including resource recovery.

4. Support a site-specific, risk-based receiving environment approach to regulations, monitoring and water quality objectives. This would also incentivize jurisdictions to develop source water protection programs that include sewershed protection plans and prioritize options for source control. Recognize where keeping contaminants out of systems is more effective than trying to remove them from wastewater through treatment.

5. Embed wastewater management considerations, wherever possible, within an integrated watershed approach to water management and governance, including the possibility of water quality trading. In addition to source control, other non-technical opportunities could be considered to address and reduce risk to local communities and the environment.

6. Coordinate investment in science and Indigenous knowledge-based research and technology transfer to improve the understanding of risks and recognize meaningful co-benefits (e.g., Centres of excellence, data dissemination, success/failure case studies, pilot plant studies, coordination of research, process certification). This initiative will be challenging, but is much needed, and must be spearheaded by the federal government and Indigenous governments across Canada.

7. Develop a federal initiative to require a future-ready strategic planning document as a condition for immediate and long-term funding, with input from all stakeholders as well as consideration of resource recovery and implementation timelines. This will support the funding of proven and promising technology and the flexibility to choose community-tailored solutions that are appropriate, robust and will have the greatest beneficial impact.

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List of Supporting Documents

Supporting Document 1: National Questionnaire Results Summary

- Questionnaire analysis & summary
- Copy of questionnaire distributed

Supporting Document 2: Wastewater Treatment Practice and Regulations in Canada

- Current wastewater treatment practice in Canada
- Regulations pertaining to wastewater treatment in Canada and in other jurisdictions

Supporting Document 3: Contaminants in Municipal Wastewater Effluents

- Major contaminant groups and impacts on environment and/or human health

Supporting Document 4: Technology Scan for Wastewater Treatment

- Table of major wastewater treatment technologies and known trade-offs and co-benefits

Appendix 1: Glossary

For the purposes of this report, the following definitions were employed:

Environmental monitoring refers to systematic programs to measure individual constituents in aquatic environments impacted by wastewater effluent (characterization) and measuring impacts or effects in an aquatic ecosystem, including aquatic species populations and health.

Recoverable wastewater resources commonly include water (WWTP effluent improves the quality of the discharge; groundwater recharge; water reuse), nutrients such as phosphorus and nitrogen, energy and biosolids. Some of the benefits of recovering resources include net GHG reduction and credits (carbon footprint considering inputs of energy, chemicals and outputs of liquid effluent, biosolids, gases like methane, nitrous oxide and volatile organic compounds and energy (e.g., heat and power)).

Sewer collection system, also referred to as a sanitary collection system, consists of pipes or conduits and pump stations which convey wastewater, and sometimes stormwater in the case of combined sewers, to the WWTP.

Surface water can include a lake, pond, marsh, creek, spring, stream, river, estuary or marine body of water, or other surface watercourse.

Contaminants of Emerging Concern are non-conventional contaminants in wastewater effluents that were not detected previously, and which pose risks to human and environmental health that are not yet fully understood. In literature, these contaminants have also been referred to as emerging contaminants, emerging substances of concern, trace contaminants, micropollutants or microcontaminants.

Trace organic contaminants refers to a diverse and expanding array of natural and anthropogenic substances and their metabolites detected in wastewater effluents. For the purposes of this report, trace organic contaminants is used to collectively describe endocrine disrupting compounds and pharmaceuticals and personal care products.

Wastewater is a mixture of liquid wastes, primarily composed of domestic sewage, which can also include other liquid wastes from industrial, commercial and institutional sources.

Wastewater treatment plant (WWTP) is the term used in this report, although this term is being replaced in some jurisdictions with water resource recovery facilities (WRRFs), in recognition of a more holistic approach to urban water management. Municipal WWTP refers to a local or regional government or utility, or provincial or Indigenous-owned facilities which receive collected wastewater for treatment and release into the environment.

Wastewater treatment levels (liquid stream):

Preliminary treatment involves screening, shredding or grinding to remove coarse solids such as sticks, rags and other debris from the incoming wastewater. The purpose of preliminary treatment is to protect downstream treatment components like pumps and reduce maintenance or operational problems. Preliminary treatment is a common first step in all WWTPs.

