Investigating sources and pollution prevention strategies to address compounds of environmental concern (CECs) entering Metro Vancouver’s wastewater

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Disclaimer

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Executive Summary

Metro Vancouver's wastewater treatment plants (WWTPs) are designed to remove conventional contaminants from wastewater, and not for the removal of Contaminants of Emerging Concern (CECs). It is thus crucial to know the magnitude of CEC discharges and their potential sources in the region's wastewater in order to plan effective source control measures. This project seeks to identify potential residential, commercial and industrial sources that discharge four classes of hard to treat CECs into Metro Vancouver's wastewater system and compile research of best-practice pollution prevention strategies for different sectors. The first outcome of this work is a database summarizing literature data on municipal wastewater treatment plant (WWTP) influent and some industry specific discharge contaminants for the priority CECs and their reported discharge concentrations. This database exhibited a wide range of CECs concentration in wastewater around the world. For example, in the PFAS class, mean concentration of PFOS ranged from non-detect to 905 ng/L, and PFOS was identified to be the highest PFAS contaminant in the municipal WWTP influent among the five PFAS compounds selected for this study.

In the next step, the Environment and Climate Change Canada (ECCC) data (Government of Canada, 2023) was used to compare the literature data with the known CEC data from two WWTPs in the region and six other similar Canadian WWTPs. These reported concentrations were then compared with the internal database of CECs in WWTP influent that was generated in the first step. This comparison showed that the Metro Vancouver WWTPs are receiving similar CEC concentration as other Canadian WWTPs or that of other countries, and not as extreme as some reported literature data. However, we need to take effective source control measures to reduce this CEC loading in our WWTPs. In light of that, we estimated the CEC contribution from different sectors, based on the Actual Water Use (AWU) data provided by Metro Vancouver's Water Services department to approximate wastewater discharge volumes and to estimate relative contributions of CECs discharged using the previously mentioned literature based WWTP influent concentrations of CECs. Additionally, the literature CEC discharge concentrations for some specific commercial and industrial sectors was applied against the AWU data to determine sector specific CEC loadings in the region. According to our worst-case scenario estimation for the year 2021, metal fabricating industries could be one of the highest PFOS contributors in the region with approximately 814 kg/yr loading. Among the PBDEs, the predominant congener was the PBDE 209 with an estimated annual loading of 123 kg/yr. Within the region, the total MP discharge to wastewater was estimated to be $3\text{x}10^{14}$ MP/yr. Parks and playing fields were identified as the most significant dischargers of pesticides (regional Triclosan loading is estimated to be approximately 265 kg/yr). Finally, after correlating the AWU code with the North American Industry Classification System

(NAICS) codes, we identified the industries that are potential CEC contributors in the region. This approach offers an easy way to include regional businesses in the source control initiative as the importance of public awareness, engagement and inclusion of all stakeholders, was recognised in the jurisdictional scan.

Introduction

Contaminants of Emerging Concern (CECs) in the environment, especially in water and wastewater sources, are gaining attention in recent years due to the lack of required monitoring and regulations despite their adverse impact on ecological and human health. Additionally, the ever-growing number of these compounds being identified whose impact on human health and the environment is yet to be known, has led to the term 'emerging' contaminants (Deblonde, Cossu-Leguille, & Hartemann, 2011). One of the main entry pathways for CECs to the aquatic environment is through wastewater effluent. Conventional treatment technologies at wastewater treatment plants (WWTPs) are not designed to remove CECs, which are discharged to the receiving environment, potentially endangering the ecosystem (Gilbride, Hamza, & Hania, 2021). Therefore, in order to establish strategies for managing CECs that pose uncertain risks to the environment and public health in the Metro Vancouver region, this project aimed to identify potential regional sources of CECs in wastewater.

This project is the second phase in a multi-phase approach to addressing CECs in wastewater in the Metro Vancouver region. In phase one, CECs from permitted dischargers in the region were evaluated, this phase is evaluating non-permitted sources. Metro Vancouver collects and treats over 1 billion litres of wastewater per day from 21 regional municipalities, one Electoral Area and one Treaty First Nation at five wastewater treatment plants (Metro Vancouver, 2023). Pinpointing potential sources of CECs in the region's wastewater is a challenging aspect of developing an effective source control program for CECs.

With over 600 CECs recognized in literature (Gilbride et al., 2021), our research was focused on identifying potential sources of four classes of CECs that are hard to treat and thus good candidates for source control measures: per- and poly-fluoroalkyl substances (PFAS), microplastics (MPs), pesticides and flame retardants. There are several entry points and pathways for CECs into wastewater including residential sources, commercial sources and industrial activities. The adverse effects of these CECs are not yet fully understood; evolving research indicates they are often persistent in their environment, bioaccumulative and can be toxic. Additionally, in recent years, the Metro Vancouver region has experienced impacts of climate change including extreme weather events that directly affect our wastewater systems such as atmospheric rivers, and flooding that can trigger system overflows causing unplanned wastewater discharges into receiving waterbodies. Understanding and identifying the activities and sectors contributing CECs to Metro Vancouver's wastewater will help guide source control efforts that can reduce the risks CECs pose to human health and the environment, and improve the region's climate resiliency.

Project Scope

This project included desktop research to identify significant sources of CECs in Metro Vancouver's wastewater. Through this work, we investigated industrial, commercial and residential activities that contribute CECs from four hard to treat classes into wastewater discharges, identified priority sectors and researched best practices to inform Metro Vancouver's future source control efforts.

Project Objectives

The objectives of this project are as follows:

i) To conduct a literature review of the sources and reported discharge concentrations of CEC to wastewater.
ii) To identify priority sectors discharging CECs to wastewater in Metro Vancouver and develop a database of potentially significant commercial sources and industries to focus source control efforts in Metro Vancouver.
iii) To compare Environment Canada CEC data with Literature data and Metro Vancouver data
iv) To conduct a jurisdictional review of best practice management strategies.

Background

Among the numerous CECs present in wastewater, microplastics, per- and polyfluoroalkyl substances (PFAS), pesticides, and flame retardants have been raising alarms due to their widespread presence and potential adverse impacts, along with the difficulty in treating them using conventional wastewater treatment technology.

Microplastics (MPs) originate from two main processes: the breakdown of larger plastic items, leading to the creation of fibers, fragments, or sheets; and the manufacturing of resin pellets or beads designed to produce larger plastic goods. These MPs encompass a size spectrum spanning from 1µm to 5mm (Akdemir & Gedik, 2023; Nash et al., 2023). These tiny plastic fragments find their way into wastewater through multiple routes such as the shedding of microplastics and microfibres from textiles during laundering everyday household and personal care items, industrial and commercial activities (e.g., cosmetics industry, synthetic rubber tires, clothing and furnishings, plastic or polymer manufacturing) (Bitter & Lackner, 2020; Nash et al., 2023). As a result, WWTPs are not only the most significant receptors of both industrial and household MP releases, they are also recognized as a primary discharger of MPs into aquatic ecosystems (Long, Wang, Yu, Lin, & Chen, 2021).

Per- and polyfluoroalkyl substances (PFAS) are a group of manufactured organic chemicals containing a very strong and stable fluorine-carbon bond that makes them persistent in the environment, hence named as ‘forever chemicals’ (ECCC and Health Canada, 2023; EPA, 2021). Perfluoroalkyl substances (PFAS) are water and oil repellent which promotes their wide application in protective coatings, electroplating, fire-fighting foams, and insecticides (Loos et al., 2012). While over 4,700 synthetic compounds have been identified within the PFAS group, two in particular, perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), are gaining much attention in terms of monitoring due to their bio-accumulative nature, toxicity, and adverse health impacts (EPA, 2021; European Environment Agency, 2023).

Flame retardants are another class of CECs that are used in commercial and household products to prevent combustion of the products or slow down ignition and thus the spread of fires. Polybrominated diphenyl ethers (PBDEs) are one of the most common and widely used flame retardants for manufacturing of plastics and foams, fabric, and electronic equipment (Cristale & Lacorte, 2015; Deng, Chen, & Tam, 2015; Xiang et al., 2014). To meet flammability standards, PBDEs are applied as additives, that are not chemically bound to the product matrix, and easily end up in the outdoor and indoor environment (Deng et al., 2015). Due to their accumulative property, high resistance to degradation, and long-range transport capability, they are found in the environment, which is a great concern due to their toxicity. Two of the three major commercial PBDE mixtures, penta-BDE and octa-BDE, were the first to be banned globally. After the European Court of Justice banned deca-BDE in 2008 (EFSA, 2023), the US and China started phasing out their production (Cristale & Lacorte, 2015). However, deca-BDE is still present in Canadian wastewater.

