‘Contaminants of emerging concern’ in wastewater: Are current analytical technologies, policy development and industry guidelines enough to protect human and ecological health?

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1.0 Executive Summary

1.1 Background

The presence of 'contaminants of emerging concern' (CEC) in water sources is a well-documented phenomenon. The term CEC is broadly defined as compounds present in water sources that are not monitored or regulated currently. Research has shown that CEC discharged from wastewater treatment plants (WWTPs) are present in downstream freshwater sources, which are relied upon for drinking water and fish habitat. However, the lack of a CEC regulatory framework for WWTPs combined with the narrow characterization of CEC as discrete chemicals without understanding the cumulative and synergistic impacts of these chemicals upon human and ecological health has resulted in a knowledge gap. Consequently, CEC scientific knowledge has not yet been translated to support the development of evidence-based decision-making tools and legal regulations that could protect freshwater sources, ecosystems, and human health, and be relied upon by municipalities and First Nations that are charged with operating WWTPs.

1.2 Objectives

Four objectives were achieved in this research:

a) To classify the types, numbers and effects of CEC currently documented in wastewater through a comprehensible and multi-sectoral search of scientific, legal and grey literature.

b) To determine if and how CEC in wastewater is monitored and measured using literature data and interviews of relevant experts.

c) To examine the operational burden imposed upon industry and municipalities by a risk-management CEC monitoring regime (and how monitoring might look) using interviews of industry and policy experts.

d) To compare international, national, provincial, and municipal legal frameworks to inform the development of a regulatory response that could consider Indigenous knowledge and the categorization of CEC compounds while being protective of human and ecological health.

1.3 Results

The definition of CEC has morphed into an open-ended and ambiguous term. In general, the term CEC is used to describe any compound detected in water sources that may cause an adverse impact on human or ecological health and is not monitored nor regulated under current environmental laws nor wastewater regulations that apply to a WWTP. Research has shown that CEC discharged from WWTPs are present in downstream freshwater sources. Many of these water bodies are relied upon for drinking water and habitat for fish, wildlife and microbiota, yet are impacted by chemical pollution. Currently, this CEC scientific knowledge has not yet been translated to support research on CEC WWTP removal technologies, evidence-based decision-making tools, nor to reform wastewater legal regulations that could protect human and ecological health.

This research highlights that further research is needed to understand the opportunities for technology innovation in the WWTP sector, the infrastructure costs needed to protect human and ecological health, and how Indigenous knowledge and First Nation communities are directly affected by this issue but are absent in the literature, regulatory regimes and WWTPs practices. With over 600 CEC recognized in the literature, our research was focussed on identifying the scope of the CEC classification system, and led to examining three CEC case studies (i.e., pharmaceuticals (PhACs), microplastics (MPs) and per- and poly-fluoroalkyl substances (PFAS)) to understand the knowledge gap in WWTP sector regarding the impact of CEC on human and environmental health, and whether Indigenous knowledge is considered. CEC lifecycle impacts, CEC transformation by-products, and their synergetic and cumulative effects that are currently documented in WWTP research, along with monitoring techniques in WWTP and the receiving environment, have all been considered. The comprehensive interdisciplinary literature review has led to three manuscripts that are currently being prepared for publication. Our findings using investigative surveys via interviews of experts (i.e., operators, engineers, and policymakers) suggest opportunities for innovative technologies in partnership with private industry and that the WWTP sector is highly responsive to legislation requirements. It appears CEC will only be monitored in a WWTP once these compounds are identified as a risk to human health suggesting further research and funding is needed. The dominant regulatory idea advanced by regulators and supported at a municipal level is preventing CEC from entering the municipal wastewater system by stopping the release of CEC at the source (i.e., industry, commercial) rather than an end-of-pipe regulatory regime that places the costs upon municipalities, and ultimately, taxpayers. In other words, advancing corporate environmental responsibility is key. Missing is a normative legal framework that advances contemporary environmental law principles and the linkages to public health standards as well as corporate social responsibility norms such as a sustainable WWTP governance framework based on principles of subsidiarity, sustainability, precautionary principle, user-pay, inter/intra generational equity, and transparency for citizens.

1.4 Key Messages

1) The classifications and number of compounds that fall under the CEC definition is growing each year — to date, at least 600 CEC are known to exist.

2) Most experts agree that there is little to no data on the risks imposed by CEC in WWTP effluent streams.

3) Current analytical methods are sensitive enough to detect compounds at parts per billion (ppb), however, because the risk to human health is uncertain a regulatory push to legislative a CEC WWTP monitoring regime is lacking.

4) Most experts advocate for source regulation that prevents CEC from entering the municipal wastewater system, and for regulation directed at the source provider (e.g., industry).

5) Wastewater treatment systems need to be modernized to address chemical pollution. Innovative research directed at CEC removal techniques, and to determine if, and how these techniques can be scaled from a pilot stage are required. In Canada, wastewater industry modernization is overdue.

6) Most experts indicate that the WWTP industry is responsive to a regulatory push. Currently, no CEC monitoring regulatory framework exists that directs the monitoring behaviour of WWTP operators, and requires the monitoring and detection of CEC in WWTP effluent streams. In effect, this regulatory gap permits operators to overlook CEC pollution because there is no legislative drive to detect or monitor CEC in wastewater streams, and leaves open a public and ecological health gap.

7) In contrast to the drinking water sector, the impact of CEC discharges from WWTP treatment systems (e.g., lagoons) upon First Nations communities is unknown. The focus in the literature appears to be drinking water within First Nations not the connection of wastewater treatment systems to drinking water sources, and effects of chemical pollution.

1.5 Methodology

A qualitative research approach that included a comprehensive interdisciplinary literature review, and 22 interviews with industry and policy experts. The literature review resulted in a broad definition of CEC that included a wide range of compounds and consumer products (for example, personal care products, pharmaceuticals, antibiotics, perfluoroalkyl and polyfluoroalkyl substances (PFAS), and microplastics, to name a few). The scope of the literature review also included CEC lifecycle impacts, CEC transformation by-products, their synergetic and cumulative effects, along with techniques for their monitoring in WWTP and the receiving environment. Finally, we developed three cases studies to better answer the questions: Is a WWTP the most appropriate site to treat and manage the discharge of CEC? And should different treatment and governance strategies be implemented for specific groups of CEC?

2.0 Final report

2.1 Background: CEC in wastewater

Throughout the last decade, the definition of a CEC has been difficult to define precisely as the term “emerging” is relative, and in the literature, CEC has been used to describe recent chemical contaminants and legacy contaminants in the environment where scientific research has raised environmental and health concerns. Regardless of the terminology used, a key question is: What chemical contaminant is considered a high-risk CEC? The uncertain nature of the term reflects the emergent state of scientific research on the characteristics and classification of these contaminants. This uncertainty means CEC can be defined to include all those contaminants recently identified as chemicals of concern that are or are not monitored nor measured in wastewater treatment processes (Lei et al., 2015; Sauvé and Desrosiers, 2014). Overlooked by this broad definition is the risks associated with these compounds over longer periods of time and the possible risk effects of two or more compounds that may synergistically or additively create new risks and impacts. In other words, the cumulative and synergistic effects from CEC pollution requires further research. Recently, industry practices and public discourse have added to the debate on the definition of CEC and has led to expanding the list of CEC. For example, in 2018, in reaction to research findings that recreational drugs were detected in wastewater and then discharged in downstream waters (Bai et al., 2018; Baker et al., 2014; Metcalfe et al., 2010, 2003; Salvatore et al., 2017) fueled public outcry calling for a regulatory response and the naming of recreational drugs as a CEC.

CEC are ubiquitous in aquatic environments (Daughton, 2013, 2008, 2005; Gilbride and Levinson, 2008; Petrie et al., 2015, 2013; Sauvé and Desrosiers, 2014) and are known to be emitted from numerous point and non-point sources. Agricultural run-offs, industrial and hospital effluents, septic tanks seepage, animal husbandry practices, and waste storage sites (household and industrial) are all examples of sources of CEC pollution. In the literature and policy circles, it is generally accepted that one of the main sources of CEC is municipal wastewater discharges. The problem is that existing WWTP infrastructure in Canada is dated and was designed to remove solids, nutrients, and biodegradable organic matter not CECs. Moreover, Canadian WWTP processes currently lack protocols to effectively detect and quantify the long list of CEC at a tolerable level of risk as delineated by the contaminant’s form and impact (Arlos et al., 2015; Bai et al., 2018; Chen et al., 2006; Hamza et al., 2016; Petrie et al., 2013). Measurable quantities of CEC in surface water and drinking water sources have been found to be extremely small leading some scholars and experts to raise little concern over human and ecological health impacts, however, high concentrations of CEC have also been documented downstream of a WWTP (Baalbaki et al., 2017). Public and ecological health concerns highlight the need to understand not only the persistent presence and low-dose cumulative effects of these contaminants in wastewater streams that can contribute to human health and the environmental risks but also the need to identify high-risk sectors, communities and populations at risk, including vulnerable populations such as pregnant women, infants and the elderly (Gerrard, 2009; Naidu et al., 2016; Scott and Lewis, 2015).

One problem idenitified in the literature is the method of classification for CEC. The classification method is primarily focused on identifying each compound independently, then categorizing it within a group of compounds with similar environmental behaviour or effect to determine its risk on human and environmental health (Mavinic et al., 2018). It is expected that additional emerging contaminants will be discovered as the use of anthropogenic drug compounds increases. For example, in Canada, the use of therapeutic drugs increased at an annual rate of 12% between 1985 and 1992; likewise, between 1998 and 2007, spending on prescription drugs used outside of hospitals grew from $8.0 billion to $19.0 billion (Li et al., 2019; Metcalfe et al., 2003;

Morgan, 2005, 2004). Complicating this increase in pharmaceutical use by humans is the increase in animal drug use and research exposing the stable nature of excreted drugs. It is estimated that 30-90% of oral drugs excreted in urine remain stable as active substances pointing to potential cumulative and synergistic impacts that need to be understood (Santos et al., 2007; Zuccato et al., 2008).

In wastewater treatment practice, environmental monitoring lacks transparency and WWTP operators face monitoring challenges. Regulatory regimes do not require the monitoring of CEC. Generally, WWTP reporting does not provide affected stakeholders data to assess the risk not only of each contaminant but also of the cumulative impacts and removal rates of CEC. In addition, WWTP operators face the problem of deciding what data to collect and what to measure when assessing the risk of CEC. Complicating monitoring protocols is also determining the occurrence, seasonal timing, and spatial distribution of CEC in order to effectively monitor, predict and mitigate the health and ecological impacts. Research from the United States' EPA demonstrated that CEC sampling concentrations varied significantly and were dependent on sampling locations and seasons, where it was found that CEC were less persistent during a spring freshet compared with a baseflow period (Bai et al., 2018).

The traditional analytical approaches to monitoring CEC apply targeted screening with low-resolution mass spectrometry and have been found to produce misleading test results raising doubt as to the efficacy of this approach for WWTP operators. Hamza et al. (Hamza et al., 2016) have shown that these misleading results can be explained by chemicals acting as transformation products, which may exhibit similar chemical activity and toxicity levels to the parent CEC compound, and then can become undetected in the WWT monitoring of influents and effluents (Petrie et al., 2015). These findings not only demonstrate the inadequacy of the current contaminant-by-contaminant classification system that informs the traditional monitoring approach but also Hamza et al.'s research supports water policymakers call for a precautionary and adaptive management approach (Hamza et al., 2016; Mavinic et al., 2018) that has not yet been developed.

Innovative and alternative monitoring methods are lacking. Alternative CEC monitoring approaches are being advanced in the literature, with each method contributing to specific knowledge on CEC and environmental impacts. However, wastewater regulatory regimes have failed to keep pace with the monitoring research thus a regulatory gap and safety gap exists within the legislative sphere. Alternative monitoring methods such as an integrated analytical approach is discussed in the literature as a method to complement targeted and non-targeted screening of specific CEC and the use of biological assays to measure ecological impacts (Petrie et al., 2015) by relying upon technologies such as *in situ* real-time sensors and analytical method(s) that can determine CEC at the enantiomeric level. Implementing this approach allows WWTP operators to monitor the transformation by-product, which may exhibit cumulative features, which may be more toxic than the original compounds (Lv et al., 2018). An indicator species method is another alternative monitoring method where sentinel marine species together with a non-targeted analytical approach can provide a proactive approach to environmental contaminant monitoring (Cossaboon et al., 2019). Petrie et al. (Petrie et al., 2015) highlighted that non-targeted screening has several limitations as the chemistry of the CEC in question is unknown, and thus the CEC may not be recovered/discovered during sample preparation or during analysis. Instead, chemical analysis needs to be supported with novel bioanalytical techniques (e.g., metabolomics), which can yield information on organism function and health at the molecular level (Bundy et al., 2009).

2.1.1 Wastewater treatment plant regulations: A fragmented regulatory framework

In Canada, a legislative gap exists regarding the regulation of CEC effluents from WWTPs. It is well understood that this gap stems from the shared constitutional responsibility for water resources and wastewater treatment.

Regulation of WWTPs in Canada is shared between federal and provincial governments, and where municipal governments are charged with operating WWTP.[1] Currently, all three levels of government operate under a widely adopted general framework for WWTP regulations that was developed by the Canadian Council of Ministers of the Environment (CCME). In 2009, CCME published the Canada-wide Strategy for Municipal Wastewater Effluent ("Strategy") that is still in use today.[2] Under the Strategy, CCME established a clear "strategic vision for water" to ensure that "Canadians have access to clean, safe and sufficient water to meet their needs in ways that also maintain the integrity of ecosystems,"[3] while providing a "harmonized framework that is protective of human health and the environment", while simultaneously accounting for specific financial and practical limitations at the local level.[4]

Implementation of the Strategy led to two categories of WWTP legal instruments at a national and local level. The national regulations are the "National Performance Standards" that apply to all WWTPs across Canada, and have been phased-in (required to meet over time based on different implementation timetables).[5] The standards include regulations for pollutants common to most wastewater discharge, and include effluent monitoring and filtering for toxicity, carbonaceous biochemical oxygen demand, suspended solids, total residual chlorine, and un-ionized ammonia.[6] At a local level the "site-specific effluent discharge objectives" are in place where individual jurisdictions are required to develop and meet these objectives to address "specific substances that are of concern to a particular discharge or environment."[7] Each jurisdiction is responsible for both implementing the National Performance Standards and developing a system for identifying and managing site-specific risks through an Environmental Risk Assessment.[8] The strategy also includes requirements for monitoring and reporting, as well as additional pollution prevention mechanisms such as reduction at the source

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[1] Government of Canada, "NPRI Sector Overview: Wastewater" (last viewed 30 August 2021), online: https://maps.canada.ca/journal/content-en.html?lang=en&appid=59868c2a9bc84c5fa1b8dbc765a6a2f3&appidalt=986abeafee6f4a1abfa081e7fc1bf2cd .

[2] Canadian Council of Ministers of the Environment, "Water" (last viewed 30 August 2021), online: https://ccme.ca/en/current-activities/water . Canadian Council of Ministers of the Environment, "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (17 February 2009), online (pdf): https://ccme.ca/en/res/mwwe_strategy_e.pdf .

[3] Canadian Council of Ministers of the Environment, "Water" (last viewed 30 August 2021), online: https://ccme.ca/en/current-activities/water .

[4] Canadian Council of Ministers of the Environment, "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (17 February 2009), online (pdf): https://ccme.ca/en/res/mwwe_strategy_e.pdf .