Primary treatment follows preliminary treatment and involves the use of primary devices that allow flows to be reduced and for solids to settle due to gravity. Commonly, sedimentation tanks detain flows for 2 to 6 hours to allow solids to settle and be drawn off for separate solids treatment. Typical BOD_5 and TSS removal rates in primary treatment are 30% and 60%, respectively. On stand-alone primary treatment, primary effluents can be treated with chemical disinfection prior to release. Primary treatment can also be enhanced using chemicals in which inorganic or organic flocculants are introduced into the wastewater to help improve the effluent quality over primary treatment alone.

Secondary treatment normally follows primary treatment and is specifically designed for the removal of biodegradable organic matter (in solution or suspension) and the removal of suspended solids. Secondary treatment can include nutrient removal. Typical wastewater effluent quality achieved is a $CBOD_5$ and TSS of 15 mg/L. The physical, chemical and biological processes in the process design may also fortuitously (not by design) remove other trace contaminants at unpredictable levels.

Lagoons (or stabilization ponds or aerated facultative lagoons) are one of the more common biological treatment processes used in Canada, principally due to low cost and simplicity of operation. Effluent quality from lagoon systems varies, depending on the type, size and configuration of the treatment cells (i.e., anaerobic, facultative, aerated or storage cells) and operational mode (i.e., seasonal or continuous discharge mode). A lagoon system with several months of storage capacity, such as systems with once-per-year discharge, can consistently produce very good effluent quality if the biological activity is not hindered. Recognizing that effluent quality varies with the size, type, configuration and retention time, a range of wastewater effluent quality can be achieved for $CBOD_5$ of 5 to 25 mg/L and for TSS of 10 to 30 mg/L. Compliance standards are commonly set higher to allow for operational variability.

Tertiary treatment is the additional treatment needed to remove suspended, colloidal and dissolved constituents remaining after conventional secondary treatment (Metcalf and Eddy 2003). In Canada, this term can refer to physical processes that further remove suspended solids, such as sand filtration. Tertiary treatment may include biological processes for removal of nutrients. Typical tertiary effluent $CBOD_5$ and TSS values are 5 mg/L. The movement of trace contaminants and metals from the liquid to the side streams is generally enhanced due to the additional physio-chemical or extended processes which are involved.

Nutrient removal refers to treatment steps used to remove nitrogen and phosphorus from MWWE. Common types of nutrient removal treatment methods include nitrification (i.e., conversion of ammonia to nitrates), denitrification (i.e., conversion of nitrates to nitrogen gas), and chemical or enhanced biological phosphorus removal. These processes can be incorporated into either primary, secondary or tertiary treatment for enhanced removal of nitrogen or phosphorus (or both) to protect sensitive receiving environments. Typical systems with nutrient removal can achieve wastewater effluent concentration levels of total phosphorus down to 0.1 mg/L, total ammonia-nitrogen down to 5 mg/L in winter and less than 1 mg/L in summer. Total nitrogen (TKN + NOx) or 10 mg N/L can also be achieved.

Disinfection of wastewater effluent is typically accomplished by using appropriate dosages of chlorine, hypochlorite or ultraviolet (UV) radiation. Disinfection systems are designed to achieve low levels of indicator microorganisms such as *E. coli* in the range of 100 counts per 100 mL.

Advanced or quaternary treatment refers to the treatment processes that are used to further enhance the quality of wastewater effluent beyond that produced by tertiary treatment. This level of treatment is required where enhanced source water protection is required or for water reuse applications. Advanced treatment technologies include membrane filtration, reverse osmosis, advanced oxidation processes and (physical and biological) activated carbon technologies.

Wastewater solids:

Sludge refers to the solids that are settled out at various points in the wastewater treatment process (e.g., primary sludge, waste activated sludge, secondary sludge, etc.). These solids cannot be removed from WWTPs without further treatment.

Biosolids is material after it has been stabilized in a digestion process. Stabilization decomposes the solids, reduces odours and destroys most of the pathogens in the material.

Appendix 2:
National Expert Panel on Wastewater Contaminants

Donald Mavinic
Expert Panel Chair
Professor, Civil Engineering, University of British Columbia

Donald Mavinic, PEng, PhD, is an internationally recognized expert in wastewater treatment. He has received numerous awards in recognition of his achievements, including the Ernest C. Manning Innovation Award, NSERC Synergy Award, Killam Senior Research Award and the Meritorious Achievement Award from APEGBC. In 2016, he was awarded a gold medal by Engineers Canada.

