

Water Quality Assessment and Updated Proposed Objectives for Burrard Inlet: PPCPs Technical Report



November 2019



Tseil-Waututh Nation
səlilwətal



This Technical Report forms part of a series of water quality parameter reports whose purpose is to inform updates to the 1990 Provincial Water Quality Objectives for Burrard Inlet. This report and others in the series assess the current state and impacts of contamination in Burrard Inlet; incorporate new scientific research and monitoring of water quality; and reflect a broader understanding of goals and values, including those of First Nations, to improve the health of the marine waters of Burrard Inlet. Updating the 1990 [Provincial Water Quality Objectives](#) is a priority action identified in the Tsleil-Waututh Nation's [Burrard Inlet Action Plan](#) which has been an impetus for this work.

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Underwater monitoring equipment is installed from the Tsleil-Waututh Nation boat in Burrard Inlet. Photo credit; Tsleil-Waututh Nation.

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CHAPTER SUMMARY

This chapter presents current information on pharmaceuticals and personal care products (PPCPs) in Burrard Inlet. Relevant background information, a literature review of toxicity studies, and an overview of current information about PPCP levels in water, sediment, and biota in Burrard Inlet are used to discuss an approach towards creating water quality objectives for PPCPs. Although there are many different PPCPs¹ that can potentially be found in marine receiving environments, only PPCPs that have been detected in Burrard Inlet to date are discussed, with the exception of hormones (i.e., synthetic estrogens). Synthetic estrogens have been included in this chapter because they represent a PPCP with potential adverse effects at low concentrations, and have been detected in other aquatic environments and effluents (Feng et al., 2010). For the purpose of this report, PPCPs have been grouped into the following classes:

- Analgesics
- Antimicrobials
- Antihypertensives
- Antihistamines
- Selective Serotonin Reuptake Inhibitors (SSRIs)
- Stimulants/recreational drugs/personal care products
- Hormones

PPCPs are entirely anthropogenic. PPCPs are usually released into the marine environment via sewage from municipal sources, illegal sewage release from marine vessels, and combined sewer overflows (CSOs). Aquaculture and agriculture waste and run-off, and leachate from landfills can also be sources of PPCPs; however, since there is no landfill or aquaculture/agriculture directly adjacent to Burrard Inlet, these potential sources are not discussed in this report. The main potential source of PPCPs in Burrard Inlet is from municipal sewage releases.

When PPCPs reach the marine receiving environment, photodegradation, biodegradation and other abiotic transformation processes, such as hydrolysis, occur, which can reduce their concentrations. PPCPs can also be transported in the marine environment, depending on their physico-chemical properties and environmental factors (e.g., pH, temperature, and the amount of sunlight exposure).

Since PPCPs are active molecules with target receptors in most vertebrates, their presence in the environment is highly concerning. To date, PPCP concentrations measured in Burrard Inlet waters are all below the acute and chronic toxicity thresholds found in the literature. However, these thresholds are derived from acute exposure experiments and do not likely reflect environmentally-relevant low dose chronic exposures. In addition to exposure to a single PPCP, there is also the potential for toxicity from complex mixtures of PPCPs, through additive, synergistic and antagonistic interactions.

Water quality benchmarks for the protection of marine life were not found for the PPCPs that were detected in Burrard Inlet. There is currently insufficient toxicological information to propose quantitative marine water quality objectives for the PPCPs outlined in this report. Until marine-relevant toxicity data are available, management priorities should be source control and monitoring, with the goal of reducing concentrations of PPCPs in water, sediment, and biota over time.

¹ Alkylphenols will be addressed in a separate report.

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ACRONYMS

B.C.	British Columbia
CSO	Combined sewer overflow
DEET	N,N-Diethyl-meta-toluamide
EE2	Estrogen 17 α -ethinylestradiol
ENV	Ministry of Environment and Climate Change Strategy
ISMP	Integrated Stormwater Management Plan
LOEC	Lowest observed effect concentration
NOEC	No observed effect concentration
NSAID	Non-steroidal anti-inflammatory drug
PPCPs	Pharmaceuticals and personal care products
SSRI	Selective serotonin reuptake inhibitor
VTG	Vitellogenin
WWTP	Wastewater treatment plant

1. INTRODUCTION

1.1 Overview

This chapter presents current information on pharmaceuticals and personal care products (PPCPs) in Burrard Inlet. It includes relevant background information, a literature review of toxicity studies, and an overview of current information about PPCP levels in water, and sediment and biota in Burrard Inlet. Although there are currently no water quality objectives developed for PPCPs, a rationale for an approach to creating water quality objectives will be discussed. Recommendations for future monitoring as well as management options to help reduce PPCP levels in Burrard Inlet are also included.