[5]Canadian Council of Ministers of the Environment, "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (17 February 2009), online (pdf): https://ccme.ca/en/res/mwwe_strategy_e.pdf . See also Canadian Council of Ministers of the Environment, "Technical Supplement 2 Environmental Risk Management: Framework and Guidance" (June 2008), online (pdf): https://ccme.ca/en/res/mwwe_techsupp_2_e.pdf . Canadian Council of Ministers of the Environment, "Municipal Wastewater Effluent Strategy" (last viewed 30 August 2021), online: https://ccme.ca/en/municipal-wastewater-effluent .

[6]Canadian Council of Ministers of the Environment, "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (17 February 2009), online (pdf): https://ccme.ca/en/res/mwwe_strategy_e.pdf ; See also Canadian Council of Ministers of the Environment, "Technical Supplement 2 Environmental Risk Management: Framework and Guidance" (June 2008), online (pdf): https://ccme.ca/en/res/mwwe_techsupp_2_e.pdf .

[7] Canadian Council of Ministers of the Environment, "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (17 February 2009), online (pdf): https://ccme.ca/en/res/mwwe_strategy_e.pdf . See also Canadian Council of Ministers of the Environment, "Technical Supplement 3 Standard Method and Contracting Provisions for the Environmental Risk Assessment" (June 2008), online (pdf): https://ccme.ca/en/res/mwwe_techsupp_3_e.pdf .

[8] Canadian Council of Ministers of the Environment, "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (17 February 2009), online (pdf): https://ccme.ca/en/res/mwwe_strategy_e.pdf . See also See also Canadian Council of Ministers of the Environment, "Technical Supplement 2 Environmental Risk Management: Framework and Guidance" (June 2008), online (pdf): https://ccme.ca/en/res/mwwe_techsupp_2_e.pdf .

for the "elimination or reduction of pollutants" that "cannot or can only be partially treated by wastewater facilities."[9]

2.1.1.1 Federal regulations

The federal government has generally assumed the responsibility for implementing regulations that mandate the introduction of the National Performance Standards set forth in the Canada-wide Strategy. This responsibility is achieved through the *Wastewater Systems Effluent Regulations*[10] (WSER), implemented under the *Fisheries Act*[11] in 2012.[12] WSER, [which is discussed in more detail throughout this paper] establishes regulations that "set national standards for wastewater effluent to reduce the threats to fish, their habitat and human consumption of fish."[13] WSER is limited to substances of national concern, specifically only including effluent standards for carbonaceous biochemical oxygen demanding matter; suspended solids; total residual chlorine; and un-ionized ammonia.[14]

In 1999, the federal government, under the direction of Environment and Climate Change Canada, introduced the National Pollutant Release Inventory (NPRI) under the *Canadian Environmental Protection Act, 1999*[15] (CEPA).[16] The NPRI functions as an "inventory of pollutants released to the air, water and land.[17] The information gathered is used by the federal government to "set environmental priorities and monitor environmental performance."[18] In order to comply with NPRI requirements, WWTPs are required to collect and report data on up to 87 different substances, depending on the size of the facility.[19] Certain contaminants of emerging concern that were reviewed for this report, however, were not included in the NPRI reporting database. Of particular note, the substance list does not appear to include any perfluoroalkyl substances or

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[9] Canadian Council of Ministers of the Environment, "Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (17 February 2009), online (pdf): https://ccme.ca/en/res/mwwe_strategy_e.pdf.

[10] *Wastewater System Effluent Regulations*, SOR/2012-139.

[11] *Fisheries Act*, RSC 1985, c. F-14.

[12] Government of Canada, "NPRI Sector Overview: Wastewater" (last viewed 30 August 2021), online: https://maps.canada.ca/journal/content-en.html?lang=en&appid=59868c2a9bc84c5fa1b8dbc765a6a2f3&appidalt=986abeafee6f4a1abfa081e7fc1bf2cd .

[13] Government of Canada, "NPRI Sector Overview: Wastewater" (last viewed 30 August 2021), online: https://maps.canada.ca/journal/content-en.html?lang=en&appid=59868c2a9bc84c5fa1b8dbc765a6a2f3&appidalt=986abeafee6f4a1abfa081e7fc1bf2cd .

[14] See *Wastewater System Effluent Regulations, supra*, s. 5.

[15] *Canadian Environmental Protection Act, 1999*, SC 1999, c. 33.

[16] Government of Canada, "Reporting Requirements Fact Sheet: National Pollutant Release Inventory" (last updated 13 December 2018), online: https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/report/requirements-fact-sheet.html .

[17] Government of Canada, "Reporting Requirements Fact Sheet: National Pollutant Release Inventory" (last updated 13 December 2018), online: https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/report/requirements-fact-sheet.html .

[18] Government of Canada, "NPRI Sector Overview: Wastewater" (last viewed 30 August 2021), online: https://maps.canada.ca/journal/content-en.html?lang=en&appid=59868c2a9bc84c5fa1b8dbc765a6a2f3&appidalt=986abeafee6f4a1abfa081e7fc1bf2cd ; See also United Nations Department of Economic and Social Affairs, Division for Sustainable Development, CSD-18/19- Thematic Profile: Chemicals, "Canada: National Reporting to CSD-18/19 Thematic Profile on Chemicals" online (pdf): https://sustainabledevelopment.un.org/content/dsd/dsd_aofw_ni/ni_natiinfo_canada.shtml .

[19] Government of Canada, "NPRI Sector Overview: Wastewater" (last viewed 30 August 2021), online: https://maps.canada.ca/journal/content-en.html?lang=en&appid=59868c2a9bc84c5fa1b8dbc765a6a2f3&appidalt=986abeafee6f4a1abfa081e7fc1bf2cd .

microplastics.[20] This gap does not appear to be lost on the federal government, however, which has specifically noted its lack of knowledge with respect to "pollutants of emerging concern" in cases where "wastewater facilities were not designed to remove or treat these substances."[21]

Under CEPA, the federal government enacted regulations that "prohibit or restrict the use of substances that are considered toxic under the Act."[22] CEPA enabled regulations are generally implemented following an assessment under Canada's Chemical Management Plan. In 2006, the Chemicals Management Plan was introduced by the federal government as a joint initiative between Environment Canada and Health Canada to assess chemicals used and found to be harmful in Canada.[23] Under the Chemicals Management Plan, working groups conduct systemic assessments of the environmental and human health risks posed by substances.[24] Depending on the results of the scientific assessment, the working group will then recommend a risk management strategy that is tailored to the specific substance and the risk it imposes.[25] This often includes new regulations under CEPA. This is the process that introduced new regulations for the contaminants of emerging concern of perfluoroalkyl substances or microplastics. Emerging contaminants are first assessed under the Chemicals Management Plan, and then appropriate regulations are drafted to respond to the risk based on the scientific assessment and consultations with different stakeholders. Apart from these national reporting, effluent discharge and monitoring standards, the federal government is generally less involved with regulating individual WWTPs leaving day-to-day the licensing, compliance and regulatory responsibility to provincial and municipal governments.

2.1.1.2 Provincial Regulations – Ontario, as an example

In 2019, Ontario's Auditor General recognized that municipal sewage and wastewater from industrial sites may contain toxic chemicals, pharmaceuticals and microplastics, and may be present in Ontario lakes.[26] Provincial governments are responsible for developing regulations and licensing schemes for individual WWTPs.[27] In

[20] Government of Canada, "Substance List by Threshold" (last updated 26 January 2021), online: https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/substances-list/threshold.html .
[21] Government of Canada, "NPRI Sector Overview: Wastewater" (last viewed 30 August 2021), online: https://maps.canada.ca/journal/content-en.html?lang=en&appid=59868c2a9bc84c5fa1b8dbc765a6a2f3&appidalt=986abeafee6f4a1abfa081e7fc1bf2cd .
[22] Canadian Council of Ministers of the Environment, "Technical Supplement 2 Environmental Risk Management: Framework and Guidance" (June 2008), online (pdf): https://ccme.ca/en/res/mwwe_techsupp_2_e.pdf ; See also United Nations Department of Economic and Social Affairs, Division for Sustainable Development, CSD-18/19- Thematic Profile: Chemicals, "Canada: National Reporting to CSD-18/19 Thematic Profile on Chemicals" online (pdf): https://sustainabledevelopment.un.org/content/dsd/dsd_aofw_ni/ni_natiinfo_canada.shtml .
[23] Government of Canada, "Overview of the Chemicals Management Plan" (24 January 2014), online: (https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/overview-chemicals-management-plan.html).
[24] Government of Canada, "Overview of the Chemicals Management Plan" (24 January 2014), online: (https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/overview-chemicals-management-plan.html).
[25] Government of Canada, "Overview of the Chemicals Management Plan" (24 January 2014), online: (https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/overview-chemicals-management-plan.html).
[26] Ontario Auditor General: Report on the Environment: Volume 2, Annual Report, (Toronto, Govt Ontario, 2019) at p 19. Govt of Ontario: online https://www.auditor.on.ca/en/content/annualreports/arreports/en19/2019AR_v2_en_web.pdf .
[27] Government of Canada, "NPRI Sector Overview: Wastewater" (last viewed 30 August 2021), online: https://maps.canada.ca/journal/content-en.html?lang=en&appid=59868c2a9bc84c5fa1b8dbc765a6a2f3&appidalt=986abeafee6f4a1abfa081e7fc1bf2cd .

Ontario, the primary legislation governing WWTPs is the *Ontario Water Resources Act (OWRA)*.[28] Under the *Water Resources Act*, the Minister of the Environment, and its appointed agents, hold broad authority to issue an order under its public interest power to any person who "owns, manages, or has control of a facility, including sewage works or water works, that may discharge material into any water or watercourse that may impair the quality of water."[29] The Act also includes a general prohibition against discharging any material into any waters or any place that may impair the quality of water, subject to its authority to regulate and license the discharge of water by entities such as WWTPs.[30] Lastly, the Act provides the Minister of the Environment and its agents with authority to develop and oversee the implementation of regulations and guidelines to "use, operate, establish, alter, extend or replace new or existing sewage works"[31] and to ensure sewage works are "maintained, kept in repair and operated in such manner and with such facilities as may be directed from time to time."[32]

Provincial licensing requirements are set out in OWRA. Through the OWRA, *Licensing of Sewage Works Operators*[33] requires the owners of all WWTP facilities to file an application with the provincial regulator for each facility.[34] Depending on the classification of the facility, an operator of each WWTP must receive a specific operator's license.[35] The classification system includes such criteria as: the size of population served, the types of sewage and services provided, as well as the toxicity of the effluent, together, the OWRA and licensing scheme ensure the WWTPs and operators are closely regulated by provincial regulators.

In addition to the power to regulate WWTPs, the OWRA also provides provincial agents with broad investigative, reporting, and compliance authority to regulate industrial or commercial enterprises that release effluent.[36] This provision includes the authority to make orders for industrial or commercial enterprises to "make investigations and submit reports," to "install, construct or arrange such facilities for the collection, transmission, treatment or disposal of sewage" and to "maintain, keep in repair and operate such facilities" in accordance with provincial regulations.[37]

While the *OWRA* is Ontario's primary legislation overseeing WWTP, WWTPs may also be subject to environmental orders under the Ontario *Environmental Protection Act*[38] (OEPA). Under the OEPA, the Minister holds oversight and inspection authority to investigate pollution and waste management issues as well as to "establish and operate demonstration and experimental sewage systems [and] waste management systems."[39] The OEPA also includes general prohibitions against discharging contaminants into the environment as well as the power to make orders with respect to environmental pollutants.[40] As a result, OEPA

[28] *Ontario Water Resources* Act, RSO 1990, c O. 40.
[29] *Ontario Water Resources Act*, *supra*, ss. 16.1,16.2.
[30] *Ontario Water Resources Act*, *supra*, ss. 29-32.
[31] *Ontario Water Resources Act*, *supra*, s. 53
[32] *Ontario Water Resources Act*, *supra*, s. 61, 62.
[33] *Licensing of Sewage Works Operators*, O. Reg 129/04.
[34] *Licensing of Sewage Works Operators, supra*, s. 4.
[35] *Licensing of Sewage Works Operators, supra*, ss. 6-7.
[36] *Ontario Water Resources Act*, *supra*, s. 91
[37] *Ontario Water Resources Act*, *supra*, s. 91.
[38] *Environmental Protection Act* (Ontario), RSO 1990, c. E. 19.
[39] Ontario *Environmental Protection Act*, *supra*, s. 4.
[40] Ontario *Environmental Protection Act*, *supra* ss. 6-9.

further provides the provincial Minister of the Environment with broad authority to issue orders and regulations that either directly or indirectly impact WWTPs.

2.1.1.3 Municipal Regulations – Toronto, as an example

While provincial laws and regulations provide the general WWTP regulatory and licensing regime, the ownership and operation of individual WWTPs generally lies with individual municipalities.[41] In 1993, the Ontario Clean Water Agency was established as an agency of the Province of Ontario with a mandate to "provide water, wastewater and other services to clients in a manner that protects human health and the environment and that encourages the conservation of water resources."[42] Under the OWRA, the Ontario Clean Water Agency has the authority to enter into agreements with municipalities for the "provision of an operation by the Agency of water works or sewage works for the municipality or municipalities."[43] This permits the Ontario Clean Water Agency to act as a shared services provider of water and wastewater treatment services for municipalities, as well as First Nations communities and private sector companies.[44] Depending on the size and resources of the municipality, they can either contract fully for the Ontario Clean Water Agency to operate its WWTP, or they can contract out certain services, such as infrastructure upgrades.[45] This resource is particularly helpful for smaller municipalities, who can take advantage of the Ontario Clean Water Agency's expertise and resources to help them meet federal and provincial WWTP standards. In 1997, ownership of WWTP was transferred from the province to municipalities under the *Water and Sewer Services Improvement Act, 1997*.[46]

To assist in the process, municipalities generally implement by-laws that regulate sewage discharge that feeds into their individual WWTPs.[47] Each municipality will often implement its own customized by-law. For the purposes of this paper, the City of Toronto sewage by-laws are used as an example, as they have been regarded as one of the "most modern and comprehensive sewer use by-laws in Canada."[48]

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[41] Canadian Council for Ministers of the Environment, "Technical Supplement 1 Economic Plan Supporting the Canada-wide Strategy for the Management of Municipal Wastewater Effluent" (April 2008), online (pdf): https://ccme.ca/en/res/mwwe_techsupp_1_e.pdf (noting that municipalities are responsible for the operation of about 70% of wastewater infrastructure in Canada).

[42] Ontario Clean Water Agency, 2020 Annual Report, online (pdf): https://www.ocwa.com/sites/default/files/2020_annual_report_final_-_english_final-s.pdf .

[43] *Ontario Water Resources Act*, *supra*, s. 63.

[44] Ontario Clean Water Agency, 2020 Annual Report, online (pdf): https://www.ocwa.com/sites/default/files/2020_annual_report_final_-_english_final-s.pdf .

[45] Ontario Clean Water Agency, 2020 Annual Report, online (pdf): https://www.ocwa.com/sites/default/files/2020_annual_report_final_-_english_final-s.pdf .

[46] Ontario Hansard – Orders of the Day, 26-May1997 online: http://hansardindex.ontla.on.ca/hansardECAT/36-1/L193-6.htm . Government of Ontario, *Local Service Realignment: A User's Guide Report* (Toronto: Queens Park Printer, Autumn 1999) at p. 5.23. "The Water and Sewage Services Act received Royal Assent on May 27, 1997" Also See: at Section 5.23 at 5.23 to 5.25. online: http://www.mah.gov.on.ca/AssetFactory.aspx?did=4997 .