Dr. Mavinic received international acclaim for leading the development of a cost-effective system to recover phosphates from municipal wastewater systems, which has subsequently been patented and adopted by cities across North America. As a consultant, he has advised more than 50 government agencies and engineering firms worldwide. His broad knowledge of the industrial, community and regulatory issues and knowledge needs both in Canada and internationally will be an asset in his role as chair of an expert panel.

Susheel Arora
Director of Wastewater and Stormwater Services
Halifax Water

Susheel Arora, MASc, PEng, is the Director of Wastewater and Stormwater Services for Halifax Water, where he is responsible for the overall operations of wastewater collection, treatment and biosolids management. Susheel leads several strategic programs for Halifax Water, such as wet weather management, biosolids management, treatment plant optimization, operations maintenance management and national benchmarking. As a senior utility executive, Susheel also participates in several other utility initiatives such as integrated resource planning, IT master planning, rate making, asset management and capital planning. He is an active member of Engineers Nova Scotia and holds two master's degrees; one in environmental engineering and the other in applied science. Susheel is also a graduate of the general management program from Harvard Business School.

Susheel has worked in water and wastewater for over 20 years, and is a member of the Water Environment Federation, American Water Works Association and International Water Association. He has participated in various committees and expert panels at a national level, including InfraGuide Best Practices for Wastewater Treatment Plant optimization.

Cecelia Brooks
Director of Research and Indigenous Knowledge, Mi'gmawe'l Tplu'taqnn; Water Grandmother, Canadian Rivers Institute

Cecelia Brooks is the director of research and Indigenous knowledge for Mi'gmawe'l Tplu'taqnn, a rights-based Mi'gmaq Chiefs organization with a mandate to promote and support the recognition, affirmation, exercise and implementation of the inherent, Aboriginal and treaty rights of the Mi'gmaq people in New Brunswick. Cecelia is also a Water Grandmother (Samaqan Nuhkumoss) with the Canadian Rivers Institute at the University of New Brunswick. In this role, she has worked on building awareness about water quality, conservation and wastewater treatment alternatives, and encouraged educational opportunities for First Nations youth in water and environmental sciences. She continues to serve on advisory boards and committees as a conduit for information sharing with First Nations leadership, Elders and other community members.

Cecelia previously served as the science director for the Maliseet Nation Conservation Council, where she worked with Maliseet (Wolastoqiyik) and Mi'gmaq community groups, Elders, government and non-governmental organizations to build partnerships and identify potential collaborations. She worked closely with Elders and knowledge holders to develop an effective and respectful method of paralleling Indigenous knowledge with scientific knowledge. Cecelia authored a chapter on traditional knowledge in the 2011 State of the Environment Report for the Saint John River (Wolastoq) with the Canadian Rivers Institute.

Yves Comeau
Professor, Geological and Mining Engineering
Polytechnique Montreal

Yves Comeau is a specialist in biological wastewater treatment. He is the director of the Laboratory of Environmental Engineering at Polytechnique Montréal and CREDEAU research centre. His research is focused on wastewater treatment to remove nutrients to minimize sludge production, and on modelling. Dr. Comeau holds a BEng from Polytechnique Montréal, as well as a MASc and PhD from the University of British Columbia. Before joining the department of civil engineering at Polytechnique Montréal, he worked as a consultant in Montréal and Vancouver. Yves was the President of the Canadian Association for Water Quality from 2003 to 2006.

Mike Darbyshire
General Manager
Alberta Capital Region Wastewater Commission

Mike Darbyshire has been the general manager of the Alberta Capital Regional Wastewater Commission (ACRWC) since 2007. He holds a bachelor of science in civil engineering from the University of Alberta. Mike's career has been focused on water and wastewater utility management in local government in British Columbia and Alberta.

At ACRWC, Mike leads a diverse team to deliver wastewater servicing to thirteen communities in the Edmonton metropolitan region. He helped develop the Edmonton Region Biosolids Strategy and sits on the advisory committee tasked to help implement the Province of Alberta's Water Management Framework for the Industrial Heartland and Capital Region.