Pharmaceuticals are medicinal drugs given to humans or animals to prevent or treat illnesses and diseases, while personal care products are used mainly to improve quality of life on a daily basis (Ebele, 2017). Worldwide, there are several thousand PPCPs produced every year, with continuous inputs of PPCPs to fresh and marine surface waters from treated and untreated wastewater (Klosterhause et al., 2013). The possible negative ecological effects of PPCPs were not recognized until the late 1990's (Daughton and Ternes, 1999), and since then PPCP use has risen significantly, with reported annual production exceeding 1 x 10⁶ tonnes worldwide (Richardson et al., 2005).

Pharmaceuticals are excreted either as parent compounds or as metabolites and end up in wastewater treatment plants (WWTPs), or are directly discharged into aquatic environments. Pharmaceuticals that are applied topically can also be washed off, similar to personal care products, such as toothpaste, creams, shampoos and other hygiene products. When these compounds are washed away, they are transferred to WWTPs where they are either removed or flushed into receiving waters (McEneff, 2015). Available information on each class of PPCP detected in Burrard Inlet is summarized below, and relevant marine toxicity data for marine organisms are provided to help direct future research in establishing water quality objectives.

Burrard Inlet data collected by Metro Vancouver and Ocean Wise Conservation Association (Ocean Wise) were used to create a list of relevant PPCPs of interest in water and sediment (Table 1) (Enkon, 2012; Golder Associates, 2013; Ocean Wise, 2018). Although there are many different PPCPs² that can

² Alkylphenols will be addressed in a separate report.

potentially be found in marine receiving environments, only the PPCPs that have been detected in Burrard Inlet will be discussed with the exception of hormones (i.e., synthetic estrogens). These PPCPs are discussed in detail in Sections 1.2 to 1.8. Synthetic estrogens have been included in this chapter, as they have a high rate of usage, potential adverse effects at low concentrations, and have been detected in other aquatic environments and effluents (Feng et al., 2010). For the purpose of this report, PPCPs have been grouped into the following classes:

- Analgesics
- Antimicrobials
- Antihypertensives
- Antihistamines
- Selective Serotonin Reuptake Inhibitors (SSRIs)
- Stimulants/recreational drugs/personal care products
- Hormones

1.2 Analgesics

Analgesics include the non-steroidal anti-inflammatory drugs (NSAIDs), such as ibuprofen, naproxen, or aspirin, which are one of the most widely used pharmaceuticals globally. NSAIDs represent 15% of the compounds found in influents and effluents of WWTPs, surface waters, groundwater, and drinking water (Santos et. al., 2010; Mezellani et al., 2016). These pharmaceuticals are commonly used for pain relief and work through the peripheral and central nervous systems in humans and animals.

1.3 Antimicrobials (antibiotics and antifungals)

Antimicrobials are agents that kill or stop the growth of any microorganisms in humans and animals. They include two categories:

- Antibiotics are used to prevent bacterial growth.
- Antifungals are used to prevent growth of fungi.

Antibiotics have been prescribed worldwide for the past 30 years, and are the most frequently found pharmaceutical in marine waters globally, with the highest concentrations reported in areas that are densely populated (Grenni et al., 2018). The BC Center for Disease Control (2014) listed the three most widely used antibiotics in British Columbia as penicillins, tetracyclins and macrolids, with the latter being relatively persistent in the environment (Huang et al., 2001).

1.4 Anti-hypertensives

Anti-hypertensive pharmaceuticals are used to treat high blood pressure, and are one of the therapeutic classes of pharmaceuticals found most frequently in the environment, reflecting growing consumption of these drugs worldwide. Anti-hypertensives are also known to be ineffectively removed in conventional WWTPs and have a high persistence in water matrices (Godoy et al., 2015).

1.5 Antihistamines

Antihistamines are pharmaceuticals used to relieve allergy symptoms and work by decreasing the effects of histamine at its cell receptors (Potter, 2012). As one of the most common antihistamines in production worldwide, diphenhydramine is relatively abundant in municipal effluents, sediment, and in the tissues of fish (Potter, 2012). Antihistamines are also poorly removed during wastewater treatment, and are primarily removed via adsorption to sludge (Ryu et al., 2013).