[47] Government of Canada, "NPRI Sector Overview: Wastewater" (last viewed 30 August 2021), online: https://maps.canada.ca/journal/content-en.html?lang=en&appid=59868c2a9bc84c5fa1b8dbc765a6a2f3&appidalt=986abeafee6f4a1abfa081e7fc1bf2cd .

[48] Canadian Council of Ministers of the Environment, "Technical Supplement 2 Environmental Risk Management: Framework and Guidance" (June 2008), online (pdf): https://ccme.ca/en/res/mwwe_techsupp_2_e.pdf .

The applicable by-laws in Toronto can be categorized across three types: Water Supply By-Laws, Sewers By-Laws, and Water-Related Permits.[49] Water Supply By-Laws provide "rules regarding water meters, fire hydrants, and mandatory backflow prevention for businesses." Water-Related Permits provides a permitting regime for "permits for temporary sewer discharge, fire hydrant use and flow tests, and information on related services."[50] Lastly, the most applicable to WWTPs, are the Sewers By-Laws, which provide "limits on what can be discharged into the sewers and waterways and what to do if you see a spill."[51]

Sewer By-Laws are an integral part of the WWTPs regulatory system as it provides municipalities with the authority to restrict the discharge of certain substances where the WWTP is unable to fully filter out the contaminants.[52] In these instances, municipalities have the option to either completely prohibit the discharge of certain substances, restrict it to a safe limit, or charge the polluter for the increased cost of handling the contaminant at the WWTP.[53]

The City of Toronto By-Law, for example, includes general prohibitions against discharging sewage, directly or indirectly, into the city sewage system any effluent that contains concentrations of prescribed chemicals above the minimums provided in the by-law.[54] There is an exception, however, if the effluent discharge is expressly authorized in a management plan or in accordance with a valid discharge agreement or permit.[55] This permits the city to enter into express agreements with largescale polluters that either limits the amount of discharge or charges polluters a fee for the excess cost of filtering out any excess discharge.

In addition to general discharge regulations, the City of Toronto By-Laws also contain provisions that require certain industrial polluters to submit a Pollution Prevention Plan to the General Manager that, among other things, describes the processes, pollutants, concentration, treatment etc. targets that the polluter expects to undertake within 3 to 6 years.[56] The City of Toronto By-Laws also contain more specific regulations targeted at specific polluters, such as mandatory interceptors for food related grease, motor oil, sand etc.[57]

2.1.1.4 Regulatory gap leading to a safety gap

Overall, Environment and Climate Change Canada administers the legislative instrument (i.e., the Wastewater Systems Effluent Regulations (WSER -SOR/2012-139)) that falls under the *Fisheries Act* at the federal level. This 2012 federal regulation sets a quality baseline for monitoring effluent discharges. However, a provincial

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[49] City of Toronto, "Water & Sewer Related Permits and Bylaws" (last viewed 30 August 2021), online: https://www.toronto.ca/services-payments/water-environment/water-sewer-related-permits-and-bylaws/ .
[50] City of Toronto, "Water & Sewer Related Permits and Bylaws" (last viewed 30 August 2021), online: https://www.toronto.ca/services-payments/water-environment/water-sewer-related-permits-and-bylaws/ .
[51] City of Toronto, "Water & Sewer Related Permits and Bylaws" (last viewed 30 August 2021), online: https://www.toronto.ca/services-payments/water-environment/water-sewer-related-permits-and-bylaws/ .
[52] City of Toronto, "Sewers By-law" (last viewed 30 August 2021), online: https://www.toronto.ca/services-payments/water-environment/water-sewer-related-permits-and-bylaws/sewers-by-law/ .
[53] City of Toronto, "Sewers By-law" (last viewed 30 August 2021), online: https://www.toronto.ca/services-payments/water-environment/water-sewer-related-permits-and-bylaws/sewers-by-law/ . City of Toronto, "Industrial Waste Control" (last viewed 30 August 2021), online: https://www.toronto.ca/services-payments/water-environment/water-sewer-related-permits-and-bylaws/sewers-by-law/industrial-waste-control/ . See also Toronto Environmental Alliance, "Understanding Toronto's Sewers By-Law" (25 July 2014), online: https://www.torontoenvironment.org/understanding_toronto_s_sewers_by_law .
[54] Toronto Municipal Code Chapter 681, Sewers. S. 681-2A.
[55] Toronto Municipal Code Chapter 681, Sewers. S. 681-2A (5), 681-6.
[56] Toronto Municipal Code Chapter 681, Sewers. S. 681-5.
[57] Toronto Municipal Code Chapter 681, Sewers. S. 681-10.

government can choose to adopt the federal regulation or not, and in this way, the regulation can be considered non-binding upon provincial and municipal governments. Under WSER, both CEC and influents into wastewater systems on industrial, commercial and institutional sites are overlooked. Nevertheless, WWTPs are managed at a municipal level, and in practice, may consider the 2012 WSER federal regulation. Overlooked in this overall fragmented regulatory framework is the inclusion of Indigenous knowledge as directed by First Nations and informed by Indigenous law.

Leading Canada's law and policy reform in the WWTP sector has been non-governmental organizations. For example, a 2019 Pollution Probe Report examining the sources, pathways, and impacts of pharmaceuticals in the Great Lakes identified municipal wastewater as one of the primary sources and pathway for pharmaceuticals entering the lakes. The report identified that a gap existed in "ecotoxicology data on active pharmaceutical ingredients and mixtures" highlighting the absence of federal and Ontario wastewater regulations on "the management of pharmaceutical pollutants" (Pollution Probe & Clean Water Foundation, 2019). The report recommended prioritizing research on "active pharmaceuticals" as well as site-specific monitoring of wastewaters at "pharmaceutical manufacturers" and healthcare institutions while also considering "pre-treating on site prior to release to WWT facility" (Pollution Probe & Clean Water Foundation, 2019). In 2018, the Canadian Water Network published a comprehensive pan-Canadian public awareness report affirming the regulatory gap and the WWT challenges facing federal and provincial governments (Mavinic et al., 2018). These reports leave open for further research the task of identifying and prioritizing CEC from the growing list that are "most significant health risks to receiving waters and environment" (Mavinic et al., 2018).

Currently, other jurisdictions have developed legislative responses to manage CEC in water sources, however, these instruments are not directed at CEC in WWTP influents and effluents. EU Directive 2013/39/EU enumerates a list of priority substances and an EU watch list of CEC for monitoring water quality (Decision 2015/495/EU, Decision 2018/840/EU) (European Commission, 2018, 2013; The European Commission, 2015). In the United States, PFAS in drinking water sources is a growing concern for communities across the country; however, no federal EPA standards have been promulgated. In response to public outcry, seven states have developed their own standards for PFAS (Cordner et al., 2019; EPA, 2018; Winkens et al., 2017). It is expected that the list of CEC will be expanded as research develops on CEC.

In summary, developing suitable and standardized sampling protocols as well as adaptive and holistic environmental monitoring strategies supported by legislation are the first steps to assess what actions are needed for treating and regulating CEC. Determining the impact of CEC across their complete life cycle, their transformation by-products, and their synergetic effects could begin to address the gap in the scientific knowledge underpinning the development of a responsive environmental risk assessment, which will, in turn, will be informative in developing robust regulatory measures.

2.2 Objectives

The overall goals of this research are to synthesize and understand the current knowledge and significant gaps in the scientific, legal, and indigenous knowledge literature including industry grey literature on the detection, monitoring and governance framework concerning CEC in wastewater. The following objectives were used to accomplish our goals:

1. To classify the types, numbers and effects of CEC currently documented in wastewater through a comprehensible and multi sectoral search of scientific, legal and grey literature,

2. To determine if and how CEC in wastewater are monitored and measured using literature data and interviews of relevant experts,
3. To determine the operational financial burden imposed upon industry and municipalities by a risk-management CEC monitoring regime (and how that might look) using interviews of industry and policy experts, and
4. And to determine what international, national and provincial or municipal legal frameworks take into account synergistic effects of CEC, and categorize compounds for the protection of human and ecological health, and whether these legal frameworks are inclusive of indigenous knowledge of CEC?

2.3 Methodology

2.3.1 Phases of research

The research was divided into three phases. **Phase 1** consisted of a comprehensive review of primary literature, original source documents and grey literature. **Phase 2** consisted of the development of a survey instrument (i.e., questionnaire) that was used to interview experts knowledgeable about CEC including industry, environmental, policy, government individuals and those with indigenous knowledge (Appendix I). **Phase 3** was a workshop to bring together all the stakeholders to discuss the gaps in knowledge identified in the literature or through our interviews.

2.3.1.1 Phase 1:

This research employed a two-part deeply-mined search for scientific and management literature to review science, engineering, industry, management, and policy research studies. The search adopted a broad definition of CEC and included, personal care products, pharmaceuticals (PhAcs), antibiotics, perfluoroalkyl and polyfluoroalkyl substances (PFAS), and microplastics (MPs). We analyzed English language peer-reviewed journal articles from the following databases: ACM Association for Computing Machinery Digital Library, Alternative Press Index, Bibliography of Native North Americans, Business Source complete, Canadian Business and Current Affairs, CINAHL, Ebscohost Business Source Complete, Econlit, Elsevier, HeinOnline, IEEEXplore, INSPEC, Medline, Nursing & Allied HealthPAIS Index, Politica Collection, ProQuest, Sage Journals, Scholars Portal, SSRN Legal Scholarship Network, Statista and Wiley. The search results of our three case studies are discussed below: Case study One: Pharmaceuticals (PhACs), Case Study Two: Microplastics (MPs), and Case Study Three: Per- and poly-fluoralkyl compounds (PFAS). **Table 1** shows the search keywords, search criteria, and databases covered and the number of articles selected in our study after reviewing the eligibility criteria.

2.3.1.2 Phase 2:

A questionnaire that was informed by the literature generated in phase 1 was developed (Appendix I) and passed Ryerson's ethics board approval (Appendix II). Virtual interviews were then conducted with 22 participants. The audio recording was transcribed by the graduate students involved in the project and transcripts were reviewed in full by the PIs before being sent back to the interviewee for their approval. We then analysed the information in the transcripts by utilizing the themes set out in the questionnaire, which informed the key messages.

Table 1. Summary of literature and legislative review.

Case study	Pharmaceuticals	Microplastics	PFAS*	Legal/Regulatory	Legislation/Regulations/ CaseLaw
Search terms	Pharmaceuticals “AND”/ “OR” WW; Impacts of Pharmaceuticals in WW; Pharmaceuticals “AND” management strategies	Microplastics /Microplastics “AND” WW; Microfibres “AND” WW/ WWTPs/ microfiber pollution; Plastic pollution/ Plastic pollution “AND” WW/WWTPs	PFAS “OR” PFOA* “OR” PFOS* “AND” WW	“Contaminants of Emerging Concern”; “Pharmaceuticals AND Wastewater”; Microplastics AND Wastewater; [PFOA OR PFAS] AND Wastewater	Microplastics; Microbeads; PFAS; PFOA; Perfluorooctane; Perfluorooctanoic; Wastewater; Sewage
1st search results	>2600	>5000	>5000	> 500	~500
Filters	• Last 10 years • Peer reviewed • Search terms in title, abstract, or keyword	• Last 10 years • Peer reviewed • Search terms in title, abstract, or keyword	• Last 10 years • Peer reviewed • Search terms in title, abstract, or keywords	• Last 10 years • Peer reviewed • Search terms in title, abstract, or keywords	• Federal and Ontario
2nd search results	170	120	97	100	25
Databases	Business Premium Collection; Business Source complete; Canadian Business and Current Affairs; CINAHL; Econlit; IEEEXplore; Informit Indigenous Collection; Medline; Nursing & Allied Health; PAIS Index; Politics Collection; ProQuest; Sage Journals; Springerlink; Scholars Portal	Alternative Press Index; Bibliography of Native North Americans; Canadian Business and Current Affairs; Econlit; PAIS Index; Business Source complete; INSPEC; Statista; CINAHL; Medline; Nursing & Allied Health; Informit Indigenous Collection; Business Premium Collection; Scopus; Google Scholar; Springer; Journal citation reports; Scientific journal rankings; Proquest	Alternative Press Index; Bibliography of Native North Americans; Canadian Business and Current Affairs; PAIS Index; Politics Collection; Business Premium Collection; Business Source Complete; IEEEXplore; Medline; Nursing & Allied Health; Google scholar; Elsevier	HeinOnline; SSRN Legal Scholarship Network; Wiley; Sage Journals; Canada Chemicals Management Plan	WestlawNext Canada

* PFAS, poly-fluoroalkyl substances; PFOS, perfluorooctane sulfonate; PFOA, perfluorooctanoic acid.

2.3.1.3 Phase 3

An in-person workshop is still being organized (due to the pandemic measures we have been prevented from hosting it sooner). This will be a one-day format with both scheduled presentations and break out sessions to discuss the information collected to date and facilitate discussions between stakeholders to produce a white paper on the current state of CEC in WWTP.

2.4 Results

2.4.1. Literature review analysis

The presence of CEC from WWTP effluents is a well-documented challenge facing the Canadian WWTP sector. However, this research revealed a dearth of research exists concerning the pressing problem of the discharge of CEC from WWTP effluents into receiving waters, and the subsequent impacts upon human and ecological health. While over 600 types of CEC have been classified in the natural science literature, the literature review did identify three groups of CEC as priority substances (i.e., pharmaceutics (PhACs), microplastics (MPs) and per- and poly-fluoroalkyl substances (PFAS)) that led to narrowing the scope of the research to three CEC case studies. The aim of this research was to understand the knowledge gap in WWTP sector with respect to the impact of CEC on human and ecological health, and whether Indigenous knowledge is considered in the governance and operation of WWTP.

Another challenge emerged from the literature review is the method of classification for CEC, which highlights a definitional problem. Currently, there is no generally accepted definition of a CEC. In our research, CEC was defined as: “any pollutant that may pose a risk (concern) but is not currently monitored in wastewater.” While the majority of the study participants demonstrated some understanding of types of CEC, as illustrated by their ability to name, for example, plastics, personal care products, endocrine disruptive chemicals, very few participants could provide a definition. This definitional problem perhaps points to the emerging nature of this subject area and that a gap in knowledge exists with respect to emergent issues facing the WWTP sector. Both this definitional problem and this gap raises doubt that the sector fully understands CEC issue and can communicate the presence and associated CEC risks that may exist within a WWTP. The collective inability of the participants to define CEC is a systemic communication barrier. Establishing a CEC definition is needed in order to move to the next stage of research that includes structuring a classification method, which would lead to the next phase — CEC measurement and detection sampling in order to understand risks to human and ecological health.

A significant knowledge gap facing the WWTP sector is understanding how to infuse Indigenous knowledge into WWTP practices. Our interviews revealed a desire by First Nation leadership for respectful collaboration and an “ethical space for dialogue” with different levels of government where environmental stewardship is promoted and CEC pollution is viewed as a threat to health but also to cultural and traditional activities: [when a] “waterbody is contaminated, it really impacts First Nations peoples’ right to access fish and to use water spiritually and all of their spiritual cultural activities.” On the issue of WWTP technologies in First Nations and CEC impacts it was revealed that numerous communities rely upon a lagoon system as a wastewater treatment process, and the study participant expressed a view that “I don’t know if those lagoons have the capacity to deal with CEC to the extent of removing them.” It was also disclosed that at the WWTP operator level many First Nations face a regulatory knowledge capacity gap with respect to interpretating and implementing existing regulatory instruments (e.g., WSER) and may require further regulatory training as well as continued support.