Pesticides are class of chemicals that are used for pest control including insecticides, fungicides, and rodenticides (EPA, 2009). Common pesticides include organophosphorus, organochlorine, triazine, and pyrethroid. Usage of pesticides is dominant within agricultural activities, as well as landscaping activities, park and playing field maintenance, residential lawn and garden maintenance, golf courses, along with building foundations. As a result, pesticides end up in surface runoff or leachate, making their way to WWTPs through combined storm and sanitary sewers. Depending on different climatic conditions, the use of different pesticides can vary with the seasons. In addition, precipitation patterns can impact wastewater influent flow and concentrations, especially when a combined sewer system is in place (Luo et al., 2014). As there are combined sewers within the region, there will be impacts on discharges of pesticides from seasonal precipitation variations and climate change.

These four classes of CECs can enter municipal wastewater through countless point and non-point sources. These sources include residential activities (e.g., cleaning, laundry, bathing, and toilet flushing), industrial effluent from manufacturing processes such as plastics, chemicals, and synthetic fibers; food processing and packaging industries; landfills leachates; surface run-offs, commercial dry-cleaning and laundry services (EPA, 2009; Gilbride et al., 2021; Morin-Crini et al., 2022).

The Metro Vancouver Liquid Waste Services (LWS) department undertook this project to identify potential source control actions for CECs in Metro Vancouver's wastewater and divided the project into two phases. In the first phase, wastewater data from the five WWTPs including influent concentrations and loadings of the four hard to treat CEC classes was analyzed along with the permitted discharge data from landfills, laundry/linen operations, and metal plating/finishers sectors. Three of the four identified hard to treat CEC classes (PFAS, pesticides, and flame retardants) were considered in phase one due to lack of readily available data on MPs. Phase one results identified permitted landfills as a significant source of PFAS in WWTP influent in the region, due to the large discharge volume from landfills relative to the other evaluated permitted sectors. However, the majority of PFAS loading is from unpermitted/unknown sources. For pesticides and flame retardants, permitted dischargers contributed a small fraction of CEC loading to WWTPs. Therefore, the highest contributing sources of CECs in the region were still unknown and were investigated in this second phase of the project.

Research Approach

This project first focused on literature-based research findings to identify industrial, commercial and residential activities that discharge CECs and their reported discharge concentrations. All the articles reviewed have been assigned catalog numbers in the excel database for the ease of future study and shared with Metro Vancouver (a snapshot of the database is provided in appendix A). We selected some compounds from each of the four CEC classes based on their prevalence in the wastewater, and environmental and human health concerns. For the same compounds we then prepared another excel file comparing the literature data with that of Metro Vancouvers' phase 1 data, and the Environment and Climate Change Canada (ECCC) data (Government of Canada, 2023) consisting CEC data of two major WWTPs in the region and six other similar Canadian WWTPs under worst-case scenario. We chose plants A, P, W, and RM for comparison together due to their similarity in terms of treatment processes, influent flow and sources, as well as receiving water bodies. Similarly, we selected plants IO, M, V, and N to compare together.

For the estimation of the CEC contribution from different sectors, we used Actual Water Use (AWU) data provided by Metro Vancouver's Water Services department and created another database. This second database summarizes the approximate annual wastewater discharge volumes from different sectors under each AWU code and category (a snapshot of the database is provided in appendix B). Using this database, we then estimated relative contributions of CECs discharged in Metro Vancouver wastewater using WWTP influent concentrations of CECs. We then estimated CEC loadings in the region for some specific commercial and industrial activity based on the literature CEC discharge concentrations and AWU data. Following this step, the North American Industry Classification System (NAICS) codes were aligned with that of Metro Vancouver AWU codes (appendix C) to prepare a potential list of significant dischargers of CECs in the region based on the Hoover's Database business directory. Finally, we conducted a jurisdictional scan based on existing literature to understand how other jurisdictions manage CECs and to identify best practice approaches for CEC source control measures.

Findings

CECs in Metro Vancouver Wastewater

The qualitative research approach in this project identified un-permitted potential sources of CECs for Metro Vancouver's wastewater system. Hence, the contributions from these sources to the wastewater stream are unknown. Due to the limitation of time and data resources, it was important to focus our efforts on select CECs from the four hard to treat classes based on their prevalence in wastewater and adverse impacts on the environment and human health.

We selected five PFAS compounds: perfluorooctane sulphonate (PFOS), perfluorooctanoate (PFOA), perfluoroheptanoic acid (PFHpA), perfluorononanoic acid (PFNA), and perfluorodecanoic acid (PFDA), to construct a database on reported wastewater influent concentration in municipal WWTPs in 20 countries, along with some industrial effluent discharge data. Based on these literature data, we plotted the CEC concentrations in wastewater under a worst-case scenario (i.e., considering the maximum reported concentration), shown in Figure 1. Among the five PFAS compounds, PFOS and PFOA are the most dominant contaminants. As expected, PFAS manufacturing effluent contains all five compounds in high concentrations. PFOS concentration in metal plating industries is exceptionally high (100-10,000 times higher than other discharger effluent).

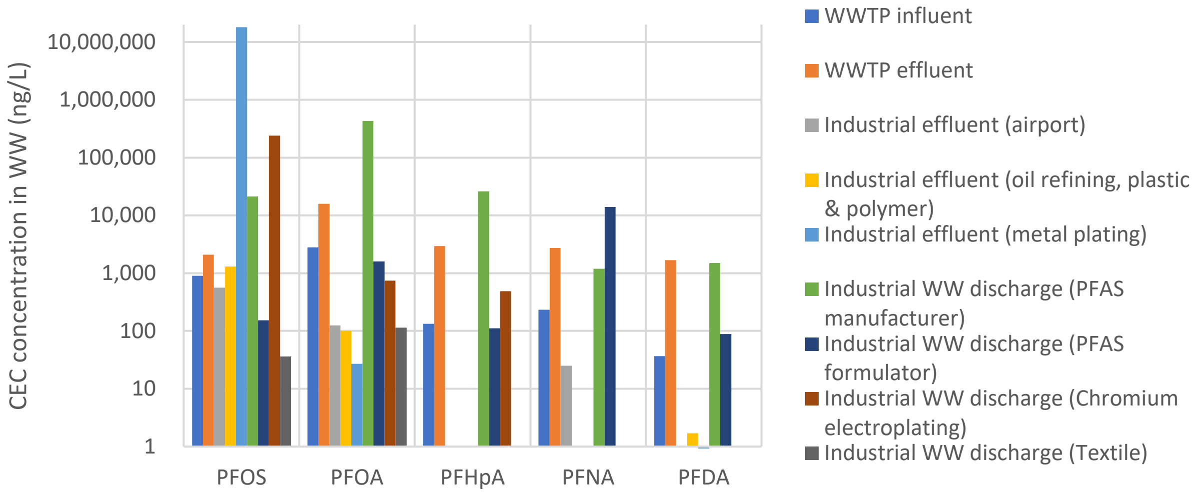

Figure 1: PFAS concentration in municipal and industrial wastewater from literature

The literature data for municipal WWTP influent was compared with the ECCC data (five Canadian and two Metro Vancouver WWTPs data, denoted as A, P, W, IO, M, V, and N) and phase one Metro Vancouver data under the same scenario, shown in Figure 2.