1.6 Selective Serotonin Reuptake Inhibitors (SSRIs)

Serotonin reuptake inhibitors (SSRIs) are used in the treatment of antidepressive disorders, and are among the most widely prescribed antidepressants (Estévez-Calvar et al., 2017). SSRI's were detected in Burrard Inlet sediment sampling, and have also been frequently detected in wastewater samples from several sewage treatment plants in Galicia, Spain (Pablo Lamas et al., 2004), as well as from a WWTP in Southern Ontario (Metcalf et al., 2010); however there is very little data on the occurrence of SSRIs in the marine environment and their potential toxic effects on marine life (Estévez-Calvar et al., 2017).

1.7 Stimulants/Recreational Drugs/Personal Care Products

The presence of the stimulant caffeine in marine water samples could result from either consumption of coffee and other caffeinated beverages, or from use of certain medications that contain caffeine (Environment Canada, 2014). Along with caffeine, its metabolite 1,7-dimethylxanthine was also detected in Burrard Inlet (Enkon, 2012).

Cocaine is considered an illicit drug, and levels in receiving environments often reflect the consumption rate of the surrounding population (Montagner et al., 2019). The metabolite benzoylecgonine is commonly found at higher concentrations than cocaine due to its stability in aqueous samples, and it is also excreted at higher concentrations than cocaine. There is little known about the effects of cocaine and its metabolites on marine life (Montagner et al., 2019).

Personal care products include consumer products used for personal hygiene and for beautification purposes. These products can enter the marine environment when they wash off during a shower, or via excretion, since some can be absorbed into the body. One of the most common personal care products found in marine monitoring studies is the antibacterial chemical triclocarban, which is widely used in soaps, shampoos, liquid toothpastes, and cosmetics (Chalew, 2009).

Another personal care product that was detected in sediment and water samples around the Lions Gate WWTP outflow was N,N-Diethyl-meta-toluamide (DEET) (Enkon, 2012). DEET is a common ingredient in insect repellents. DEET is known to enter marine waters mainly from WWTPs and to a lesser degree from atmospheric deposition (Weigel et al., 2002).

1.8 Hormones

Hormones that might be present in Burrard Inlet include the synthetic, bioactive estrogen 17 α -ethinylestradiol (EE2). This estrogen is used in oral contraceptives and is transported into marine waters via sewage treatment plants (Nagpal and Meays, 2009). Although sediment and water sampling around Lions Gate WWTP by Metro Vancouver³ (Enkon, 2012 and Golder, 2015) did not detect EE2, this hormone was detected in Metro Vancouver sampling of male English sole (Enkon, 2012) from Burrard Inlet in 2012 and therefore, included in this chapter. It is also a relevant pollutant to include, due to its potential toxicity at low concentrations indicating that there is some exposure to endocrine disrupting compounds in the inlet, as well as its presence in other aquatic environments and effluents, including the Annacis Island WWTP (Nagpal and Meays, 2009).

2. BACKGROUND

2.1 Values and Potential Effects

PPCPs are a unique class of pollutants, as they are engineered to target specific organs in humans and animals to produce therapeutic effects. Once they enter marine waters, some of these compounds are

³ EE2 was not analyzed for in *PollutionTracker* samples.

able to pass through biological membranes and exert effects at low concentrations, as well as persist in aquatic ecosystems; however, bioaccumulation of PPCPs, and resulting effects, are not well understood yet.

As PPCPs produce physiological effects in humans and domestic animals at relatively low doses, they can also have unintended effects on non-target organisms once released into the environment. Most of these effects are unknown, and as some pharmaceuticals can affect organisms well below concentrations typically used in pharmaceutical safety and efficacy tests⁴, determining these effects at environmentally relevant concentrations is challenging. Breakdown products and mixtures of different PPCPs interacting with each other also have the potential to affect the health of receiving aquatic environments.

Values requiring protection from PPCP pollution include aquatic life and human consumption of finfish and shellfish. Given the wide range of compounds included in this category, the most sensitive values may vary. Because the effects of PPCPs in the marine environment are poorly understood, it may not be possible at this time to indicate which value is most sensitive to each compound.

2.1.1 Marine Ecotoxicity Studies

Results of standardized toxicity tests for the PPCPs included in this report are provided in **Table 1** to give an overview of the potential toxicity of these compounds.