The dominant regulatory idea advanced by regulators and supported at a WWTP level is "source control". Study participants generally viewed source control as preventing CEC from entering the municipal wastewater system by stopping the release of CEC at the source (i.e., industry, commercial, hospital) rather than at the end-of-pipe of the sewer pipe that places the costs upon municipalities, and ultimately, taxpayers. Our interviews with industry and policy experts point to the opportunity for innovative WWTP technologies in partnership with private industry as the majority of study participants identified a strong belief in the WWTP sector that source control should be promoted by regulators and adopted by industrial, commercial and public sectors. Both "product stewardship" and "polluter pay" principles informed the study participant's desire for source control. In other words, advancing corporate environmental responsibility is key.

Importantly, the three distinct case studies (i.e., PhACs, MPs and PFAS) examined in this research raise two key questions: Is a WWTP the most appropriate site to treat and manage the discharge of CEC? Should different treatment and governance strategies be implemented for each group of CEC? Unlike PFAS and MPs, the broad number of PhAC users and sites highlights the need for different governance strategies. A WWTP is the most pragmatic site for PhAC source control through the use of novel or innovative treatment technologies. While this research advances the idea of source control for all three CEC case studies, it remains doubtful that controlling PhACs at all types of sites, and especially, at a residential source would be an effective strategy. Instead, PhAC removal technologies should be introduced into the wastewater treatment train process, as done in Europe, and at individual high hazard discharge facilities (e.g., PhAC industrial sites, hospitals, nursing homes). However, for PFAS and MPs – regulatory tools like a product ban and source control at the site commercial, industrial and public health facility should be adopted. MPs (i.e., fibres) and would also benefit from an industry promoted product redesign (for example, designing washing machines with filters to catch fibre debris).

In parallel to PhAC removal technologies, our research pointed to the need for PhAC educational campaigns to be advanced by regulators, industry and the health care profession to offset the "out of sight-out of mind" mindset of flushing PhACs down toilets and discharging PhAC into sewers. These education campaigns should foster public awareness of the human health and environmental effects of flushing PhACs, and the analysis of the effectiveness of the campaigns would also be helpful. For example, "no flushing" and "PhAC bottle return" campaigns (with product labelling on dispensed PhACs packages) directed at users (general public – households), the health care sector (care providers – nurses, doctors), animal care (veterinarian) including general public awareness campaigns support by PhAC and pharmacy industries as well as respective professional associations could be an effective strategy.

A prevailing perspective held in WWTP sector is that wastewater management is responsive to a regulatory push. Study participants advanced the idea that: "without regulation, CEC will not be monitored." Currently, the existing wastewater treatment legislative framework does not prescribe CEC monitoring nor detection requirements; hence, CEC are not monitored in WWTP. In essence, the legislative framework upholds a dated WWTP technology approach that was designed to remove solids, nutrients, and biodegradable organic matter, and is not responsive to the current state of science. Recent scientific research has identified the three CEC under study as harmful to human health and aquatic species. However, the existing regulatory regime governing the operation of WWTP has yet taken into account recent CEC research, and the fact that two of the CEC (i.e., MPs and PFAS) under study are listed as toxic substances under the *Canadian Environmental Protection Act*

(CEPA).[58] In practice, this means that MPs and PFAS, known toxic substances listed under CEPA, are not monitored in WWTP. Essentially, CEC pollution is legislatively permitted to enter, and to be discharged from the WWTP into receiving waters and the environment. Hence, the extent of CEC in WWTP influents and effluents is not monitored nor reported and the associated risk to human and ecological health is unknown.

Our research suggests that CEC will only be monitored in a WWTP once these compounds are identified as a risk to human health suggesting further CEC research, funding, and designing a resilient regulatory regime is needed. Study participants conceded that "without the evidence" it is difficult to ascertain the risk that CEC presents to human and ecosystem health. Generally, participants viewed the risks to human or environmental health from the discharge of CEC as not yet established by the research, and in their view, this lack of research continues to reinforce the current state of a lack of CEC regulatory monitoring at WWTPs.

Missing in the existing multi-level fragmented WWTP regulatory regime is a normative legal framework that advances contemporary environmental law, public health, and corporate social responsibility norms such a sustainable WWTP governance framework based on principles of net-zero emissions, subsidiarity, sustainability, precautionary principle, user pay, inter/intra generational equity, and data transparency for citizens.

Finally, study participants called for federal leadership and a national water strategy. Our research illustrates that the political will to introduce an integrative regulatory framework and incentivize innovative engineering solutions has lagged. The existing legislative framework has failed to advance innovative WWTP engineering solutions to protect water and land sources from CEC pollution and these research findings are illustrated by the three case studies. Each case study presented below includes a description of the CEC, a discussion of the applicable regulatory regime, and the regulatory gaps: Case study one: Per- and poly-fluoralkyl compounds (PFAS), case study two: Microplastics (MPs), and case study three: Pharmaceuticals (PhACs).

2.4.2 Case study one: Per- and poly-fluoroalkyl substances

Per- and polyfluoroalkyl substances (PFAS) are human-made organic compounds. Since the 1950s PFAS have been used in the manufacturing of a variety of commercial and industrial goods (for example, printing, textile, laundry and cleaning, paper, cosmetics, electrical and metal industries, firefighting foams, Teflon, Scotchgard and Gore-Tex coatings) (EPA, 2018). The PFAS chemical compound (i.e., Carbon-Fluorine bond) is one of the strongest organic bonds resulting in a substance that is resistant to degradation in the environment.

The PFAS compound is considered toxic, bioaccumulative, and persistent in the environment leading to the compound being named a 'forever' chemical (EPA, 2018). To date, in Canada, four types (or groups) of PFAS have been named and listed as toxic under the *Canadian Environmental Protection Act's* (CEPA) - List of Toxic Substances (toxic list): Perfluorooctanoic acid (PFOA), perfluorinated alkyl group, in which $n = 7$ or 8, perfluorocarboxylic acid (PFCA), in which $8 \leq n \leq 20$, and perfluorinated alkyl group, in which $8 \leq n \leq 20$. Currently, CEPA's toxic list does not include short-chain PFAS nor the replacement chemicals nor the alternative chemistry substances nor poly-fluorinated PFAS. In effect, this regulatory gap has opened the door for some manufacturers to switch to short-chain PFAS (Ateia et al., 2019). Many of these short-chain PFAS still offer the chemical and thermal stable features sought after by manufacturers. From a chemical compound perspective, these short-chain PFAS are known to be just as environmentally persistent, bio-accumulative, and long-lasting in the human body, fish and the environment and water-soluble and this water characteristic means

[58] Canadian Environmental Protection Act (bill C-28) online: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/related-documents.html

these compounds are considered both mobile and persistent in water (Cordner et al., 2019; Reemtsma et al., 2016).

Interestingly, PFAS can also adsorb or adhere to other CEC, such as microplastics in the environment, then possibly desorb in aquatic species. In effect, a sticky PFAS becomes mobile in a freshwater ecosystem as the plastic's pathway creates a corridor for the sticky PFAS to move beyond its point of entry into the receiving waters. These features of short-chain PFAS are a significant threat to drinking water and ecosystem safety, and perhaps, with further innovative research we can have a better understanding of the functioning of PFAS in WWTP processes. However, the existing WWTP regulatory detection or monitoring framework does not take into account these toxic substances — PFAS Hence, we are unable to assess the risk to human and ecological health.

PFAS in the aquatic environment can partly be attributed to WWTPs because a WWTP is both a conveyor and producer of PFAS (EPA, 2018). As a conveyor, WWTPs receive raw sewage from industrial, residential, commercial, and firefighting foam waste streams. Some studies have shown that over 85% of PFOA and 50% of PFOS compounds in the sewage are being discharged with the wastewater effluent, and into the receiving water bodies (Arvaniti et al., 2014). As a producer, some precursor PFAS in the WWTP process can biotransform into PFCAs and PFSAs, which is then discharged in the effluent and then, released into lakes, rivers or oceans further spreading the PFAS contaminants to wildlife, fish and microbiota habitat, and humans. Experiments for determining the fate and transport of PFAS in WWTPs showed that precursor PFAS compounds were readily broken down into several persistent intermediates and terminal short-chain PFCAs such as PFOA that end up in the effluent at concentrations much greater than those in the influent (Hamid and Li, 2016). Worldwide, PFOS and PFOA in the effluents of WWTPS were found at concentrations ranging from few nanograms to tens of milligrams per liter (Phong Vo et al., 2020). The literature has shown that higher concentrations are caused by industrial sources, with fire-fighting training grounds sites reflecting peak spikes in concentrations (Houtz et al., 2016). These are extremely high concentrations and frequent occurrences further stress the importance of adequate removal technologies and regulations for PFAS in wastewater effluents. Despite the availability of several remediation options, the data is inconsistent and it has been shown that PFOS and PFOA do not degrade under aerobic or anaerobic conditions (Remde and Debus, 1996). Yet several other research publications that showed biodegradation for PFOA and PFOS (Huang and Jaffe, 2019) demonstrating drawbacks and limitations for the real-scale implementation of removal technologies and need for further research.

Several established methods exist for the measurement of targeted PFAS molecules exist (e.g., Isotope dilution anion exchange solid phase extraction (SEE) and liquid chromatography-mass spectroscopy (LC-MS/MS)). But these methods lack standardization. Complicating this problem is that the chemical structure of many PFAS compounds have yet to be determined, which creates a detection problem in the WWTP when relying on current detection methods and standards. There is a need for additional methods combining fast preparation and analyzing complex matrices with minimal sample pre-treatment. Current PFAS removal and remediation technologies come with high energy and chemical consumption, and some have not even been tested in complex matrices such as wastewater. The reported concentrations of PFAS in the environment is extremely high emphasizing the need for innovative wastewater removal technologies and regulations directed at the PFAS producer that should also include disclosure requirements under securities regulations.

2.4.1.1 PFAS/PFOA Regulation:

At a federal level, *The Canadian Environmental Protection Act (CEPA)*[59] is the key environmental protection legislation that is aimed at pollution prevention, sustainable development and the protection of human health.[60] Under *CEPA*, PFAS and PFOA are listed as toxic substances, however, these substances are not incorporated into the WWTP regulatory regime nor is *CEPA* cross-referenced. Under *CEPA*, both PFOS (i.e., "Perfluorooctane sulfonate and its salts") and PFOA (i.e., "Perfluorooctanoic acid $C_7F_{15}CO_2H$, and its salts")[61] are listed under Schedule 1: List of Toxic Substances, and under *CEPA's* regulation: *Prohibition Against Certain Toxic Substances Regulations, 2012*.[62] Under these regulations, PFOS are subject to general restrictions against the manufacturing, use, sale, or import of PFOS or PFOA, or products containing PFOS or PFOA, subject to certain exemptions.[63]

However, broad exemptions still allow PFOS to be used for:[64]

(a) Photoresists or anti-reflective coatings for photolithography processes;

(b) Photographic films, papers and printing plates;

(c) In aqueous film forming foam present in a military vessel or military fire-fighting vehicle contaminated during a foreign military operation; and

(d) Aqueous film forming foam, provided the concentration limit does not exceed 10 ppm

And, PFOA may still be used for:[65]

(a) Aqueous film forming foam used in fire-fighting;

Individuals and corporations may apply for a permit to receive an exemption to the prohibition against the use of PFOS or PFOA if they were a manufacturer or importer of the substance prior to it being added to the regulations.[66] Under the regulations, the Minister **must** issue a permit provided that:[67]

(a) there is no technically or economically feasible alternative or substitute available to the applicant at the time of the application, other than a substance regulated under these Regulations, for the toxic substance;

(b) the applicant has taken the necessary measures to minimize or eliminate any harmful effect of the toxic substance on the environment and human health; and

(c) a plan has been prepared respecting the toxic substance identifying the measures that will be taken by the applicant to comply with these Regulations, and the period within which the plan is to be

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[59] Cite SC 1999

[60] S.C. 1999, c. 33. "Declaration: It is hereby declared that the protection of the environment is essential to the well-being of Canadians and that the primary purpose of this Act is to contribute to sustainable development through pollution prevention."

[61] CEPA, *supra* Schedule I.

[62] *Prohibition of Certain Toxic Substances Regulations, 2012, SOR/2012-285*

[63] *Prohibition of Certain Toxic Substances Regulations, 2012, SOR/2012-285, s. 6(1),(2).*

[64] *Prohibition of Certain Toxic Substances Regulations, 2012, SOR/2012-285, s. 6(1),(2), Schedule 2*

[65] *Prohibition of Certain Toxic Substances Regulations, 2012, SOR/2012-285, s. 6(1),(2), Schedule 2*

[66] *Prohibition of Certain Toxic Substances Regulations, 2012, SOR/2012-285, s. 9*

[67] *Prohibition of Certain Toxic Substances Regulations, 2012, SOR/2012-285, s. 10(1)*

implemented does not exceed three years after the day on which a permit is first issued to the applicant.

In 2018, Environment Canada released a proposal to remove certain exemptions for the use of PFOS, including the use in aqueous film-forming foam, given the availability of alternatives globally.[68] The first draft of the regulatory amendments was originally expected to be published in Spring 2021, but have since been delayed until Fall 2021.[69] The Minister of the Environment publishes a list of permits under the Canadian Environmental Protection Act Registry. As of May 16, 2019, Environment Canada has not published any permits relating to PFOS or PFOA under the Canadian Environmental Protection Act Registry. [70]

2.4.1.2 PFAS/PFOA Regulatory Gaps:

Under *CEPA*, a primary gap is the restricted scope of Perfluoroalkyl Substances that limits the legislation to specific chemical compounds. Currently, only **per**fluorinated PFAS are included as toxic substances under *CEPA* and are managed under the *Prohibition Against Certain Toxic Substances Regulations, 2012*. This limited scope of *CEPA* means manufacturers or importers are able to use other **poly**fluoroalkyl substances (for example, 6:2 fluorotelomer alcohol (6:2 FTOH) and 6:2 fluorotemer sulfonate (6:2 FTS) are used in food and textile industries and fire-fighting foam). These polyfluoralkyl substance are more water soluble that their perfluornainated alternatives and thus may have similar environmental and human health impacts as the restricted substances/products (i.e. PFSAs and PFCAs) without violating federal environmental laws.[71] Further, the additional Perfluoroalkyl Substances (such as short chain compounds) recognized as CEC have not been identified as substances for review under the Canadian Chemicals Management Plan.[72] Accordingly, it appears that these additional Perfluoroalkyl Substances are not being considered for future regulation, and Environment and Climate Change Canada may not fully understand the risk and extent to which these substances impact human and environmental health.

The second gap results from exemptions for specific uses of PFOS and PFOA under the *Prohibition Against Certain Toxic Substances Regulations, 2012*. Accordingly, PFOS and PFOA are still permitted for use by certain frequent users, such as Aqueous film forming foam (i.e., AFFF). AFFF is fire-fighting foam that is permitted to be used by certain users, including military and fire fighters.[73] Based on regulatory discussions to remove these exemptions, it appears that there are alternatives that could be used in place of PFOS and PFOA.[74]

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[68] Environment Canada, "Proposed Amendments to the Prohibition of Certain Toxic Substances Regulations: 2018 consultation document" (last updated, 04 September 2020), online: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/proposed-amendments-certain-toxic-substances-2018-consultation.html#toc , part 2.1.