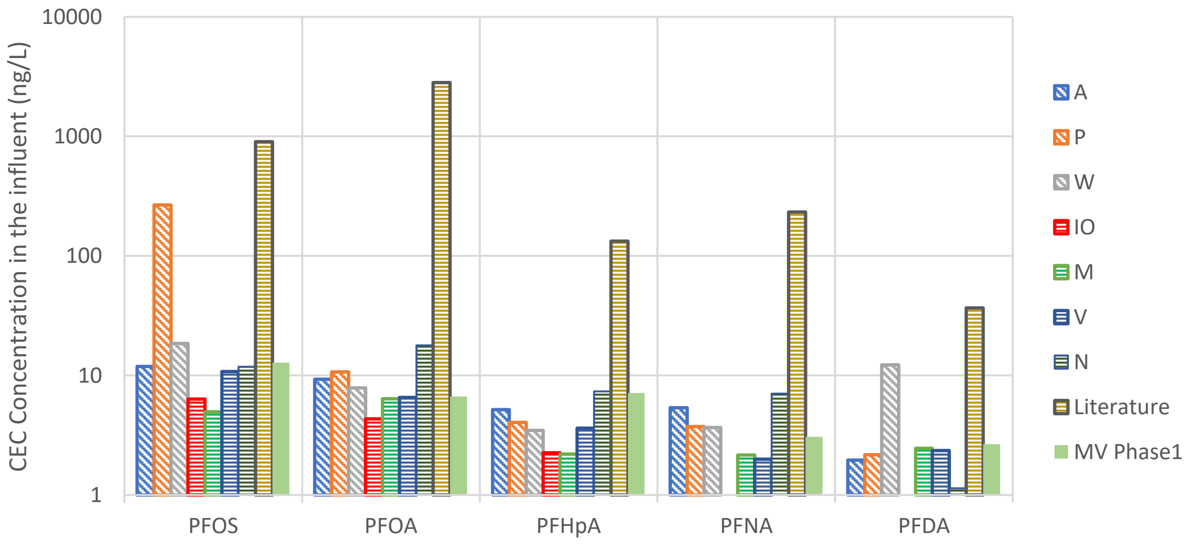

Figure 2: PFAS concentration in WWTPs influent comparing literature, ECCC and Phase 1 MV data

Though the literature data shows very high values, the results are skewed by one study, as we considered maximum reported concentration. All other studies a reported similar range to both ECCC data and Metro Vancouver data.

Using only the AWU data, the estimated relative contributions from wastewater dischargers in the region for the year 2021 are 74%, 12%, 11%, and 3% from commercial, industrial, institutional, and other sectors respectively (Figure 3). This estimation returns the same result for all CEC classes as the specific discharge concentration within influent wastewater for each sector is unknown. Since we used highest reported CEC concentration in the literature and applying it to all sectors (as our worst-case scenario), the loading breakdown is therefore directly proportional to the discharge volume for each sector.

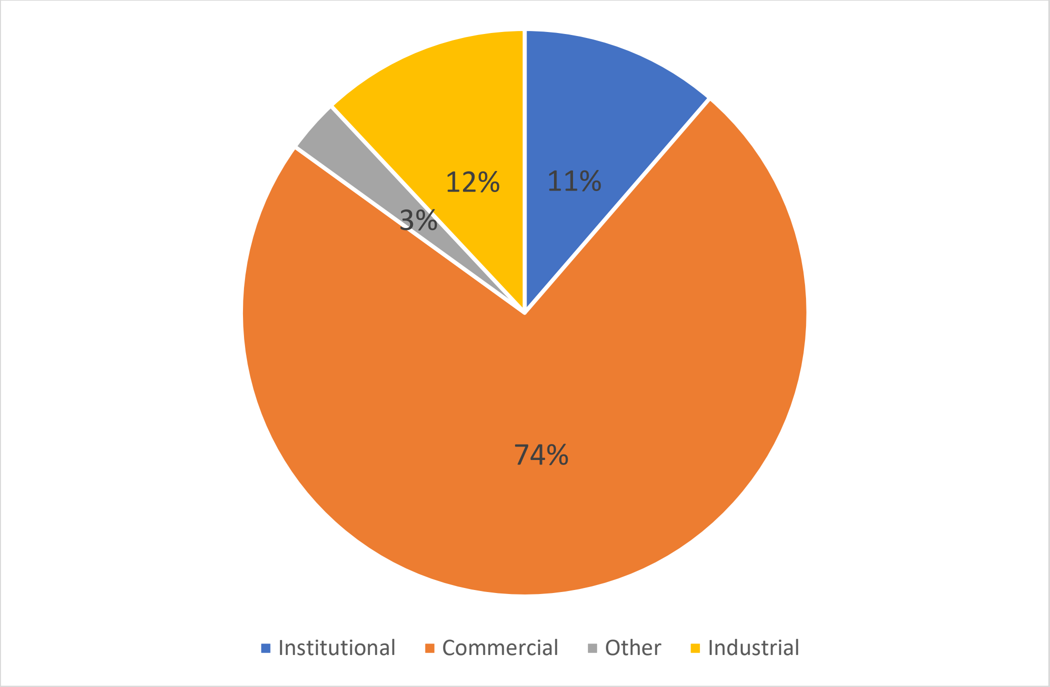

Figure 3: Contribution of CECs from different sectors in Metro Vancouver wastewater based on actual water usage

Applying the highest PFAS concentrations from the literature database to annual AWU data for the four sectors (i.e., 905 ng/L of PFOS, 2813 ng/L of PFOA, 133 ng/L of PFHpA, 233 ng/L of PFNA, and 37 ng/L of PFDA), PFAS annual loading for the year 2021 was estimated (Figure 4). This estimation suggests the commercial sector as the highest potential contributor due to the highest water usage volume (i.e., 74% as shown in Figure 3).

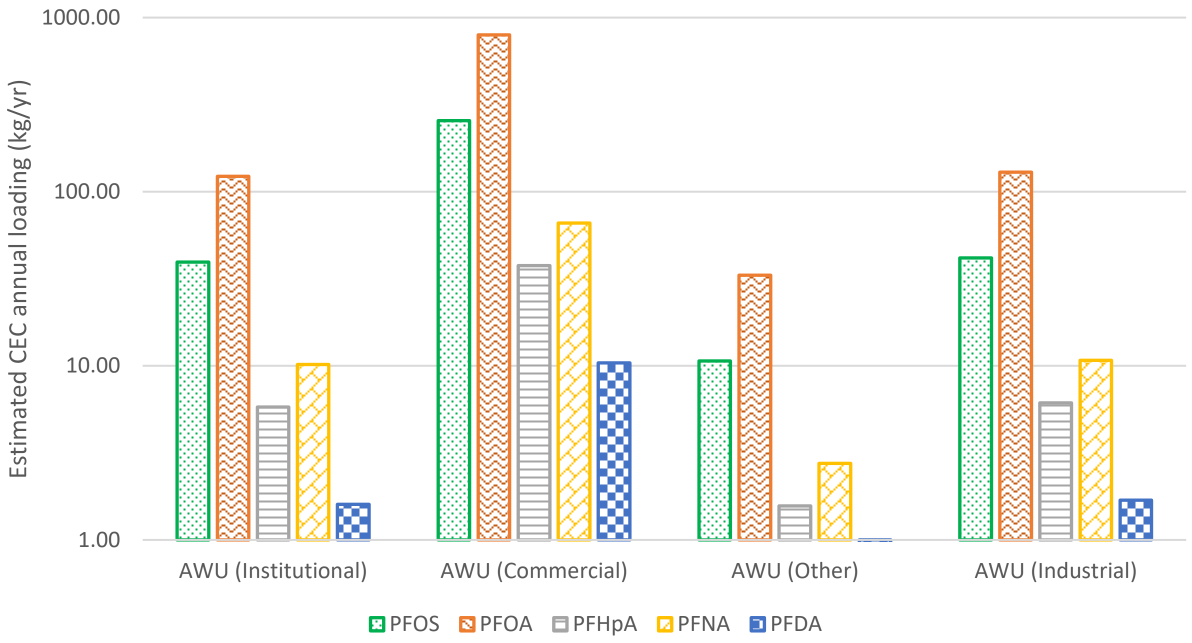

Figure 4: Estimated annual PFAS loading from different sectors using 2021 AWU data

Despite the higher water usage and thus discharge volume by commercial sectors, CECs loading can be very high in the industrial sector, especially in some industries due to the high concentration as per literature values. Hence we focused on industrial sector instead of commercial and institutional mainly due to two reasons: lack of literature on discharge concentrations for specific commercial & institutional activities, and higher concentrations of contaminants in industrial effluent than commercial or institutional sources. We identified seven such types of industries in the region as potential significant dischargers: pulp and paper mills, oil refining plants, rubber and plastics products, textiles and knitting mills, metal fabricating industries, electrical and electronics product industries, as well as airports and heliports. The estimated annual CEC loading from these industries for the year 2021 is plotted in Figure 5.