Table 1. Chronic and acute toxicity data for PPCPs for marine and freshwater species
(- denotes no information available)

Compound	Class	Marine Species	Freshwater Species	Endpoint/ Duration	LOEC (µg/L)	NOEC (µg/L)	Acute 48 and 72hr EC50 (µg/L)	Reference
Acetaminophen	Analgesic	<i>V. Fisheri</i>	-	30-min EC50	650,000	-	-	Brausch et al., 2012
		<i>M. galloprovincialis</i>	-	10-day behaviour feeding rate	>403	403	-	Brausch et al., 2012
		<i>Artemia salina</i>	-	-	-	-	>1000 (48hr)	Minguez et al., 2014
Naproxen	Analgesic	-	<i>B. calciflorus</i>	48-hr reproduction	560	-	-	Isidori et al., 2005
		-	<i>P. subcapitata</i>	96-hr growth	31,820	-	-	Isidori et al., 2005
		-	<i>C. dubia</i>	7 day reproduction	330	-	-	Isidori et al., 2005
		<i>Artemia salina</i>	-	-	-	-	>1000 (48hr)	Minguez et al 2014
Clarithromycin	Antimicrobial	-	<i>D. magna</i>	21-day reproduction	6.3	3.1	-	Brausch et al., 2012

⁴ Efficacy tests are used to determine the capacity of a pharmaceutical to produce a desired effect on either humans or animals, while safety tests usually determine the acute toxicity of a pharmaceutical on a mammalian species.

Compound	Class	Marine Species	Freshwater Species	Endpoint/ Duration	LOEC (µg/L)	NOEC (µg/L)	Acute 48 and 72hr EC50 (µg/L)	Reference
		-	<i>B. calyciflorus</i>	48-hr population growth	12,210 (EC50)	-	-	Brausch et al., 2012
		-	<i>C. dubia</i>	7-day population growth	8,160 (EC50)	-	-	Brausch et al., 2012
		<i>Artemia salina</i>	-	-	-	-	>1000 (48hr)	Minguez et al., 2014
		<i>Skeletonema marinoi</i>	-	-	-	-	1.52 (72hr)	Minguez et al., 2014
Ciprofloxacin	Antimicrobial	-	<i>L. gibba</i>	7-day growth	106 (EC10), 698 (EC50)	-	-	Brausch et al., 2012
		-	<i>L. minor</i>	7-day growth	203 (EC50)	-	-	Brausch et al., 2012
Erythromycin	Antimicrobial	-	<i>C. dubia</i>	7-day population growth	220 (EC50)	-	-	Brausch et al., 2012
		-	<i>B. calyciflorus</i>	48-hr population growth	940 (EC50)	-	-	Brausch et al., 2012
		-	<i>D. magna</i>	21-day survival	-	248	-	Brausch et al., 2012
Miconazole	Antimicrobial	<i>Artemia salina</i>	-	-	-	-	1690(48hr)	Minguez et al., 2014
		<i>Skeletonema marinoi</i>	-	-	-	-	170 (72hr)	Minguez et al., 2014
Diphenhydramine	Antihistamine	-	<i>D. magna</i>	10-day	5.94	2.94	-	Kristofco et al., 2014
Caffeine	Stimulant	-	<i>C. dubia</i>	7-day growth, mortality	40,000-50,000 (LC50)	20,000-50,000 (EC25)	-	Brausch et al., 2012
		-	<i>P. promelas</i>	7-day growth, mortality	50,000-60,000(LC50)	30,000-90,000 (EC50)	-	Brausch et al., 2012
		-	<i>L. gibba</i>	7-day growth	>1,000 (EC50)	-	-	Brausch et al., 2012
N,N-Diethyl-meta-toluamide (DEET)	Personal Care Product	-	<i>D. magna + green algae</i>	-	500 – 24,000	-	-	Weeks et al., 2011
		-	<i>D. magna</i>	-	-	-	75000 (48hr)	Costanzo et al., 2007
		-	<i>Chlorella protothecoides</i>	-	-	-	388000 (24hr)	Costanzo et al., 2007
		-	<i>Oncorhynchus mykiss</i>	-	-	-	71300 (96 hr)	Costanzo et al., 2007

Compound	Class	Marine Species	Freshwater Species	Endpoint/ Duration	LOEC (µg/L)	NOEC (µg/L)	Acute 48 and 72hr EC50 (µg/L)	Reference
Triclocarban	Personal Care Product	<i>Artemia salina</i>	-	-	-	-	171.1 (24hr)	Xu et al., 2015

To date, PPCP concentrations measured in Burrard Inlet waters (Table 3) are all below the acute and chronic toxicity thresholds found in the literature. However, these thresholds are derived from acute exposure experiments and do not likely reflect environmentally-relevant low dose chronic exposures (Fabbri and Franzellitti, 2016). In addition, most of these tests are limited to freshwater algae, daphnia and/or freshwater fish rather than marine organisms, and therefore, results do not fully represent potential effects in marine organisms. Differences in physico-chemical conditions between freshwater and seawater, including salinity, pH, and organic matter can impact the environmental fate of pharmaceuticals and, therefore, uptake and effects.