Mike is currently a member of the Canadian Municipal Water Consortium's leadership group. Previously, he served as a board member of the Canadian Water and Wastewater Association representing utility members from Alberta and is a past-president of the association.

Karen Kidd
Steven A. Jarislowsky Chair in Environment and Health
McMaster University

Karen Kidd is a leading and internationally-renowned researcher in how municipal, industrial and other anthropogenic activities impact the health of aquatic organisms and food web structure, and in the fate of persistent contaminants in freshwater and marine ecosystems.

Karen held a Tier 1 Canada Research Chair in Chemical Contamination of Food Webs at the University of New Brunswick. She led the seminal research on estrogen impacts on ecosystems at the Experimental Lakes Area and was co-editor of an international United Nations Environment Program and World Health Organization report on the state-of-the-science on endocrine disrupting chemicals.

Theresa McClenaghan
Executive Director, Canadian Environmental Law Association

Theresa McClenaghan was appointed as the executive director of the Canadian Environmental Law Association (CELA) in 2007. She holds an LLB from Western University and an LLM in constitutional law from Osgoode Hall Law School, as well as a diploma in environmental health from McMaster University. She was called to the Bars of Manitoba and Ontario.

Focusing on environmental health and environmental safety in the areas of energy and water, Theresa has practised public interest environmental law for over twenty-five years in private practice and at CELA since 1998. From 2006 - 2007, Theresa was a senior water policy advisor to the Ontario Minister of the Environment, where she was responsible for overseeing the passage of the Clean Water Act and implementation of the remaining Walkerton Inquiry recommendations.

Theresa has represented clients at the Supreme Court of Canada, Federal Court of Appeal and Trial Division, and the Ontario Court of Appeal. She was co-counsel representing Walkerton citizens in both phases of the Walkerton Inquiry, and has appeared on behalf of her clients at a variety of environmental, land use and energy tribunals. Theresa is also a co-author of the recently published 3-volume annotated Ontario Water Law.

Mark Servos
Canada Research Chair in Water Quality Protection,
University of Waterloo

Mark Servos is a world leading researcher in the area of environmental assessment and risk of trace contaminants, including pharmaceuticals and personal care products. He has participated in many national and international projects and panels, including the European Union's sixth framework project on pharmaceuticals and the environment (ERAPharm) and the SETAC expert panel that examined the wastewater issue in Victoria, British Columbia. Dr. Servos and his group have been leaders in conducting detailed studies looking at the fate and effects of contaminants in wastewater effluents on responses in fish, from genes to communities. Their recent work has documented the recovery of fish in receiving environments in response to major infrastructure upgrades in wastewater plants discharging to Canadian rivers.

Appendix 3: Invited Working Session Experts

Barbara Anderson
(Retired) Ontario Ministry of the Environment and Climate Change

Nicholas Ashbolt
Professor, School of Public Health, University of Alberta

Ken Ashley
Director, Rivers Institute, British Columbia Institute of Technology

Siobhan Burland Ross
Manager, Environmental Approvals, Municipal and Industrial Section
Manitoba Sustainable Development

Paul Clow
Senior Municipal Planning Officer, Government of Nunavut

Patrick Coleman
Principal Process Engineer, Black & Veatch

Tim Fletcher
Manager, Water Standards, Ontario Ministry of the Environment and Climate Change

Steve Hrudey
Professor Emeritus, Analytical and Environmental Toxicology, University of Alberta

Ken Johnson
Associate, Stantec Consulting

Alexis Kanu
Executive Director, Lake Winnipeg Foundation

Megan Lusty
Manager of Municipal Works, Government of Nunavut

Matthew McCandless
Executive Director, IISD Experimental Lakes Area Inc.

Susan McKay
Head, Wastewater Risk Management, Environment and Climate Change Canada

Mark McMaster
Research Scientist, Environment and Climate Change Canada

Jan Oleszkiewicz
Distinguished Professor, Civil Engineering, University of Manitoba

Wayne Parker
Professor, Civil and Environmental Engineering, University of Waterloo

Peter Ross
Director, Ocean Pollution Research Program, Vancouver Aquarium

Dean Shiskowski
Vice President, Water Resource Recovery, Associated Engineering (BC) Ltd.