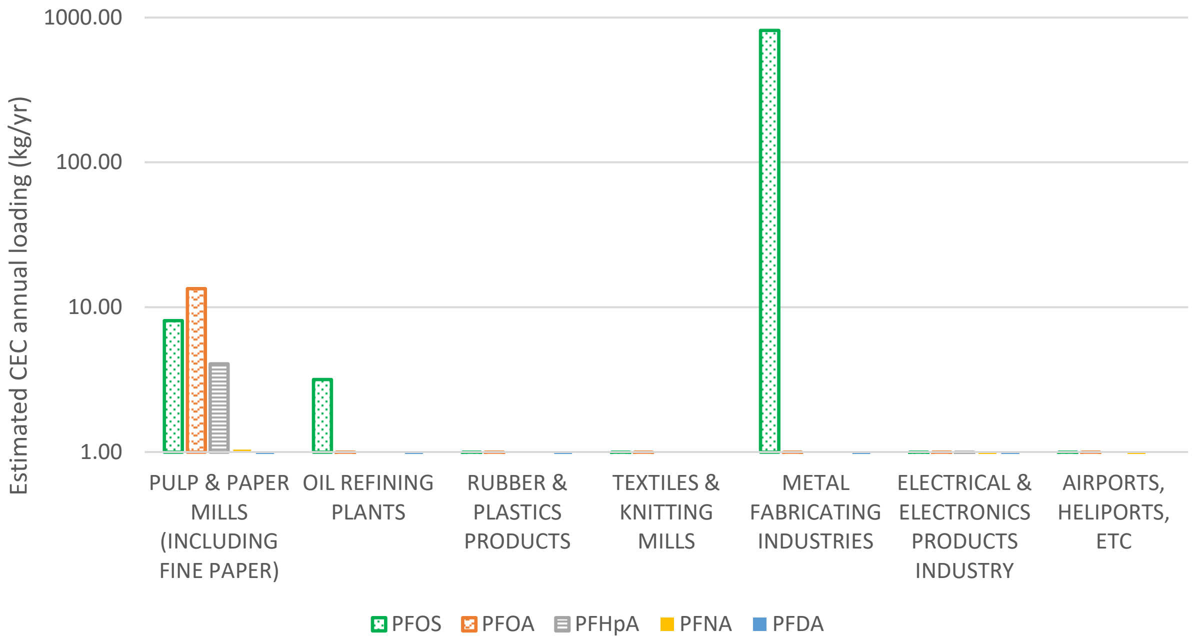

Figure 5: Estimated annual PFAS loading from industrial effluent sources using 2021 AWU data

The same methodology was then followed for other three classes of CECs (PBDEs, MPs and pesticides), to identify potential dischargers in the region. We selected seven PBDE congeners (PBDE 28, PBDE 47, PBDE 99, PBDE 100, PBDE 153, PBDE 183, and PBDE 209) reported in all articles reviewed due to their presence in wastewater around the world. Figure 6 shows similar PBDE range for both ECCC data and Metro Vancouver data compared to the literature where PBDE congener is the predominant one. As per our literature search, all the data for PBDEs in WW were for WWTP influent, we couldn't find concentration data for the specific industries. Only one study showed a relative concentration of some industrial effluent that supported our focused industrial sectors as it showed that PBDE 209 concentration was higher (i.e., 70-75%) in metal industrial effluent than that of aircraft modification effluent (i.e., 50%) (Wong, 2022).

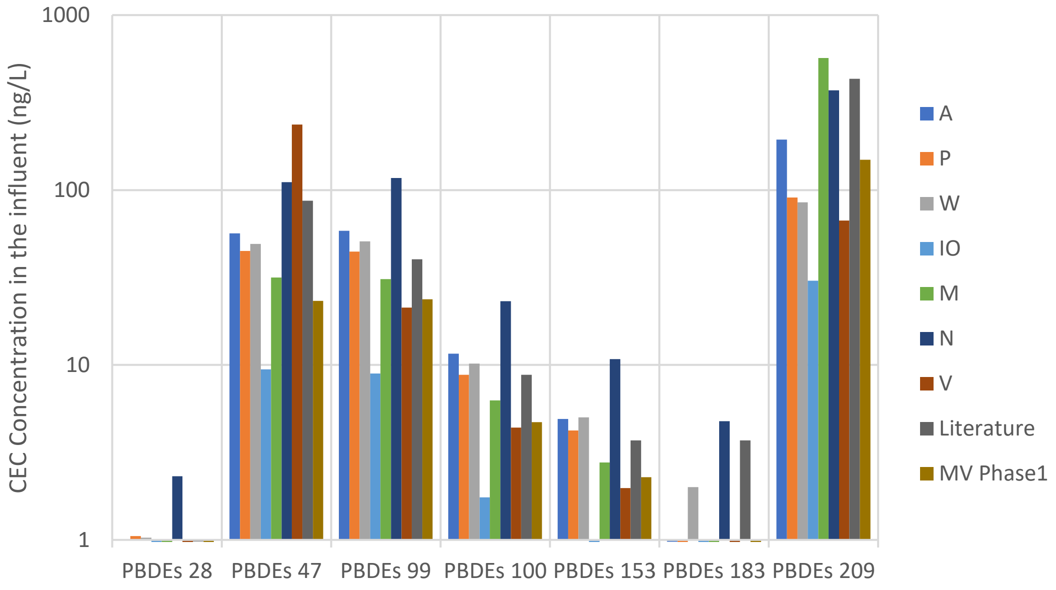

Figure 6: PBDE concentration in WWTPs influent comparing literature, ECCC and Phase 1 MV data

The estimated PBDE annual loading for the year 2021 based on AWU data and literature influent concentration (highest reported concentration) is shown in Figure 7, where highest PBDE 209 loading was approximately 123 kg/yr from commercial activities.

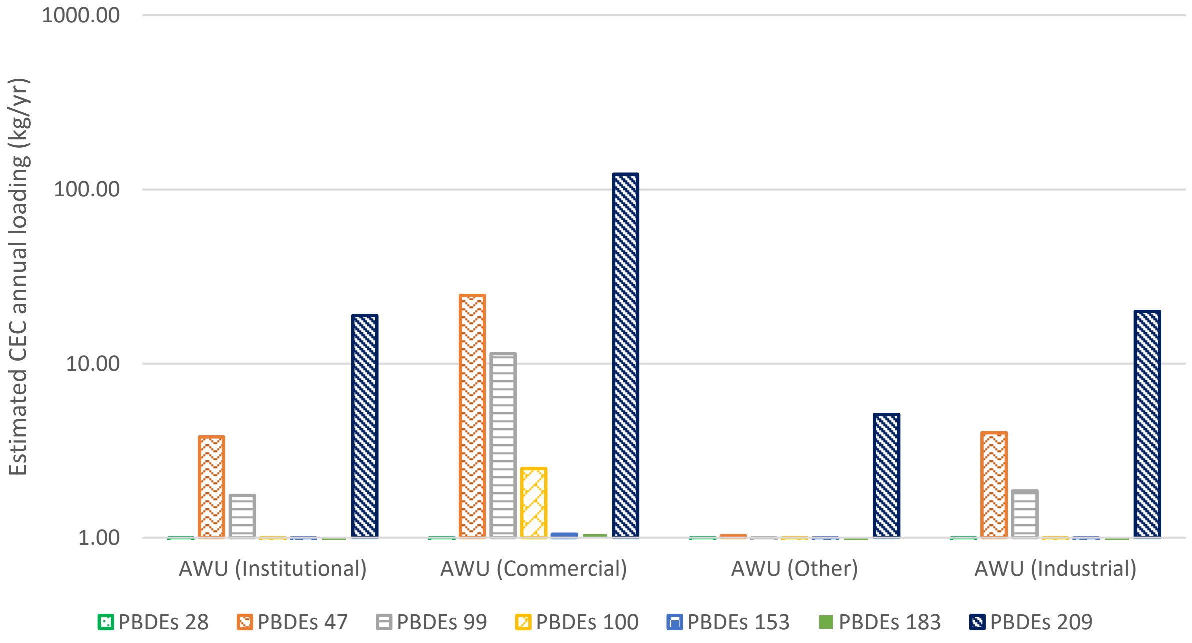

Figure 7: Estimated annual PBDE loading from different sectors using 2021 AWU data

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The concentration of MPs in wastewater is reported in three different units, where the most common unit is MP/L (number of microplastic per volume). Recently very few studies are analyzing wastewater samples utilizing newer techniques such as Differential Scanning Calorimetry to measure mass per volume concentrations, however most literature is still reporting using MP/L units. Figure 8 shows the reported highest microplastic concentration in the literature search.