[69] Ibid.

[70] Canadian Environmental Protection Act Registry (16-May-2019), online: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry.html

[71] CEPA does not contain broad regulations encompassing multiple forms of perfluoroalkyl substances. Instead, current regulations are limited to perfluorooctane sulfonates, perfluorooctane sulfonamides and perfluorooctane sulfonyls. See *Canadian Environmental Protection Act, 1999*, *supra*, Schedule 3.

[72] See Government of Canada, "Chemicals Management Plan" (last updated 02 June 2016), online: https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan.html.

[73] Ibid. See also Canada Gazette, Vol. 150, No. 20 (5 October 2016).

[74] See Government of Canada, "Proposed amendments to the Prohibition of Certain Toxic Substances Regulations, 2018 consultation document: Chapter 2" (last updated 21 December 2018), online: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/proposed-amendments-certain-toxic-substances-2018-consultation/chapter-2.html#toc4.

Due to the extended time period associated with the regulatory process, however, the federal government has been slow in passing regulations to remove these exemptions.

The final gap reflects the lack of provincial regulations controlling effluents that encompass Perfluoroalkyl substances. Often federal and provincial environmental legislation and regulations concerning chemicals has taken one of two forms—broad bans on manufacturing and use at the federal level, or regulations on the amount and type of effluents allowed at the provincial/municipal level. PFOS and PFOA fall within federal regulation. Accordingly, respecting the division of constitutional powers, there are no regulations of PFOS/PFOA effluent restrictions at the provincial level because jurisdiction is held by federal government. For this reason, the Perfluoroalkyl substances that are permitted to be discharged fall within one of the above-noted federal exemptions or are outside the definition of PFOS, PFOA or PFCA based on the federal definitions resulting in a lack of provincial oversight because these chemicals are not regulated in WWTP (i.e., monitored or detected in WWTP waste streams) at a provincial/municipal level.

2.4.2 Case study two: Microplastics

WWTPs are major pathways through which MPs enter the environment. Currently, there in no clear-cut agreement on a comprehensive all-inclusive definition of MPs (Frias and Nash, 2019; Hartmann et al., 2019). However, the most common definition is plastics that are less than 5 mm in size are called MPs (Akarsu et al., 2020; Dioses-Salinas et al., 2020; Masura et al., 2015; Ngo et al., 2019; Prata, 2018; Schmidt et al., 2020) and those plastic items with length equal or larger than 5 mm have been defined as macroplastics (Lechthaler et al., 2020; Piehl et al., 2018; Taïbi et al., 2021). Due to their small sizes, light weight, high relative surface area, and ability to travel through different environmental media, MPs can absorb, transport, and leach out contaminated and endocrine-disrupting toxins and act as vectors of bacterial pathogens (Cristaldi et al., 2020; Hu et al., 2019). Researchers have found that MPs are present in Lake Winnipeg and all five Great Lakes (i.e., Ontario, Erie, Michigan, Superior, and Huron). For example, Environment and Climate Change Canada researchers found that microbeads and fibres were the most abundant MP in Lake Erie, downstream from the Windsor/ Fort Erie region (Costello and Ebert, 2020; Lenaker et al., 2021) It is estimated that 533 million microfibre pieces are discharged annually from Canadian households into municipal sewers (Vassilenko et al., 2019). The increased global consumption of plastic products, synthetic textiles, inadequate disposal techniques and releases from consumer and industrial products has contributed to this microplastic/micropfibre threat to aquatic environments and freshwater sources.

In the environment, MPs are persistent and accumulative due to their stable carbon-hydrogen bonds that make them resistant to degradation (Westphalen and Abdelrasoul., 2018). Microplastics can also contain other compounds such as lubricants, dyes, plasticizers, fillers and stabilizers as additives hindering the degradation and removal from environments. MPs are also known to be hydrophobic, which means they can adsorb to toxic pollutants like flame retardants, polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls, heavy metals, pathogenic microorganisms, polycyclic aromatic hydrocarbons, pesticides, carcinogenic and endocrine-disrupting substances, and petroleum hydrocarbons (Kwon et al., 2017) These MPs are found in many everyday products, for example, industrial products (e.g., abrasives, scrubbers), commercial products (e.g., synthetic textiles, plastic powders, plastic pellets like nurdles) and personal care products (e.g., toothpaste, body wash, detergents, and facial cleansers). Today, the quantity of microplastics in the environment continues to increase each year (Carlini and Kleine, 2018; Laglbauer et al., 2014). This increase in consumption and use of plastics in society points to the risk of the continued contamination of freshwaters from WWTPs, which are not designed to remove MPs.

Everyday a WWTP operator must manage a range of sizes, types and vast quantities of MPs that pass through the treatment plant every day that illustrates the design removal challenge. Research has shown that microplastic fibers (MPF), microbeads and fragments are the most common MP in WWTPs (Ngo et al., 2019). The problem is these microfiber fragments are continuously released from synthetic textiles (e.g., polyester - stretchy jeans) every time our clothes are washed and dried in household laundry machines and the waste waters are released into municipal sewers or the receving environment. In 2018, researchers reported the release of 6,000,000 to 17,700,000 fibres from a single 5kg washing machine. These researchers estimated that 80% of these fibers travel through WWTP and are released into receiving waters (De Falco et al., 2020, 2018). The concentration of MPs downstream of WWTPs has been reported at varying amounts as high as over 400 MP/L (Estahbanati and Fahrenfeld, 2016; Sun et al., 2019). Specifically, polyester and modified cellulose have been found to be the most prominent type of MPs in remote areas, indicating a potential for being transported over long distances (Carr et al., 2016; Ziajahromi et al., 2016). Rayon, a non-plastic synthetic polymer, represents almost 57 % of all fibres discovered in marine debris: twice the level of polyester, which constitutes more than 50 % of just the MP fibres found. Around 50% of fibres detected in effluents from wastewater in Lake Ontario were blue denim fibres (Grbić et al., 2020). Currently, microfibre filters on washing machines are not required in Canada, nor do regulations exist that prevent the release of fibres into sewers or from WWTP into freshwaters. Despite the ubiquity of microplastics and microfibers in wastewater and the inevitable release into freshwater sources, little is known about the direct health effects of MPs on humans. A few studies have demonstrated the potentiality of metabolic disturbances, neurotoxicity, and increased cancer risk in humans but the effect of microplastics is much more complex due to their ability to produce flocculating particles in freshwater that can both sink and float (Carr et al., 2016; Fortin et al., 2019; Ngo et al., 2019; Segovia-Mendoza et al., 2020; Sun et al., 2019).

Research on MP is limted by the uncertainty surrounding microplastic sampling, detection, quantification, and characterization. Despite the various studies of MPs in sea and fresh water, soil sediments and WWTPs, variances still exist in the sampling protocols, results, methodologies, quantification, characterization methods, and locations (Cheng et al., 2021; Fortin et al., 2019; Grbić et al., 2020; Okoffo et al., 2019; Sun et al., 2019). This heterogeneity has led to difficulties in collaborations and comparison of results between researchers. Standard methods should be established to make comparison of microplastic data sets between researchers feasible and possible. MPs can be reduced if WWTPs devise more efficient treatment methods and regulations are put in place regarding plastics disposal and effluent limits in WWTPs (Alimi et al., 2018; Rogowska et al., 2020; Schmiedgruber et al., 2019; Thushari and Senevirathna, 2020; Woods et al., 2021). Without the modernization of WWTPs, industry incentives to innovate and directed research on the removal and impacts of MP/MPFs upon aquatic environments and freshwater sources, the discharge problem will continue. Source reduction should also be explored as a means of reducing contamination or MP level in the environment.

2.4.2.1 Microplastics Regulation

In April 2021, "Plastic Manufactured Items" were listed as a toxic substance, under CEPA.[75] While "Plastic Manufactured Items" is undefined in the legislation, the Canada Gazette publication offers a definition that informed the listing of the plastics as a toxic substance:

> Plastic manufactured items are any items made of plastic formed into a specific physical shape or design during manufacture, and have, for their intended use, a function or functions dependent in whole or in part on their shape or design. They can include final products, as well as components of products. All plastic manufactured items have the potential to become plastic pollution.[75]

The regulatory process that led to the addition of plastics to *CEPA* commenced in October 2020 when the federal government published "Science Assessment of Plastic Pollution."[76] The report found that plastic pollution, including microplastic pollution, is increasingly prevalent in the environment, and specifically, *macroplastics* "have been shown to cause physical harm to individual animals and to have the potential to negatively affect the habitat of animals."[77] In contrast, the report findings with respect to *microplastics* noted that "the evidence for potential effects of microplastics on individual animals, the environment, and human health is less clear and requires more research."[78]

On October 7, 2020, the government published a discussion paper on "A Proposed Integrated Management Approach to Plastic Products to Prevent Waste and Pollution" for a two-month consultation period. At the same time, the federal Ministry of the Environment published a Canada Gazette Part I proposed regulation to add plastic to the toxic substances list. After a consultation period, the final order adding plastics to *Canadian Environmental Protection Act's (CEPA*) toxic substance list was published in the Canada Gazette Part II on April 23, 2021.[79] The amendment added "Plastic Manufactured Items" as a toxic substance under *CEPA*.

One of the main objections to the addition of "Plastic Manufactured Items" as a toxic substance is that the definition was overly broad and encompasses plastic items that are not toxic and have not been shown to be detrimental to human health. However, the government's response to this criticism relied upon the precautionary principle as exhibited in supporting the Canada Gazette publication.[80] Despite acknowledging that "exposure to macroplastics (as pollution or otherwise) is not expected to be of concern for human health," and animal health was considered a concern where plastic pollution can lead to "entanglement [and] suffocation, strangulation or smothering, and can even result in mortality."[80] The proposed legislative addition of plastics was justified on a precautionary basis where "The science assessment recommends pursuing action

[75] Canada Gazette, Part II, Volume 155, Number 10, Registration
SOR/2021-86 April 23, 2021, Canadian Environmental Protection Act, 1999, P.C. 2021-316 April 23, 2021 #163 Gov't Canada, May 12, 2021, online: https://canadagazette.gc.ca/rp-pr/p2/2021/2021-05-12/html/sor-dors86-eng.html

[76] Government of Canada, "Science Assessment of Plastic Pollution" (October 2020), online: https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/science-assessment-plastic-pollution.html.

[77] Government of Canada, "Plastic pollution- information sheet" (last updated 12 May 2021), online: https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/chemicals-glance/plastic-pollution.html.

[78] Ibid.

[79] Canada Gazette, Part II, Volume 155, Number 10 (23 April 2021) "Order Adding a Toxic Substance to Schedule 1 to the Canadian Environmental Protection Act, 1999" SOR/2021-86, online: https://canadagazette.gc.ca/rp-pr/p2/2021/2021-05-12/html/sor-dors86-eng.html.

[80] *CEPA,* The Preamble includes the precautionary principle: "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;"

to reduce macroplastics and microplastics that end up in the environment, *in accordance with the precautionary principle*."[81]

The government's commitment and reliance on the precautionary principle was strongly emphasized and is found in the following section of the Canada Gazette posting:

> *Given the current state of the science, the departments have not identified concerns for human health at this time, and agree with the need for further research in several study areas. The departments acknowledge that the science assessment presents some conflicting evidence in the scientific literature regarding the ecological impacts of microplastic pollution and, accordingly, the science assessment calls for further research in this realm. Notwithstanding the data gaps in these areas, the departments maintain that the findings of the science assessment underlying the Order hold: macroplastic pollution can cause harm to the environment.*
>
> *Any risk management measures developed under CEPA will be guided by the precautionary principle as set out in paragraph 2(1)(a) of the Act.*

The Canada Gazette publication also emphasized that the amendments to the Act did not create any new restrictions on the use of plastic products. Instead, the federal government with this legislative change now can "target sources of plastic pollution and change behaviour at key stages in the lifecycle of plastic products."[82] Any new regulations that are made on the basis of this definition will be considered on the basis of the science and the potential costs as it is introduced.

As noted above, the new amendments to the *Canadian Environmental Protection Act, 1999* do not add any new regulations or restrictions on the use of "Plastic Manufactured Items", to date. The introduction of "Plastic Manufactured Items" as a toxic substance under CEPA merely provides the legal basis to introduce new regulations under the Act in the future. This appears to be just the first step in the federal government's larger policy strategy to curb plastic waste, as outlined in its discussion paper entitled "A Proposed Integrated Approach to Plastic Products to Prevent Waste and Pollution."[83] The final regulations, however, may take years to develop and implement.

2.4.2.2 Regulatory Gaps

Similar to the PFAS/PFOA listed under *CEPA's* toxic substance list, plastics known as 'manufactured plastic items' are also considered a toxic substance under *CEPA* yet plastics (like PFAS/PFOA) have not been integrated into the WWTP regulatory framework. This regulatory oversight means there is no regulatory requirement at a provincial nor municipal level that requires detection nor monitoring of plastics within WWTP processes.

What is interesting about the recent addition of the manufactured plastic items to CEPA's toxic substance list is the reliance upon precautionary principle to justify the addition of plastics to CEPA's toxic list. In contrast to PFAS listings, the precautionary principle was not relied upon for the listing of discrete perfloroalkyl substances. Within the WWTP process PFAS compounds can biotransform into PFCAs and PFSAs, which are

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[81] Ibid (emphasis added).

[82] Ibid.

[83] Government of Canada, "A Proposed Integrated Management Approach to Plastic Products: Discussion Paper" (October 2020), online: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/plastics-proposed-integrated-management-approach.html .

considered sister chemicals to PFAS, and PFOS and hold similar chemical characteristics that are known to be just as toxic to humans. Surprisingly, the precautionary principle has not been relied upon as the rationale to support the listing of these forever chemicals such as polyfloroalkyl substances.

Similar to the chemical industry's Responsible Care Program or ENERGY STAR® certification program the government should include as a factor (or advance a certification system) to promote the use of filters in washing machines, and support research to determine the most effective filter for use in Canadian households to address the problem of microfibre shedding. Microfibre shedding from synthetic clothes during washing is well documented in the literature. Recent research on the effectiveness of washing machine filters to capture microfibres offers a design feature to be added to washing machines that can reduce microfibre shedding at the source (Napper et al., 2020).

2.4.3 Case study three: Pharmaceuticals

Pharmaceuticals (PhACs) are prescription, veterinary, and over-the-counter therapeutic drugs used to treat human and animal diseases. They can include nonsteroidal anti-inflammatory drugs (NSAIDs), psychiatric drugs, hormones, lipid regulators, β-blockers, and antibiotics. When PhACs are consumed they are not completely metabolized in the human body, and once excreted are carried in sewage to WWTPs and discharged in the effluent. We identified and classified 6 main types of pharmaceuticals in WWTP effluents. WWPTs were not designed to remove PhACs and therefore discharge PhACs into receiving waters which explains, in part, why fresh waters have been found to contain varying concentrations of PhACs downstream of WWTPs (Bouki et al., 2013; Caldwell, 2016; Gilbride and Levinson, 2008). Many scholars have suggested that WWTPs are a hotspot for PhACs residues that enter the aquatic environment (Caldwell, 2016; Santos et al., 2007). Even though the presence, persistence, and potential ecological impacts of these chemical compounds in the environment have been studied for many decades, PhACs continue to gain increasing attention as CEC. Numerous researchers have linked the presence of PhACs in source waters to the disruption of endocrine system pathways in vertebrates, increased oxidative stress, reduced reproductive capacity and are known to bioaccumulate in fish and modify their sexual characteristics (Blázquez et al., 2012; Kim et al., 2012; Nakada et al., 2006). Within a WWTP, PhACs are not monitored because an integrated CEC regulatory framework does not exist.

Complicating the absence of a CEC monitoring process in WWTPs is the problem of a lack of transparency with respect to the types and concentrations of pharmaceutical compounds that are present in the effluents discharged by industries and healthcare facilities. This monitoring gap is further complicated by a lack of regulation, which may explain why pharmaceutical compounds are found to be present and persist in drinking water sources at low concentrations. Researchers pointed out that though these substances are present in low concentrations, continuous low dose exposure, especially to sensitive life stages, may have significant effects (Daughton, 2008; Vasquez et al., 2014).

Another concern is the potential mixture of two or more pharmaceuticals in the environment, in which the synergistic effects of such mixtures may be different from their individual observed effects. One of the main concerns of the impact of active pharmaceuticals in the environment is their ability to bioaccumulate in non-target aquatic organisms. Further research is needed to understand the long-term impacts of PhACs on aquatic ecosystems, including the synergistic and possible additive effects of combinations of pharmaceuticals, or combinations of pharmaceuticals with other compounds upon ecological and human health.

The antibiotic resistance global health phenomenon is another example of CEC contamination of freshwaters that is attributed to the overuse of antibiotics in human and veterinary medicines. WWTP processes do not eliminate all of the antibiotic residues resulting in a release of CEC into aquatic environments. According to the World Health Organization (WHO), the death toll due to antibiotic resistance is expected to rise to ten million deaths by the year 2050, which raises the question: How do WWTPs contribute to this global health problem (WHO, 2014)? In the literature, this question remains unanswered. The accumulation of antibiotic resistant bacteria (ARB) and antibiotic resistant bacteria genes (ARGs) in wastewaters of WWTPs is a known contributor to this particular problem (Ben et al., 2017; Guo et al., 2017). For example, the train of WWTP treatment processes includes a biological process (e.g., activated sludge) which can facilitate the accumulation of ARBs by establishing a suitable environment to support resistance development and spread from bacteria to bacteria. Currently, WWTP treatment methods are not designed to effectively eliminate PhACs and ARGs, therefore releasing these antibiotic residues and genetic materials from microorganisms into receiving freshwaters (Hultman et al., 2018; Karkman et al., 2018; Mao et al., 2015; Pruden et al., 2006). More research into the impacts upon receiving freshwater sources and their ecosystems is needed. It is expected that since antibiotic and pharmaceuticals, in general, are vital medicinal compounds, their residues will continue to contaminate wastewater, therefore research is needed to design and implement new innovative wastewater processes to remove these compounds at the WWTP level.

2.4.3.1 PhACs Regulation

Health Canada is the federal department responsible for the administration of pharmaceuticals under the *Food and Drug Act*, R.S.C., 1985, c. F-27. Under the Act, the legislative aim of protecting human health and the public's safety is carried out by Health Canada's Health Product and Food Branch, which includes the role of conducting a pre-market evaluation of the safety and effectiveness of a drug. However, this function is limited to assessing risk to human health and does not consider the risks to the environment nor the interconnection of public and environmental health.

While none of the pharmaceutical products/additives that were reviewed for this project are explicitly regulated under Canadian federal or provincial environmental laws, the federal government did, however, include a list of 28 substances to be reviewed under the federal Chemicals Management Plan that is carried out under the mandate of Health Canada and Environment and Climate Change Canada.[84] These substances were identified as priorities based on their potential concern to the environment or human health. They did not, however, encompass the entirety of the pharmaceutical products identified as CEC for the scope of this project.

The federal government completed and published its initial screening assessment of these 28 substances on February 21, 2015.[85] The report found that 23 of the 28 substances were not expected to remain in the environment for a long time or accumulate in organisms. Of the five substances that were found to remain in the environment for an extended period of time (tamoxifen, doxorubicin, etoposide, cyclosporin A and cyclosporin E), they were found not to accumulate in organisms. In summary, the government found that the quantity of the 28 substances that may be released into the environment was below the level to cause harm to organisms, constitute danger to the environment, or be harmful to human health. As a result, no new environmental regulations with respect to pharmaceuticals were recommended or introduced following the

[84] Government of Canada, "Certain Substances on the Domestic Substances List used primarily as pharmaceuticals fact sheet" (last updated 20 February 2015), online: https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/chemicals-glance/substances-domestic-substances-list-used-primarily-pharmaceuticals-fact-sheet.html .
[85] Ibid.

study. It should be noted that pharmaceuticals are assessed for the safety and effectiveness as pharmaceuticals under the *Food and Drugs Act*.[86]

Antibiotics: None of the antibiotic CEC under study are expressly regulated under the Canadian environmental laws and regulations reviewed for this report. Accordingly, it is unlikely that the impact of antibiotics on the environment has been assessed by Canadian environmental regulators. Further, antibiotics are not listed as a category for assessment under Canada's Chemical Management Plan. The pharmaceuticals assessment of the Canadian Chemicals Management Plan was last updated on February 20, 2015.[87]

A regulatory overlap does exists between environmental assessment and antibiotic regulations through the "Antimicrobial resistance and Use in Canada: A Federal Framework for Action" regulatory program published by the Minister of Health in 2014.[88] The framework lays out the federal government's regulatory plan for responding to the risk of antimicrobial resistance in Canada. The regulatory framework recognizes a "post-antibiotic era where common infections and minor injuries are once against deadly is a very real possibility for the 21st century"[89] and noted that the World Economic Forum's 2013 Annual Report noted that "arguably the greatest risk… to human health comes in the form of antibiotic-resistant bacteria."[90] The World Health Assembly Member States also endorsed a global call to action in 2014 to develop a plan to address the issue of antimicrobial resistance.[91]

Canada's action plan involves three areas of focus: Surveillance, Stewardship, and Innovation.[92]

a) **Surveillance:** The surveillance function of Canada's Framework for Action Plan involves "detecting and monitoring trends and threats in order to inform strategies to reduce the risks and impacts of antimicrobial resistance." The surveillance functions are primarily carried out by Public Health Agency of Canada in monitoring antimicrobial use and resistance in hospitalized patients (via the Canadian Nosocomial Infection Surveillance Program) and in monitoring antimicrobial resistance in humans, animals and the food supply (Canadian Integrated Program for Antimicrobial Resistance Surveillance). The 2014 Action Framework also noted that a new Canadian Antimicrobial Resistance Surveillance System would be created to further the government's efforts to collect data on antimicrobial resistance in Canada.

b) **Stewardship:** The stewardship function of Canada's Framework for Framework for Action Plan involves "conserving the effectiveness of existing treatments through infection prevention and control guidelines, education and awareness, regulations, and oversight." This aspect of the Framework for Action Plan primarily focuses on education initiatives to prevent the inappropriate use of antimicrobials in human and veterinary medicine, and in the agricultural industry. It also includes potential regulations

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86 *Food and Drugs Act*, RSC 1985, c. F-27.
87 Ibid.
88 (last updated, 13 November 2014), online: https://www.canada.ca/en/public-health/services/antibiotic-antimicrobial-resistance/antimicrobial-resistance-use-canada-federal-framework-action.html
89 Government of Canada, "Antimicrobial Resistance and Use in Canada: A Federal Framework for Action" (October 2014), online (pdf): https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/alt/pdf/drugs-products-medicaments-produits/buying-using-achat-utilisation/antibiotic-resistance-antibiotique/antimicrobial-framework-cadre-antimicrobiens-eng.pdf at 3.
90 Ibid at 5.
91 Ibid.
92 Ibid at 8-12.

with regards to agriculture feeds and vaccines through the Canadian Food Inspection Agency and Health Canada.

c) **Innovation:** The innovation function of Canada's Framework for Action Plan involves "Creating new solutions to counteract loss in antimicrobial effectiveness through research and development." The goal of this function is to foster "new methods and tools to that combat antimicrobial resistance and improve antimicrobial use." This function is integrated with the Canadian Framework for Action Plan on Vaccine Research, Innovation and Development to prioritize solutions to the threat of antimicrobial resistance, in addition to funding for the Canadian Institutes of Health Research-funded Canada-UK partnership on antimicrobial resistance, and other Canadian Institutes of Health Research funded projects.

In 2015, one year following the Federal Framework for Action, the federal government published the "Federal Action Plan on Antimicrobial Resistance and Use in Canada."[93] The Action Plan sets out a set of priorities for the following government organizations to help implement the previously-reported framework: (a) Public Health Agency of Canada; (b) Health Canada; (c) Canadian Food Inspection Agency; (d) Canadian Institute of Health Research; (e) Agriculture and Agri-Food Canada; (f) National Research Council; and (g) Industry Canada.[94]

In response, a series of regulations have been made in an effort to address antimicrobial resistance. In 2017, the *Food and Drug Regulations*[95] were updated to provide increased regulatory oversight of microbials for veterinary use. The updated regulations included increased oversight over veterinary active pharmaceutical ingredients imported or sold in Canada, the packaging of veterinary products, and restricted the use of important or use of unauthorized veterinary drugs.[96]

In 2018, Health Canada took another step in its action plan to combat antimicrobial resistance by releasing for consultation and publishing a pathogens of interest list.[97] The purpose of the list was twofold: (a) To inform sponsors and manufacturers of the bacterial pathogens creating the most urgent need for innovative therapeutic drugs and/or diagnostic devices in Canada; and (b) To guide the development of new tools and policy approaches by Health Canada."[98] The publication of this list was Phase I in Health Canada's action plan. Phase II involves further engagement with stakeholders and new ways to incentivize innovation. No further updates

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[93] Government of Canada, "Federal Action Plan on Antimicrobial Resistance and Use in Canada" (March 2015), online (pdf): https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/alt/pdf/publications/drugs-products-medicaments-produits/antibiotic-resistance-antibiotique/action-plan-daction-eng.pdf

[94] A full description of the role of each organization can be found on page 1 of the Action Plan (ibid).

[95] CRC, c. 870.

[96] Canada Gazzette, Part I, volume 150, No 27 (2 July 2016), online: http://www.gazette.gc.ca/rp-pr/p1/2016/2016-07-02/html/reg2-eng.html .

[97] Health Canada, "Notice- Health Canada's efforts to support innovative human therapeutic products to combat antimicrobial resistance (AMR)" (15 November 2018), online: https://www.canada.ca/en/health-canada/programs/consultation-proposed-pathogens-interest-list/notice-efforts-combat-antimicrobial-resistance.html

[98] Ibid.

to Phase II have been published on the "Antibiotic (antimicrobial) resistance" Government of Canada information page, which was last updated in November 2018.[99]

In July 2018, the Government of Canada published a 'Progress Report on the 2015 Federal Action Plan on Antimicrobial Resistance and Use."[100] The report notes that the government has been successful in accumulating data to help understand the antimicrobial use issue and disseminating that data through public education programs. And in 2018, the Government of Canada released a report summarizing the findings of the surveillance system.[101] The Progress Report notes, however, that "work still needs to be undertaken…to address the remaining challenges in our response."[102]

2.4.3.2. Regulatory gaps

Similar to the PFAS and the microplastic case studies, a WWTP regulatory oversight exists for PhACs. This regulatory oversight means there is no regulatory requirement at a provincial nor municipal level that requires detection nor monitoring of PhACs within a WWTP. Thus, understanding the risk of PhAC impacts to human and ecological health as result of WWTP acting as a conveyer and a producer of PhAC chemical pollutants and the discharge into the environment is still an elusive issue in the wastewater sector.

Minimal research has been conducted to understand how PhACs in water sources and, in particular, in wastewater treatment processes contribute not only to the spread of antimicrobials in the environment but also to an increased risk of the global spread of antimicrobial resistance. Interestingly, federal government policy reports consistently acknowledge that antimicrobial resistance is a "global threat to human life".[103] International organizations have also recognized the threat posed by antimicrobial resistance, with the issue being one of only four health issues to be discussed in a United Nations General Assembly high level meeting (in addition to HIV, Ebola, and non-communicable diseases).[104] In response, the government has adopted a risk mitigation plan that focuses on data-gathering, education, and active participation from stakeholders to develop innovative solutions to the problem of antimicrobial.

Apart from some regulations directed at veterinary products, the majority of regulatory efforts has focused on educational campaigns. In 2020, the Public Health Agency of Canada published the most recent Canadian Antimicrobial Resistance Surveillance System Report documenting the status of antimicrobial resistance research in Canada.[105] The Report notes that the prevalence of antimicrobial-resistant organisms is increasing globally and in Canada.[106] The Report recommends that further efforts are made in collaboration between

[99] Government of Canada, "Antibiotic (antimicrobial) resistance" (last update 16 November 2018), online: https://www.canada.ca/en/public-health/services/antibiotic-antimicrobial-resistance.html .

[100] Government of Canada, "Progress Report: On the 2015 Federal Action Plan on Microbial Resistance and Use" (July 2018), online (pdf): https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/drugs-health-products/progress-report-2015-federal-action-plan-antimicrobial-resistance-use/pub-eng.pdf

[101] Government of Canada, "Canadian Antimicrobial Resistance Surveillance System: Update 2018" (November 2018), online (pdf): https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/drugs-health-products/canadian-antimicrobial-resistance-surveillance-system-2018-report-executive-summary/pub1-eng.pdf .

[102] Ibid at 15.

[103] Ibid at 1.

[104] Ibid.

[105] Public Health Agency of Canada, "Canadian Antimicrobial Resistance Surveillance System Report: Update 2020", online (pdf) https://www.canada.ca/content/dam/hc-sc/documents/services/drugs-health-products/canadian-antimicrobial-resistance-surveillance-system-2020-report/CARSS-2020-report-2020-eng.pdf .

[106] Ibid at 9.

different levels of government and partners in industry, healthcare, agriculture, academic etc. in order combat the trend of increase use and resistance of antimicrobial bacteria, which the Report describes as a "looming public health threat and potential economic disaster in Canada" if proper action is not taken.[107]

2.5 Implications

The presence and removal of CECs from WWTPs effluents is a well-documented challenge currently facing Canadian municipalities. This report presented an interdisciplinary knowledge synthesis research on CECs in WWTPs where we focussed on three case studies (PhACs, PFAS, and MPs). A comprehensive review of the current state of knowledge regarding these case studies was established, where we focussed on their impact throughout their life cycle, their transformation by-products, and their synergetic and cumulative effects currently documented in WWT research, along with techniques for their monitoring in WW and the receiving environment. We further conducted investigative surveys to determine the current state of knowledge among WWT industry stakeholders and knowledge users: operators, engineers, and policymakers. Based on our research, we identified significant gaps in the scientific, legal, and Indigenous knowledge about CECs and WWTPs. While this research was organized around four objectives, we discovered that examining the operational burden imposed upon industry and municipalities was aspirational but is a complicated issue that was beyond the scope of this project and requires further research; hence, the financial burden of CEC was not determine. The research outcomes of the project, which are presented in this comprehensive report are directed at Canadian municipalities, industries, and First Nations, and can be used for the development of CEC measurement risk management protocols and outline a proposed legislative response.