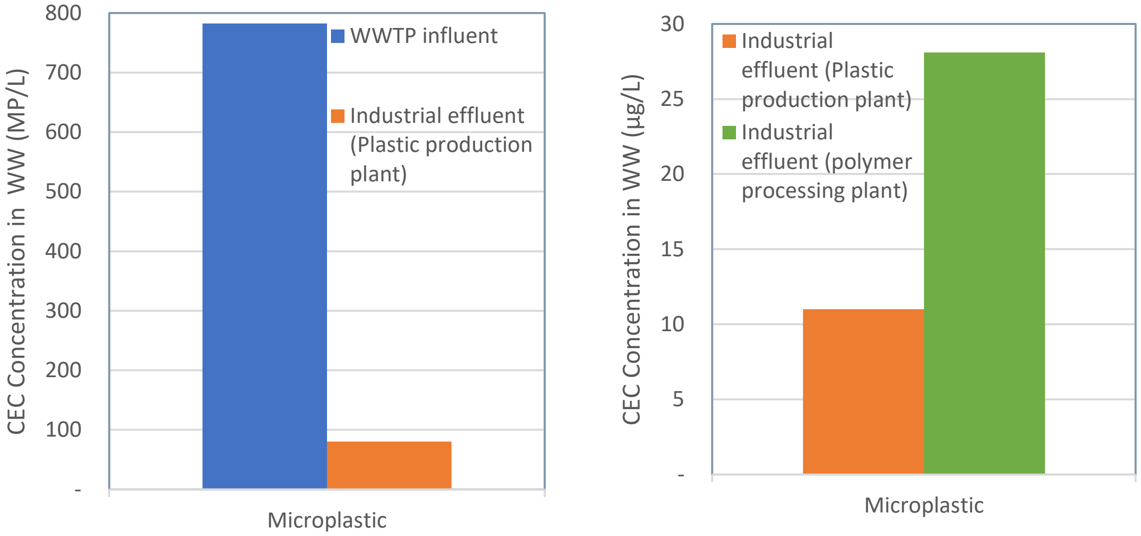

Figure 8: Microplastic concentration in wastewater

Neither ECCC nor Metro Vancouver phase one data is available for MPs. Using the influent WWTP highest influent concentration (i.e., 782.7 MP/L) and AWU data, MP concentrations in Metro Vancouver wastewater is estimated for the four sectors (Figure 9).

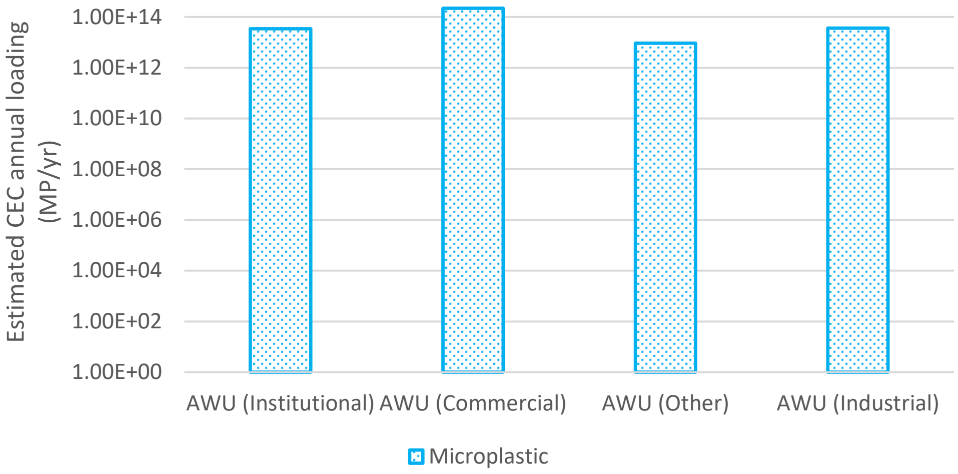

Figure 9: Estimated annual MP loading from different sectors

The most challenging task was to compare pesticide data. We were unable to find literature concentrations of pesticides in effluent from specific industries and sectors. While different studies focused on several types of pesticides, the ECCC data was only available for triclosan, and only for plant N out of the six Canadian plants considered in this study. On top of that, Metro Vancouver phase one data for Triclosan is under detection limit. The ECCC data for plant N and literature comparison is shown in Figure 10.

Figure 10: Pesticide (Triclosan) concentration in WWTPs influent comparing literature and ECCC data

Based on the Triclosan concentration of 23900 ng/L, AWU database was used to estimate triclosan loading (figure 11) that identified parks & playing fields being the most potential significant discharge of pesticide with an annual loading of approximately 265 kg/yr (2021 AWU data).

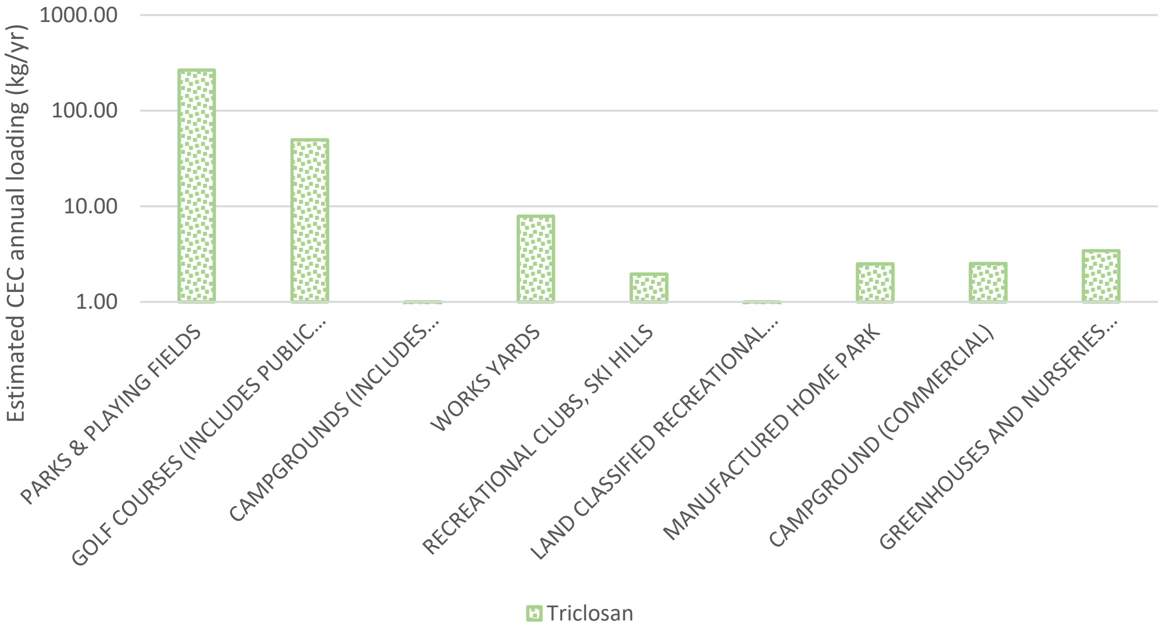

Figure 11: Estimated annual pesticide (Triclosan) loading from different sectors

In the final step, we mapped the AWU code against the NAICS code to highlight the businesses or companies in the region that fall within those seven categories of industries.

Jurisdictional review

Recognizing the need for CEC source control measures, Metro Vancouver aims to take inspiration from other jurisdictions that have successfully adopted best management practices. For example, European Union (EU) has been at the forefront of CECs management by enacting stringent regulations and initiatives. One such initiative is the EU Water Framework Directive (WFD) (EC, 2000), which establishes a framework for the protection and sustainable use of water resources across member states. In its efforts to address CECs, the WFD announced a list of 33 priority substances and mandated the development of monitoring programs to detect the presence of these contaminants in water bodies (Deblonde et al., 2011). Furthermore, the EU has strengthened its chemicals management framework through the REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) regulation. REACH places the responsibility on industry sectors to assess and manage the risks posed by chemicals they manufacture and use (European Chemicals Agency, 2023; European Commission, 2023b). This includes addressing CECs, as the regulation necessitates the evaluation of potential hazards and risks associated with such contaminants. Financial incentives play a pivotal role in motivating industries to transition towards cleaner practices and fostering a culture of innovation and research. Since the year 2015, the commission has taken initiative to include all the stakeholders (businesses, policy makers, and the public) at all stages of policymaking. They have launched an online portal through which anyone can provide feedback, ideas and evidence as well as receive notifications regarding any new initiatives (European Commission, 2023a).

Similarly, in the U.S., Environmental Protection Agency (EPA) has Clean Water Act (CWA) authorities to address CECs. Under the CWA, the National Pollutant Discharge Elimination System (NPDES) issues permits that set limits on the amount of pollutants, including CECs, that can be discharged into waterways by point sources such as industrial facilities and wastewater treatment plants, however the challenge remains due to the absence of regulatory definition of CECs (Gatz, 2021). Another recent effective initiative was the establishment of the Contaminants of Emerging Concern (CECs) Interagency Working Group (IWG) to coordinate federal research on CECs and develop an implementation plan for achieving the strategic goals. The plan includes initiatives such as reducing the time from CEC identification to risk mitigation, initiating transdisciplinary research activities among Federal and non-Federal partners, and ensuring public engagement (Joint subcommittee on environment innovation and public health, 2022). In addition, Canada, Mexico and the United States, together formed the Commission for Environmental Cooperation in 1994. Under this commission, A Pollutant Release and Transfer Register (PRTR) was created to support pollution prevention and sustainability within industry.

Singapore has demonstrated remarkable dedication to addressing the challenges posed by CECs in wastewater through the Active, Beautiful, Clean Waters (ABC Waters) Program, which integrates water-sensitive urban design and advanced engineering to enhance water quality and reduce the impact of urbanization on water bodies. Through features like naturalized waterways and rain gardens, the program indirectly contributes to reducing the release of CECs into the environment by allowing for natural filtration and attenuation processes. Furthermore, Singapore's regulatory framework, including the Environmental Protection and Management Act, empowers the National Environment Agency (NEA) to set effluent discharge standards for various industries (National Environment Agency, 2023).

In Canada, a legislative gap exists regarding the regulation of CEC effluents from WWTPs. Currently the Canada-wide Strategy for Municipal Wastewater Effluent is implemented under the *Fisheries Act*. Under the direction of ECCC, the National Pollutant Release Inventory (NPRI) is in effect, however that database is incomplete as the reporting is voluntary by the industries. Therefore, there is a need for strategic planning in the region for CEC management.

Summary

There are innovative and emerging technologies that can degrade and treat wastewater for these persistent chemicals of concern. However, since these technologies are not employed in municipal or industrial WWTPs, the best approach for managing CECs is through source control measures. Effective source control requires knowledge of the potential sectors that discharge CECs in the region. Keeping that goal in mind, in this project we first prepared a database tabulating literature data on industry specific discharge contaminants for the priority CECs and their reported discharge concentrations. Literature data on CEC concentrations in municipal WWTPs receiving only domestic wastewater or a mixture of domestic, commercial and industrial wastewater were used to estimate discharged CEC concentrations for residential and industrial/commercial wastewater. Next, we compared the literature data with that of Canadian wastewater data from ECCC and Metro Vancouver.

We then identified the potentially significant contributors of CECs from commercial sources and industries and pinpointed corresponding businesses in the region, which will be beneficial for source control efforts in Metro Vancouver region. From the jurisdictional scan, some effective CEC source control measures identified include public awareness campaigns, engagement and inclusion of all stakeholders, interdisciplinary research, financial incentives to industries or commercial companies, water-sensitive urban design, and developing regulatory limits.

Limitations and Recommendations

Some limitations of this project are literature data availability for CEC concentrations in wastewater from specific industries and activities; unknown discharge concentrations from unpermitted sectors in the region; as well as time limitation. The literature database is limited to the enlisted articles. As this is an emerging area of research, more articles might be available. Our main objective was to find out the typical range of CEC concentrations that are reported in literature and whether Metro Vancouver WWTP data aligns with those. Another limitation in the literature search is that lack of CEC concentration data from specific industries. Due to time limitations, it was not possible to search for effluent discharge concentration for each industry or commercial activity. We focused our search on few target sectors and selected compounds, however the database is prepared such that it can be easily expanded with new data in the future.

Another challenge in using concentration data from ECCC and Metro Vancouver influent sampling, is that sometimes these compounds are below the detection limit. We also identified irregularity in monitoring timing and testing compounds across the five WWTPs in the region that makes it difficult to compare the average annual loading. We used the maximum reported concentration values to estimate the worst-case scenario. A recommendation would be to create comprehensive monitoring protocols to include the seasonal variation and spatial distribution of CECs. We also had to incorporate several assumptions such as AWU volumes from commercial and industrial sectors are equivalent to wastewater discharge volumes. Moreover, we excluded residential sector due to data unavailability.

It is expected that these project findings and databases will be used by Metro Vancouver's Source Control Program in their ongoing effort to better understand CECs discharges in the region and develop pollution prevention strategies. Recommendations from this project will also be shared with members from Metro Vancouver's Liquid Waste CEC Working Group. Therefore, it is suggested to use this project methodology and findings to expand or update the research methodology and data accordingly in future and to consider the data presented as an estimate only.

For the next steps of source control actions, a recommendation is to launch an anonymous sampling program to collect and analyze wastewater samples from the listed potential CEC dischargers (businesses or companies) based on the Hoover database. To make this monitoring program attractive to the industries there should be some incentives for participation (e.g., tax rebate, water use bill discounts, etc.). In this way, Metro Vancouver could draw a better picture of the significant dischargers and collaborate with researchers to employ innovative CEC treatment technologies at those industrial effluent plants starting from bench scale or pilot scale, all the way to full scale.