Policy implications

- All levels of government and the wastewater industry are unprepared to address CEC pollution that has been identified as an ubiquitous pollution problem that affects the human health of Canadians, and ecosystems within the biosphere.
- In order to recognize the lack of political will demonstrated by all levels of government to address not only sources of CEC pollution but also the lack of modernization of WWTPs, CEC regulatory tools (production, use, or disposal) should be developed and directed at the source (e.g., industrial, commercial, and public sector sources) with goal of preventing CEC discharges into municipal sewers, and water sources.
- A regulatory risk exists for sectors of the economy that manufacture, produce, dispose of CEC into municipal sewer systems or directly into receiving waters without first treating effluent discharges from their facility.
- An opportunity exists to become a first mover in the development of innovative WWTP processes that eliminate CEC from discharge streams and advance the use of artificial intelligence methods in support of a circular economy.
- Funding opportunities are needed, perhaps developed through public-private partnerships that are directed at research and development in WWTP processes that address CEC pollution.

Practice implications

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[107] Ibid at 14-17.

- In wastewater treatment practice, environmental monitoring at WWTP should provide stakeholders data to assess the risk not only of each contaminant but also of the cumulative impacts and removal rates of CEC.
- WWTPs need to start monitoring the chemicals that are released with their effluent so that trends concentrations can be logged and better inform policies and regulations. Without science-based regulatory instruments, WWT operators face the problem of deciding what data to collect and what to measure when assessing the risk of CEC.
- The dominant regulatory idea being advanced by regulators and supported at a municipal level is preventing CEC from entering the municipal wastewater system by stopping the release of CEC at the source (i.e., industry, commercial) rather than an end-of-pipe regulatory regime that places the costs upon municipalities, and ultimately, taxpayers.
- Advancing corporate environmental responsibility is key, where a normative legal framework that advances contemporary environmental, public health and corporate social responsibility norms such as a sustainable WWTP governance framework based on principles of subsidiarity, sustainability, precautionary principle, user-pay, inter/intra generational equity, and transparency for citizens is required.

Research implications

- Regulatory research is needed to design an integrated sustainable WWTP regulatory regime that is responsive to current science and takes into account contemporary environmental law norms , public health concerns and Indigenous knowledge. The current regulatory regime is fragmented and has led to regulatory, safety and innovation gaps and overlooks wastewater treatment on First Nations.
- CEC will only be monitored in a WWTP once these compounds are identified as a risk to human health, suggesting further research and funding are needed. Research is needed on the risks associated with the currently identified CEC, their impact solely and in combination on the ecosystem and quality of water.
- The current contaminant-by-contaminant classification system is inadequate and can lead to misleading results. Misleading results can stem from CEC transformation products that may exhibit similar chemical activity and toxicity levels to the parent CEC compound and may become undetected in the WWT monitoring of influents and effluents. Further research is needed to determine the most suitable monitoring program for each type of CEC, and WWTP.
- An integrated analytical approach is recommended in the literature where targeted and non-targeted screening of specific CEC combined with biological assays to measure ecological impacts. Further research is needed to support novel bioanalytical techniques, which can yield information on organism function and health at the molecular level.
- Wastewater treatment requires more research to develop new innovative techniques to remove CEC from wastewater. Industry innovation and incentives are needed.

2.6 Conclusion

Everyday in Canadian cities, compounds that potentially adversely impact human or ecological health pass through Canadian wastewater treatment systems. These compounds originate from industries, hospitals, animal care, domestic households, and enter our sewers. WWTP are not designed to remove these CEC compounds,and often these CEC are released into receiving waters that are used for fish and animal habitats, and serve as potential drinking water sources. The risk associated with these compounds has not been definitively established by science but there is evidence that some of the compounds have endocrine disrupting properties, cause increased pressure to produce antibiotic resistance in bacteria, produce birth defects in biota among various impacts suggesting a precautionary approach should be adopted. Since these compounds are not naturally found in the environment, their presence in the environment is likely to cause an effect on the natural rhythm of the ecosystem and produce impacts that may be either acute or chronic. These pollutants are classified as 'contaminants of emerging concern' (CEC) and are present in wastewater but not currently monitored in the effluent streams.

Our research on CEC from wastewater outputs has identified at least 600 compounds that are regarded as pollutants that are introduced via anthropogenic activities. Very few of these compounds are regulated, either at the source or at the treatment level, thereby allowing CEC to continue to flow into aquatic environments. The WWTP regulatory regime for CEC is lacking and complicated as result the fragmentation of the legislation at federal, provincial and municipal levels and the dearth of risk assessment research to determine the impact of such compounds on human health and the earth's ecosystem balance. This research utilized three case studies to illustrate the challenges and gaps that exist in the scientific detection and monitoring, engineering technologies, and guidelines and policies, law and policy instruments, and WWTP data management gaps.

The case study on PFAS illustrates how controls at the source (e.g. industrial site) and bans prohibiting their use could significantly reduce the presence of these compounds at downstream locations. Although some PFAs have been regulated, many other types are not included on the CEPA toxic substance list. Since green chemical replacement compounds that have the same properties and benefits as PFAS and PFOA are not currently available, expected the continue use of these compounds, and the continued existance of CEC pollution. Laws that severely inhibit the use of these compounds will perhaps drive the need to look harder for alternatives and thereby reduce the impact of PFAS on the environment.

The case study of microplastics demonstrates the need for both source control and innovation in both product design (i.e., washing machines) and wastewater technologies to modernize WWTP. Often plastics are used as a convenience and not a necessity and therefore public awareness of the impact of these compounds on the environment may help to reduce their use. Furthermore, additional legislation can drive the search for better methodologies to remove these particles from effluent before it is discharged form WWTPs.

Lastly, the case study on pharmaceuticals highlights that this group of compounds is the most difficult to remove or reduce at the source and underlines the need for a multi-pronged regulatory approach informed by science. The benefits of drugs for the treatment of infectious diseases and medical conditions cannot be denied. However, these compounds are prevalent in WWTP effluent streams, in fresh water sources and even in drinking water attesting to their persistence in the environment. Although the current concentrations are not at levels that cause acute impacts, the chronic effects of having drugs in our water sources is unknown pointing to the need for further research to understand the public health and enivironment impacts that can inform the development of a responsive regulatory regime. There is a need to develop regulatory instruments based on acceptable discharge limits leading to data that may also advance science, inform the design of innovative WWTP technologies that could remove pharmaceuticals from effluent streams and lead to environmental protection of water sources, and human and animal health.

2.7 Knowledge mobilization activities

Throughout this interdisciplinary research, the focus has been to disseminate and discuss the knowledge synthesized in our project with cross-sectoral stakeholders: researchers, industry organizations, First Nations, all levels of government, not-for-profit and non-governmental organizations, educational institutions, university research institutions, students, and the general public. Investigative surveys via interviews of experts (i.e., operators, engineers, and policymakers) were conducted. A peer-reviewed, plain-language report with a summary brief is being prepared, which will be widely distributed via print and social media sites such as Ryerson University's website and Urban Water Research Centre. Three comprehensive review articles of the case studies covered in our project are currently being prepared for publication in scientific journals (Case study one: Pharmaceuticals (PhACs), Case study two: Microplastics (MPs), and case study three: Per- and poly-fluoralkyl compounds (PFAS). Seven conference publications were presented targeting water governance and wastewater industry-based conferences supported by the team's network of domestic and international wastewater policymakers, practitioners and academics. Further, a Toronto-based workshop will be hosted by the Urban Water Research Centre at RU in Fall 2021. The publication of the knowledge synthesis report, the academic articles and the forthcoming workshop will support robust and science-based law and policy reform in pursuit of a multi-pronged regulatory goal to protect human health and healthy aquatic systems, educate the public, and expand knowledge within academic and industry communities. A notable contribution to knowledge mobilization is our recent brief submission to the Standing Committee on Environment and Sustainable Development in response to the Freshwater in Canada Study: A Pressure Point on Canada's Freshwater Resources: Chemicals of Emerging Concern & Wastewater Treatment Plant Processes. The list of the published contributions is as follows:

Conference Presentations:

1. Abamecha, M., Aladekoyi, O., Hamza, R., Hania, P., and Gilbride, K. 2020. Occurrences and Effects of Perfluoroalkyl Substances in Wastewater Effluents. *1st Virtual Canadian Symposium on Water Quality Research*. Jul. 23-24.
2. Onyedibe, V., Hamza, R., Gilbride, K., and Hania, P. 2020. Microplastic Pollution in Wastewater Treatment Plants. *1st Virtual Canadian Symposium on Water Quality Research*. Jul. 23-24.
3. Aladekoyi, O., Abamecha, M., Hamza, R., Hania, P., and Gilbride, K. 2020. Evaluation of the impacts of pharmaceuticals in wastewater. *1st Virtual Canadian Symposium on Water Quality Research*. Jul. 23-24.
4. Hania, P. The Regulatory Gap: Chemical of Emerging Concern in the WasteWater Sector. The 8th JELP Environmental Law Conference, June 9-11, 2021.
5. Gilbride, K., Hamza, R., and Hania, P. 2020. Contaminants of emerging concern and the gap between science and policy, Canadian Science Policy Conference 2020, *Video Presentation.*
6. Ilieva, Z., Hamza, R., & Suehring, R. 2021. Removal of Per- and polyfluoroalkyl Substances (PFAS) during wastewater treatment. International Water Association - Young Water Professional Canada Conference 2021, June 23-25. *Oral presentation.* Winner of One slide-3-min presentaton.
7. Ilieva, Z., Hamza, R., Suehring, R., Gilbride, K., Hania, P. (2021). Removal of Per- and polyfluoroalkyl Substances (PFAS) during wastewater treatment. International Water Association - Young Water Professional Canada Conference 2021, June 23-25, 2021. *Oral presentation.* Winner of Oral Presentation Award.

Media Articles:

1. Gilbride, K., 2020. Contaminants of emerging concern: Pharmaceuticals pose challenges for wastewater treatment. What solutions are available? Water Canada 20:(3)8-9.

Thesis:

1. Aladekoyi, O., August 2021. The detection, monitoring and removal of pharmaceuticals from wastewater: Does the current Canadian chemical management framework protect ecological health in receiving water sources? MSc thesis, Ryerson University.
2. Siddiqui, S., May 2021. Accumulation of antibiotic contaminants of emerging concern in the environment: Have appropriate measures been taken to protect human and ecological health? 4th year thesis, Ryerson University.
3. Onyedibe, Okhade V. Effects and fate of microfibers on wastewater treatment and their removal: Insights into treatment performance, microbiome selection, and synergetic impacts on functional organisms in granular and suspended sludge reactors. PhD, Ryerson University. In progress.
4. Ilieva, Z. Fate and removal of per-and poly-fluoroalkyl substances in aerobic granular sludge reactor. MSc, Ryerson Univeristy. In progress.

Response to fresh water Bill (C-68):

1. Gilbride, K., Hamza, R., and Hania, P. Chemicals of Emerging Concern & Wastewater Treatment Plant Processes. A Brief in Response to the Freshwater in Canada Study: A Pressure Point on Canada's Freshwater Resources. Submitted to the *Standing Committee on Environment and Sustainable Development*. June 7, 2021.

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3.0 Appendices

Appendix I: Questionnaire

Appendix II: Interviewee consent form (ethics approved form)

Appendix I: Questionnaire

The Questionnaire was designed to augment the written literature by collected verbal knowledge and opinions that are not often expressed in peered reviewed literature. This knowledge based information from experts in this area was invaluable to the overall story of CEC in wastewater.

The questionnaire was vetted by the Ryerson Ethics Committee and assigned a

Questionnaire "A"

This questionnaire was designed to be used to interview wastewater engineers, operators, and laboratory personnel at WWTPs

Questionnaire "B"

This questionnaire was designed to be used to interview directors/coordinators of water agencies (provincial and federal), government agency personnel and policy people.

Questionnaire: Consist of two parts

Questionnaire Instrument Part A: Designed for WWTP Experts
Questionnaire Instrument Part B: Designed for Policy Experts

PART A:
Designed for WWTP Experts

This WWTP expert questionnaire is broken down into five categories:

A. Introduction: the demographics relating to the study participant are set out.
B. General: the details of the WWTP and its operations are established.
C. Monitoring: the details about the WWTP and CEC monitoring processes are verified.
D. Risk assessment: the details about CEC risk management at the WWTP is determined.
E. Governance: where an understanding of the governance of the WWTP and the legal regulatory knowledge is ascertained.

Section A: Introduction: (Study Participant Demographic**s) *** These questions confirm data that the interviewer has gathered prior to the interview.

Q1: * What is your title?

Q2: How long have you been in this position?

Q3: What is your role?

Q4: What responsibilities do you have in this role?

Q5: Are you the final decision maker?

Q6: Your area of expertise –

- i) How would you describe your area of expertise within the WWTP?
- ii) Have you always worked in this area of expertise or did you come to this position from another area of expertise in the WWTP sector?

Section B. General: (Description of the WWTP) * These questions confirm data that the interviewer has gathered prior to the interview.

Q1: * The WWTP:

i) Please confirm the name, location, and address:

ii) The population size the plant serves is:

iii) The WWTP discharges its final effluent into what body of water?

iv) Does the WWTP serve a First Nation community?

Q2: * The WWTP Treatment Processes:

i) What type of treatment processes are used at the WWTP?

ii) Is the treatment process: Chemical? or Aerobic? or Anaerobic? or Dewatering? or Biosolid? Or something else?

iii) What is the treated volume per year (per month)?

Q3: *The WWTP's Waste Sources:

i) Where does the plant receive its sources of waste from: municipal, industrial, institutional (e.g., hospital) or other?

ii) What percentage of the source is municipal household waste?

iii) What percentage of the source is industrial waste? – largest industrial source?

iv) What percentage of the source is institutional waste? – what institution?

v) What percentage of the source is other waste?

Q4: Raw Wastewater Loading Rates:

i) Are there certain times of the year that the WWTP experiences variations in the received raw wastewater?

ii) If yes, What type of challenges do these variations in raw wastewater present to the WWTP's operations?

Qs5&6&7: CEC & The WWTP:

Q5.:

i) How do you define CEC? Please clarify: Your definition and CEC knowledge are informed by personal or professional knowledge or both: for example, WWTP practices, industry or policy directives or educational opportunities?

ii) Do you think the WWTP receives CEC via the <u>incoming</u> raw wastewater? Yes or No or Don't know

iii) If yes, then move to Q6, if no go to Q7.

Q6.: Can you name (list) what types and amounts of CEC's that are received in the raw wastewater? into your plant?

Q7A: Do you think the WWTP <u>discharges</u> any CEC via the final effluent? Yes or No or Don't know

i) If yes, via the final effluent?

ii) If yes, via the sludge/biosolid? And, Do you know how the biosolid is disposed? (e.g., land-applied or incineration or a combination of both)

Section C: Monitoring

Q1: Do At the WWTP, are CEC compounds currently monitored (or measured)?

i) If yes, please list the CEC that are monitored (or measured)
ii) Do you know at what stage of the WWTP process CEC are monitored (or measured)? (i.e., in the raw wastewater, treated effluent or in biosolids)

Q2: How feasible do you think it would it be for a WWTP personnel to test for CEC compounds? (E.g., WWTP on-site vs off site lab? What type of analytical equipment needs would exist?, cost?)

Q3: Do you think it is the responsibility of WWTP to monitor for CEC? Or should another regulatory body be responsible for monitoring the effluent for CEC at the water source?

Section D: Risk assessment

Q1: Do you think there are any risks to human or environmental health when CEC are discharged from a WWTP into the environment?

Q2: Do you think that mixtures of CEC received in raw wastewater could create more or less risk than single CEC in wastewater?