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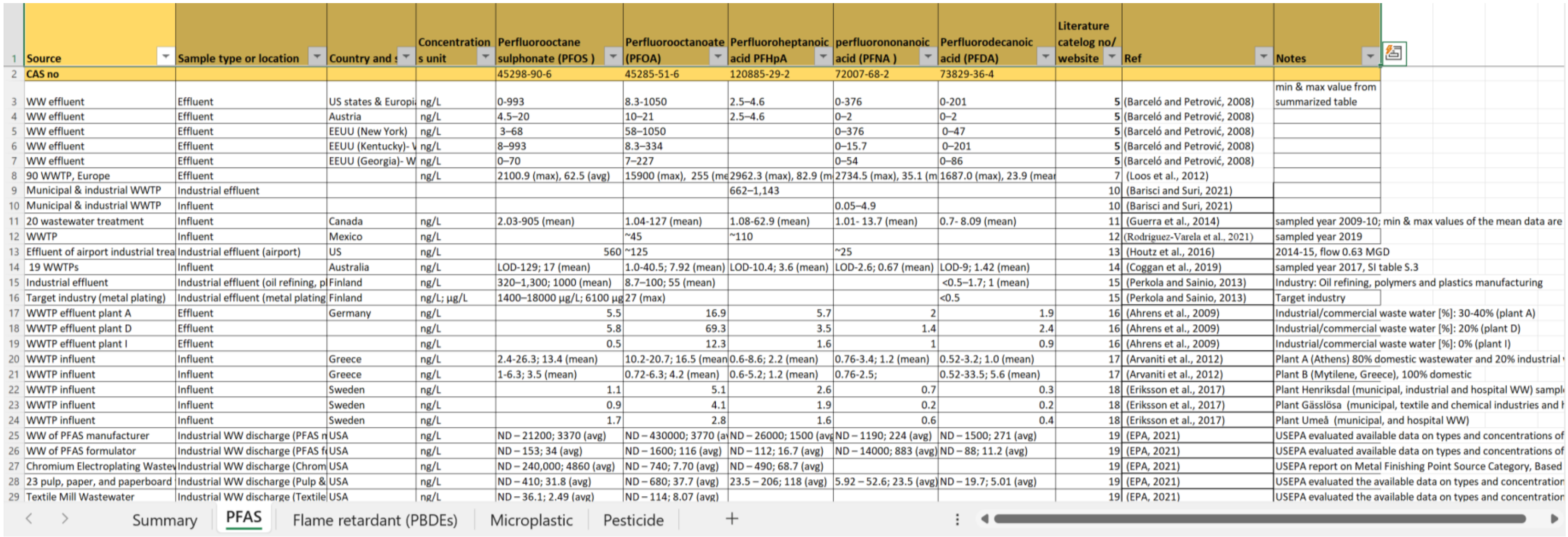
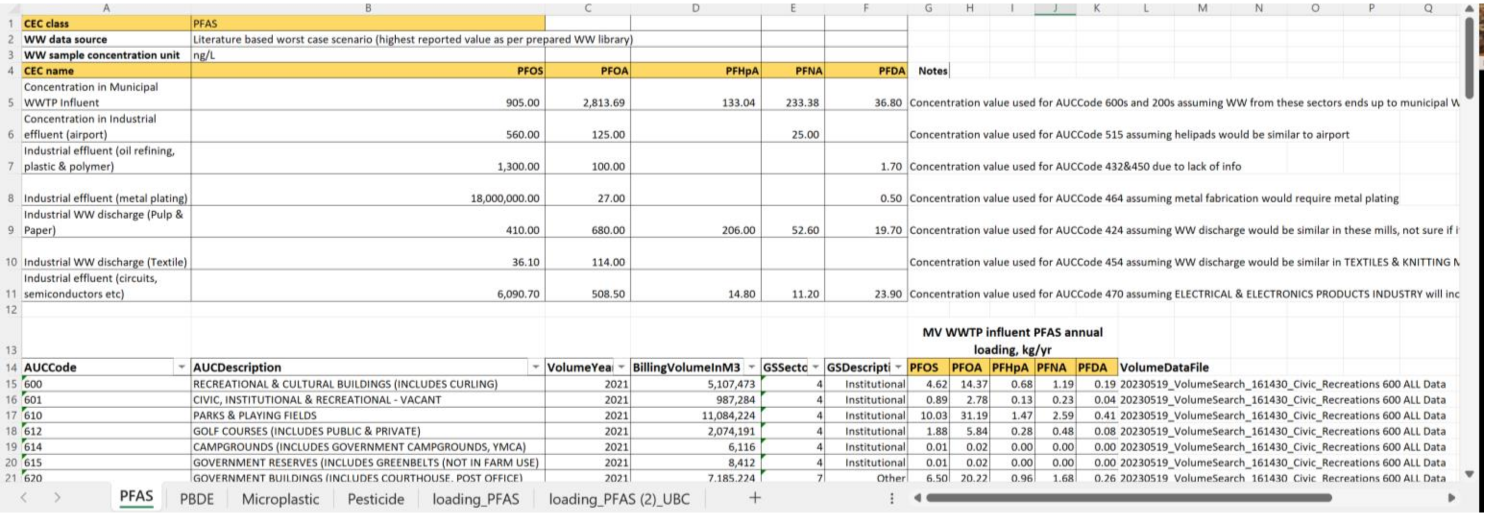
Appendices

Appendix A Snapshot of Literature Database



1	Source	Sample type or location	Country and s	Concentration s unit	Perfluorooctane sulphonate (PFOS)	Perfluorooctanoate (PFOA)	Perfluoroheptanoic acid PFHpA	perfluorononanoic acid (PFNA)	Perfluorodecanoic acid (PFDA)	Literature catelog no/ website	Ref	Notes
2	CAS no				45298-90-6	45285-51-6	120885-29-2	72007-68-2	73829-36-4			
3	WW effluent	Effluent	US states & Europi	ng/L	0-993	8.3-1050	2.5–4.6	0-376	0-201	5	(Barceló and Petrović, 2008)	min & max value from summarized table
4	WW effluent	Effluent	Austria	ng/L	4.5–20	10–21	2.5–4.6	0–2	0–2	5	(Barceló and Petrović, 2008)	
5	WW effluent	Effluent	EEUU (New York)	ng/L	3–68	58–1050		0–376	0–47	5	(Barceló and Petrović, 2008)	
6	WW effluent	Effluent	EEUU (Kentucky)- V	ng/L	8–993	8.3–334		0–15.7	0–201	5	(Barceló and Petrović, 2008)	
7	WW effluent	Effluent	EEUU (Georgia)- W	ng/L	0–70	7–227		0–54	0–86	5	(Barceló and Petrović, 2008)	
8	90 WWTP, Europe	Effluent		ng/L	2100.9 (max), 62.5 (avg)	15900 (max), 255 (me	2962.3 (max), 82.9 (m	2734.5 (max), 35.1 (m	1687.0 (max), 23.9 (mear	7	(Loos et al., 2012)	
9	Municipal & industrial WWTP	Industrial effluent					662–1,143			10	(Barisci and Suri, 2021)	
10	Municipal & industrial WWTP	Influent						0.05–4.9		10	(Barisci and Suri, 2021)	
11	20 wastewater treatment	Influent	Canada	ng/L	2.03-905 (mean)	1.04-127 (mean)	1.08-62.9 (mean)	1.01- 13.7 (mean)	0.7- 8.09 (mean)	11	(Guerra et al., 2014)	sampled year 2009-10; min & max values of the mean data are
12	WWTP	Influent	Mexico	ng/L		~45	~110			12	(Rodriguez-Varela et al., 2021)	sampled year 2019
13	Effluent of airport industrial trea	Industrial effluent (airport)	US	ng/L	560	~125		~25		13	(Houtz et al., 2016)	2014-15, flow 0.63 MGD
14	19 WWTPs	Influent	Australia	ng/L	LOD-129; 17 (mean)	1.0-40.5; 7.92 (mean)	LOD-10.4; 3.6 (mean)	LOD-2.6; 0.67 (mean)	LOD-9; 1.42 (mean)	14	(Coggan et al., 2019)	sampled year 2017, SI table S.3
15	Industrial effluent	Industrial effluent (oil refining, pl	Finland	ng/L	320–1,300; 1000 (mean)	8.7–100; 55 (mean)			<0.5–1.7; 1 (mean)	15	(Perkola and Sainio, 2013)	Industry: Oil refining, polymers and plastics manufacturing
16	Target industry (metal plating)	Industrial effluent (metal plating	Finland	ng/L; µg/L	1400–18000 µg/L; 6100 µg	27 (max)			<0.5	15	(Perkola and Sainio, 2013)	Target industry
17	WWTP effluent plant A	Effluent	Germany	ng/L	5.5	16.9	5.7	2	1.9	16	(Ahrens et al., 2009)	Industrial/commercial waste water [%]: 30-40% (plant A)
18	WWTP effluent plant D	Effluent		ng/L	5.8	69.3	3.5	1.4	2.4	16	(Ahrens et al., 2009)	Industrial/commercial waste water [%]: 20% (plant D)
19	WWTP effluent plant I	Effluent		ng/L	0.5	12.3	1.6	1	0.9	16	(Ahrens et al., 2009)	Industrial/commercial waste water [%]: 0% (plant I)
20	WWTP influent	Influent	Greece	ng/L	2.4-26.3; 13.4 (mean)	10.2-20.7; 16.5 (mean	0.6-8.6; 2.2 (mean)	0.76-3.4; 1.2 (mean)	0.52-3.2; 1.0 (mean)	17	(Arvaniti et al., 2012)	Plant A (Athens) 80% domestic wastewater and 20% industrial
21	WWTP influent	Influent	Greece	ng/L	1-6.3; 3.5 (mean)	0.72-6.3; 4.2 (mean)	0.6-5.2; 1.2 (mean)	0.76-2.5;	0.52-33.5; 5.6 (mean)	17	(Arvaniti et al., 2012)	Plant B (Mytilene, Greece), 100% domestic
22	WWTP influent	Influent	Sweden	ng/L	1.1	5.1	2.6	0.7	0.3	18	(Eriksson et al., 2017)	Plant Henriksdal (municipal, industrial and hospital WW) sampl
23	WWTP influent	Influent	Sweden	ng/L	0.9	4.1	1.9	0.2	0.2	18	(Eriksson et al., 2017)	Plant Gässlösa (municipal, textile and chemical industries and h
24	WWTP influent	Influent	Sweden	ng/L	1.7	2.8	1.6	0.6	0.4	18	(Eriksson et al., 2017)	Plant Umeå (municipal, and hospital WW)
25	WW of PFAS manufacturer	Industrial WW discharge (PFAS m	USA	ng/L	ND – 21200; 3370 (avg)	ND – 430000; 3770 (av	ND – 26000; 1500 (avg	ND – 1190; 224 (avg)	ND – 1500; 271 (avg)	19	(EPA, 2021)	USEPA evaluated available data on types and concentrations of
26	WW of PFAS formulator	Industrial WW discharge (PFAS fo	USA	ng/L	ND – 153; 34 (avg)	ND – 1600; 116 (avg)	ND – 112; 16.7 (avg)	ND – 14000; 883 (avg)	ND – 88; 11.2 (avg)	19	(EPA, 2021)	USEPA evaluated available data on types and concentrations of
27	Chromium Electroplating Wastew	Industrial WW discharge (Chrom	USA	ng/L	ND – 240,000; 4860 (avg)	ND – 740; 7.70 (avg)	ND – 490; 68.7 (avg)			19	(EPA, 2021)	USEPA report on Metal Finishing Point Source Category, Based
28	23 pulp, paper, and paperboard	Industrial WW discharge (Pulp &	USA	ng/L	ND – 410; 31.8 (avg)	ND – 680; 37.7 (avg)	23.5 – 206; 118 (avg)	5.92 – 52.6; 23.5 (avg)	ND – 19.7; 5.01 (avg)	19	(EPA, 2021)	USEPA evaluated the available data on types and concentration
29	Textile Mill Wastewater	Industrial WW discharge (Textile	USA	ng/L	ND – 36.1; 2.49 (avg)	ND – 114; 8.07 (avg)				19	(EPA, 2021)	USEPA evaluated the available data on types and concentration