Section E: Governance

Existing Regulations –

Q1: Wastewater Standards Effluents Regulations (WSER)

i) Does the WWTP meet the Wastewater Standards Effluents Regulations (WSER)? --- always? Most of the time? Sometimes? (Circle the answer)
ii) If not, what monitoring parameter is typically not met? (e.g., nitrogen, phosphorus, other?)
iii) Do you know if the WSER mandates the monitoring of CEC?

Q2.: Transitional Authorization (TA)

i) Has your plant received a Transitional Authorization (TA) permit to extend the deadline for compliance with any of the effluent monitoring and reporting requirements under the WSER?

ii) If yes, what is the TA expiry date?

iii) If yes, Do you expect to be able to meet WSER monitoring and reporting requirements by the TA expiry date?

iv) If no, Do you know if the WWTP is in the process of applying for the TA? Or intends to apply?

Q3.: Other Regulatory Instruments & Policy:

i) Is the WWTP subject to any other government authorizations or permits or municipal by-laws or industry standards (ISO) that relate to effluent releases?

ii) Please list all federal, provincial, municipal or self-regulatory bodies that you currently either work with or report to.

iii) Do you know if the plant has received any regulatory directives on CEC from the federal or provincial or municipal government?

a) If yes, what is the process for implementing these regulatory directives

b) If yes, who is responsible for overseeing the implementation of the directive at the WWTP

c) If yes, can you name the regulatory oversight body?

iv) Do you review or consider any policy guidance on CEC monitoring or controls from any non-profit organization?

Potential Regulations –

Q1: Do you think the WSER should include CEC in the regulations?

Q2: If the WSER is amended to include the monitoring of CEC, do you think a specific waste stream (i.e., final effluent, biosolid, or air stream) should be targeted? Or not? Please explain

Q3: If CEC are regulated, what challenges (e.g., monitoring, design, technology, feasibility, fiscal) do you foresee in the treatment processes or the operation of the plant or the training of plant personnel?

Q4: Do you think that any CEC should not be regulated? Please explain

Q5: What changes to WWTP processes have been implemented during Covid-19? Are there any lessons to be learned from Covid-19 implementation processes that could be applied to CEC?

Part B:
Designed for Policy Experts

This questionnaire for policy experts is broken down into five categories:

A. Introduction: the demographics relating to the study participant are set out.
B. General: the details of the WWTP and its operations are established.
C. Monitoring: the details about the WWTP and CEC monitoring processes are verified.
D. Risk assessment: the policy and governance implications of CEC and an appropriate risk management approach at WWTPs is explored.
E. Governance: where an understanding of the governance of the WWTP and the legal regulatory knowledge is ascertained.

Section A: Introduction: (Study Participant Demographic**s) *** These questions confirm data that the interviewer has gathered prior to the interview.

Q1: * What is your title?

Q2: How long have you been in this position?

Q3: What is your role?

Q4: What responsibilities do you have in this role with respect to policy formation?

Q5: Are you the final decision maker? Or do you defer to a Deputy Minister, Minister, Director or Board of Directors?

Q6: Your area of expertise –

i) How would you describe your area of expertise with respect to WWTP or CEC?

ii) Have you always worked in this area of expertise? or did you come to this position from another area of expertise in the WWTP sector? Or industry? Or academia?

Section B. General:

Q1: The WWTP:

i) How would you identify which WWTPs in Ontario are (or could be) affected by the CEC issue?

ii) Do you think certain communities (including First Nations) are at greater risk of CEC in either the raw wastewater or the final effluent or the receiving waters? Or groundwater?

iii) What do you see as the greatest challenge facing WWTPs on the CEC issue?

iv) Are you aware of any WWTP (within Ontario, other provinces or internationally) that are monitoring CEC?

Q2: The WWTP Treatment Processes:

i) Do you think one (or more) of the WWTP treatment processes should be targeted to regulate manufactured CEC?

ii) Do you think one (or more) of a WWTPs waste source (municipal, industrial, institutional or other) presents a greater risk of releasing manufactured CEC into the environment? Please explain

iii) Do you think one type of a WWTP (small or medium or large WWTP) presents a greater risk of releasing manufactured CEC into the environment? Please explain

Q3: Raw Wastewater Loading Rates: Seasonal variations or not?

i) Do you think there is a seasonal variation to WWTPs receiving CEC in the raw wastewater?

ii) How should this seasonal variation (or not) be taken into account in a CEC policy or regulation directed at WWTPs?

Qs4&5: CEC & The WWTP:

Q4.:

i) How do you define CEC? Please clarify: Your definition and CEC knowledge are informed by personal or professional knowledge or both: for example, WWTP practices, industry or policy directives or educational opportunities?

ii) Please name any report, academic article, industry standard that you would rely (or do rely) upon to develop a definition for CEC? – Why?

iii) Who are the key researchers or research agency or jurisdiction (for example, USA- EPA or EU Directives or Chemical Industry Association of Canada or Health Canada) that you rely upon to gain knowledge about CEC? Or rely upon as precedent to draft a policy or regulation?

iv) How should Indigenous knowledge be taken into account designing a policy of CEC and WWTPs?

Q5A: Do you think WWTPs (in Ontario) discharge CEC via the final effluent? Yes or No or Don't know

i) If yes, via the final effluent?
ii) If yes, via the sludge/biosolid? And, Do you know how the biosolid is disposed? (e.g., land-applied or incineration or a combination of both)
iii) What is the basis for this knowledge?

Section C: Monitoring

Q1: How feasible do you think it would it be for a WWTP personnel to test for CEC compounds? (E.g., WWTP on-site vs off site lab?, what type of analytical equipment needs would exist?, cost?)

Q2: Do you think it is the responsibility of WWTP to monitor for CEC? Or should another regulatory body be responsible for monitoring the effluent for CEC at the water source?

Q3. Do you think an interdisciplinary regulatory legislative response can be developed for this CEC issue?

Section D: Risk Assessment

Q1: Do you think there are any risks to human or environmental health when CEC are discharged from a WWTP into the environment?

Q2: Do you think that mixtures of CEC received in raw wastewater could create more or less risk than single CEC in wastewater?

Section E: Governance

Existing WWTPs Regulations

Q1: Wastewater Standards Effluents Regulations (WSER)

i) Do you think WSER is the appropriate regulatory tool to monitor CEC in WWTPS? Please explain
ii) What do you think is the appropriate regulatory body (including ISO self-regulatory bodies) and instrument to manage the manufacturing of CEC? Please explain
iii) What do you think is the appropriate regulatory body and instrument to manage and monitor the release of CEC into the environment? Please explain

Q.2: Transitional Authorization (TA)

i) Do you think the TA instrument could be used to transition the monitoring of CEC in WWTPS?

Q.3: First Nations

i) Are you aware of any CEC or WWTPS regulations (or policies) that apply to First Nation communities?

ii) Has an Indigenous law perspective of water governance been considered in these policies?

ii) How many First Nation communities have wastewater treatment plants?

Q4. Other Regulatory Instruments & Policy:

i) Do you know of any regulatory CEC directives from the federal or provincial or municipal government?

ii) What is the normative basis of these regulatory directives (e.g., state of repair or best technology or science or legal principles)?

iii) What are the strengths and weaknesses of these regulatory directives? (e.g., educational tools)

iv) How should these regulatory directives updated? (e.g., regulated - public consultation process)

v) Should industry participate in the drafting of a CEC policy instrument?

vi) How, and should the general public participate in the drafting of the policy instrument?

vii) Does your agency hold an oversight responsibility of the implementation of these instruments? Or a reporting responsibility?

Potential Regulations -

Q1: Do you think the WSER should include CEC in the regulations?

Q2: If the WSER is amended to include the monitoring of CEC, do you think a specific waste stream (i.e., final effluent, biosolid, or air stream) should be targeted? Or not? Please explain

Q3: If CEC are regulated, what challenges (e.g., monitoring, design, technology, feasibility, fiscal) do you foresee in the treatment processes or the operation of the plant or the training of plant personnel?

Q4: Do you think the proposed regulatory framework should adopt an integrated regulatory approach that takes into account a diverse range of regulations?

Q5: Do you think that any CEC should not be regulated? Please explain

Q6: Are you aware of any changes to WWTP processes that have been implemented during Covid-19? Are there any lessons to be learned from Covid-19 implementation processes that could be applied to CEC?

Appendix II: Interviewee consent form (ethics approved form)

Consent Form Template and Confirmation of Agreement Form

Ryerson University
Consent Agreement

You are being invited to participate in a research study. Please read this consent form so that you understand what your participation will involve. Before you consent to participate, please ask any questions to be sure you understand what your participation will involve.

TITLE OF THE STUDY: The Wastewater Pollution Challenge: What is an emerging contaminant? & How to protect human and ecological health?

INVESTIGATORS This research study is being conducted by the following researchers at Ryerson University:
Dr. Kim Gilbride, Dept of Chemistry and Biology, Faculty of Science (Principal Researcher)
Dr. Rania Hamza, Dept of Civil Engineering, Faculty of Architecture and Engineering Science
Dr. Patricia Hania, Law and Business Department, Ted Rogers School of Management.

This study is funded by SSHRC: Knowledge Synthesis Grant.

If you have any questions or concerns about the research, please feel free to contact Dr. Gilbride at gilbride@ryerson.ca.

What is the purpose of this Study? This research investigates the gap in knowledge regarding the presence of 'contaminants of emerging concern' (CEC) in wastewater treatment plant (WWTPs) discharges into freshwater sources. CEC compounds are characterized as contaminants that are discrete chemicals, and are known as: pharmaceuticals, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), and microplastics. While recent research has shown that CEC discharged from WWTPs are present in downstream freshwater sources relied upon for drinking water and fish habitat, a knowledge gap exists regarding the impact of these manufactured CEC on human and ecological health, and the contribution of WWTP sector. Given the manufactured nature of these chemicals our research project is focused on three classifications of CEC: microplastics including microplastic fibers, pharmaceuticals, and PFOS/PFOA. This emerging CEC problem can be linked to particular industrial sectors, and further research is needed to understand the breadth and depth of the knowledge gaps of experts in the wastewater treatment industry, environmental and public health policy experts and regulatory experts (e.g., Canadian Environmental Protection Act, Fisheries Act, Wastewater Standards Effluents Regulations, SOR/2012-139).

The purpose of this aspect of the research is to interview experts, such as yourself, in Ontario's wastewater treatment sector (e.g., WWTPs engineers and operators including government policy makers and academics) to understand your knowledge of CEC, and the gaps in scientific, legal and indigenous knowledge and practices with respect to CEC and WWTPs. The interviews will be conducted by a graduate student with oversight by one of the three investigators. The data collected will be used to develop a report that will be directed at Canadian wastewater treatment industry, municipalities, industries, First Nations and academics. A goal of the report is to inform the development of risk management measurement protocols for CEC in order to outline a proposed regulatory response.

What are study participants asked to do? If you volunteer to participate in this study, you will be asked to do the following things:

As a study participant you will be interviewed by a team member (i.e., graduate student and one investigator). The purpose of the interview is to gather data that is informed by your expert knowledge. Both open and closed-end questions will be used during the interview, and the questionnaire is designed to allow the researchers to establish the baseline knowledge and practices associated with WWTPs processes in relation to: CEC, the operation of a plant, the existing and proposed legislative regime and policies for WWTPs and CEC. It is expected that an interview will be completed in 45 minutes via a zoom call. The interviews will be recorded, with your permission. If you do not agree to be recorded, the interview will not be recorded. Once an interview is completed, the responses to the interview questions will be reviewed and edited for clarity and accuracy by a graduate student, and then, the student will email a copy of the interview document to you for your review and verification of the responses to the questions. The graduate student will also be responsible for follow-up of the interview responses with you.

The interview questions are set out in Appendix "A". The demographic data to be collected in the interview will be limited to:

1. The name and title of the person (i.e., professional position).
2. Length of time they have held their current position.
3. Area of expertise, and length of time in this area of expertise.
4. Their role.
5. Their responsibilities.
6. Their position in the decision-making process *(Note to interviewer: establish decision making).*

What are the Potential Benefits of the Research? A benefit of the research is that the knowledge gap with respect to CEC and WWTPs will be better understood by academics, researchers, policy makers, regulators and municipal officials allowing for the development of a proposed regulatory response. The development of the knowledge synthesis report and the supporting educational workshop offers will not only encourage knowledge transfer and translation with respect to the design and operation of wastewater treatment processes but also may incentivize further research and the development of WWTPs operational responses. It is expected that government officials, policy makers and regulators will be informed on how to respond to this environmental and human health protection problem, and the infrastructure funding challenges.

What are the Potential Risks to You as a Participant? The potential risks are low to study participants as their identity will remain confidential. Perhaps, learning more about CEC and the impact upon human health and the environment might create feelings of frustration given the current limited regulatory and policy response where CEC are not regulated in WWTPs.

How will confidentiality of research materials and participants be established? Your identity as a study participant will remain confidential. The study participant's interview questionnaire will be coded to protect their identity, and the interview data (i.e., individual questionnaires and tape recordings) will be stored in a secured location (i.e., locked in a filing cabinet in the Department of Chemistry and Biology, KHN312 (office of PI)) and will remain under the responsibility of the Principal Investigator – Dr. K. Gilbride for the length of time as required by Ryerson policy and procedures. You will be provided the opportunity to review and edit the recordings, and your transcript. Your signature on 'The Confirmation of Agreement form' affirms that you clearly agree to be audio/ video recorded via the zoom interview call.

What is the incentive for participating in this research? It is expected as a study participant you are interested in contributing and advancing knowledge on WWTPs treatment of CEC, and that you might also be interested in forming a professional association with Ryerson researchers for further research.

Does this interview cover any costs for participation? No. There are no anticipated costs to participate in this research interview.

Does Compensation for injury apply to this interview? No. Given there is no expected injury as this research is based on an interview via zoom during the pandemic where individuals will more than likely be interviewed in a safe location (e.g., a residence), you agree that by participating in this research that you are giving up or waiving any legal right in the event that you are harmed during the research.

Is Participation Voluntary, and Can I Withdraw from the Interview? Your participation is voluntary. As a voluntary study participant this means you can choose to answer some or all the questions. You can withdraw from the interview at any time. At any time, you can request to have your interview responses withdrawn from the analysis. If you choose to withdraw, please email Professor Gilbride. Your withdrawal will not affect your relationship with any researcher at Ryerson University nor with Ryerson University.

Who do I contact if I have any questions about the research? If you have any questions about the research now, please ask. If you have questions later about the research, you may contact:

Dr. Kim Gilbride at gilbride@ryerson.ca
Dr. Rania Hamza at rhamza@ryerson.ca
Dr. Patricia Hania at phania@ryerson.ca

This study has been reviewed by the Ryerson University Research Ethics Board. If you have questions regarding your rights as a participant in this study, please contact:

Research Ethics Board
c/o Office of the Vice President, Research and Innovation
Ryerson University
350 Victoria Street
Toronto, ON M5B 2K3

The Wastewater Pollution Challenge: What is an emerging contaminant? & How to protect human and ecological health?

CONFIRMATION OF AGREEMENT

Your signature below indicates that you have read the information in this agreement and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to participate in the study and have been told that you can change your mind and withdraw your consent to participate at any time. You have been given a copy of this agreement. You have been told that by signing this consent agreement you are not giving up any of your legal rights.

____
Name of Participant (please print)

____ ___________________
Signature of Participant Date

I agree to be audio/video recorded via zoom call for the purposes of this study. I understand how these recordings will be stored and destroyed.

____ ___________________
Signature of Participant Date