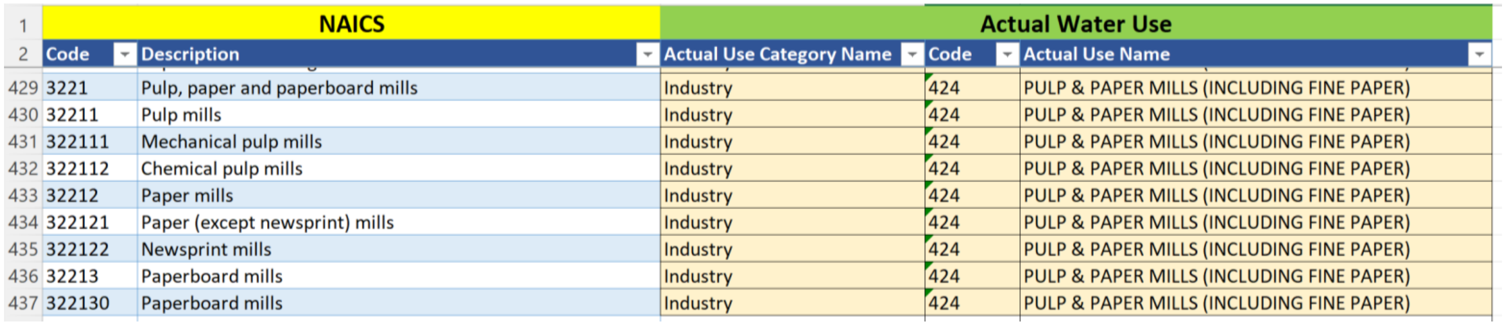
Appendix B Snapshot of AWU Database



CEC class	PFAS					
WW data source	Literature based worst case scenario (highest reported value as per prepared WW library)					
WW sample concentration unit	ng/L					
CEC name	**PFOS**	**PFOA**	**PFHpA**	**PFNA**	**PFDA**	**Notes**
Concentration in Municipal WWTP Influent	905.00	2,813.69	133.04	233.38	36.80	Concentration value used for AUCCode 600s and 200s assuming WW from these sectors ends up to municipal W
Concentration in Industrial effluent (airport)	560.00	125.00		25.00		Concentration value used for AUCCode 515 assuming helipads would be similar to airport
Industrial effluent (oil refining, plastic & polymer)	1,300.00	100.00			1.70	Concentration value used for AUCCode 432&450 due to lack of info
Industrial effluent (metal plating)	18,000,000.00	27.00			0.50	Concentration value used for AUCCode 464 assuming metal fabrication would require metal plating
Industrial WW discharge (Pulp & Paper)	410.00	680.00	206.00	52.60	19.70	Concentration value used for AUCCode 424 assuming WW discharge would be similar in these mills, not sure if i
Industrial WW discharge (Textile)	36.10	114.00				Concentration value used for AUCCode 454 assuming WW discharge would be similar in TEXTILES & KNITTING N
Industrial effluent (circuits, semiconductors etc)	6,090.70	508.50	14.80	11.20	23.90	Concentration value used for AUCCode 470 assuming ELECTRICAL & ELECTRONICS PRODUCTS INDUSTRY will inc

						MV WWTP influent PFAS annual loading, kg/yr					
AUCCode	**AUCDescription**	**VolumeYea**	**BillingVolumeInM3**	**GSSectc**	**GSDescripti**	**PFOS**	**PFOA**	**PFHpA**	**PFNA**	**PFDA**	**VolumeDataFile**
600	RECREATIONAL & CULTURAL BUILDINGS (INCLUDES CURLING)	2021	5,107,473	4	Institutional	4.62	14.37	0.68	1.19	0.19	20230519_VolumeSearch_161430_Civic_Recreations 600 ALL Data
601	CIVIC, INSTITUTIONAL & RECREATIONAL - VACANT	2021	987,284	4	Institutional	0.89	2.78	0.13	0.23	0.04	20230519_VolumeSearch_161430_Civic_Recreations 600 ALL Data
610	PARKS & PLAYING FIELDS	2021	11,084,224	4	Institutional	10.03	31.19	1.47	2.59	0.41	20230519_VolumeSearch_161430_Civic_Recreations 600 ALL Data
612	GOLF COURSES (INCLUDES PUBLIC & PRIVATE)	2021	2,074,191	4	Institutional	1.88	5.84	0.28	0.48	0.08	20230519_VolumeSearch_161430_Civic_Recreations 600 ALL Data
614	CAMPGROUNDS (INCLUDES GOVERNMENT CAMPGROUNDS, YMCA)	2021	6,116	4	Institutional	0.01	0.02	0.00	0.00	0.00	20230519_VolumeSearch_161430_Civic_Recreations 600 ALL Data
615	GOVERNMENT RESERVES (INCLUDES GREENBELTS (NOT IN FARM USE)	2021	8,412	4	Institutional	0.01	0.02	0.00	0.00	0.00	20230519_VolumeSearch_161430_Civic_Recreations 600 ALL Data
620	GOVERNMENT BUILDINGS (INCLUDES COURTHOUSE, POST OFFICE)	2021	7,185,224	7	Other	6.50	20.22	0.96	1.68	0.26	20230519_VolumeSearch_161430_Civic_Recreations 600 ALL Data

Appendix C Snapshot of NAICS code and AWU Code



NAICS		**Actual Water Use**		
Code	**Description**	**Actual Use Category Name**	**Code**	**Actual Use Name**
3221	Pulp, paper and paperboard mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)
32211	Pulp mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)
322111	Mechanical pulp mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)
322112	Chemical pulp mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)
32212	Paper mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)
322121	Paper (except newsprint) mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)
322122	Newsprint mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)
32213	Paperboard mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)
322130	Paperboard mills	Industry	424	PULP & PAPER MILLS (INCLUDING FINE PAPER)