Adverse effects such as reduced feeding rates, impacts on survival, reduced mussel byssus strength, and changes in biochemical markers and immune response have been observed in individual mussels exposed to PPCPs in seawater. Transient tissue-specific changes were reported after a 7-day exposure of mussels to 0.25 µg/L diclofenac in seawater, a concentration observed in the environment (Gaw et al., 2014).

In addition to exposure to a single PPCP, there is also the potential of toxicity from complex mixtures of PPCPs, which can have additive, synergistic and antagonistic interactions. Individual compounds may be present at low concentrations with few toxic effects, but as mixtures, they may exert considerable ecotoxicity (Ebele et al., 2016). Such mixtures can contain a wide variety of PPCPs and other compounds with different or similar modes of action. The NOECs and LOECs derived from single substance testing are therefore not ideal for deriving water quality objectives (Gaw et al., 2014).

2.1.2 Endocrine Disruption

The synthetic estrogen EE2 is a potential endocrine disruptor of marine biota in Burrard Inlet. Synthetic estrogens can exert effects directly or indirectly on marine life through receptor mediated processes, which can mimic hormones and inhibit normal hormone activities (Feng et al., 2010). Even when present at low concentrations, estrogen hormones such as EE2 can still have an effect in stimulating and inducing vitellogenin (VTG) production in male fish (Feng et al., 2010). This VTG is a protein normally synthesized by females during oocyte maturation, which can be measured in the blood of female vertebrates, and is often used as a biomarker in detecting exposure in males to environmental estrogens (Feng et al., 2010). When VTG is present in male fish, they can develop early-stage eggs in their testes, resulting in a reduction in their reproductive capacity⁵.

2.1.3 Antimicrobial Resistance

Triclocarban, a common antimicrobial, was detected in Burrard Inlet sediment samples in 2011 (Golder, 2013) and 2015 (Ocean Wise, 2018). This antimicrobial persists in the environment and exhibits toxicity towards a variety of biological receptors such as crustacea and algae, which were determined to be the most sensitive biota to triclocarban exposure (Chalew and Halden, 2009). Antimicrobial exposure can

⁵ Laboratory studies have shown decreased reproductive success of fish exposed to 1–5 ng/Lof EE2 (Kidd et al., 2007)

cause antimicrobial resistance in target and non-target bacteria, which can directly or indirectly affect microbial communities in the marine environment. Short-term effects include the disappearance of microbial communities, while long-term effects include the development of antimicrobial resistance (Grenni et al., 2018). The slow degradation rate of antimicrobials and their persistence in the aquatic environment increase the risk of resistance developing (Gaw et al., 2014). Widespread antimicrobial resistance has been reported in fish, marine mammals, and seabirds living in coastal areas around the world, with high prevalence within areas of WWTPs (Gaw et al., 2014; Rose et al., 2009). Triclocarban degradation products are also a potential source of contamination and require further research (Ogunyoku and Young, 2014).

2.1.4 PPCP Exposure in Humans

Currently, little information on human exposure to PPCPs in the marine environment exists, and scientists do not have a good understanding of potential health impacts at environmentally-relevant levels of exposure.

One concern for human health is that indirect environmental exposure to antimicrobials and medicinal products having anti-bacterial, anti-viral, or disinfectant properties may create antimicrobial or anti-viral resistance within human gut flora (ChemTrust, 2014).

Although estrogens are essential for normal physiological functions, they are also a concern if allowed to accumulate in the environment and enter the human food chain. Above a certain level, estrogens increase the risk of cardiovascular disease and cancer, specifically breast cancer in women and prostate cancer in men. This is because estrogens are able to bind with receptor cells in breast tissue and prostate tissue, which leads to cell proliferation causing tumour growth (Adeel et al., 2017).

Marine resources are an important value for the Tsleil-Waututh Nation and other First Nations communities around Burrard Inlet. Given the potential for PPCPs to accumulate in marine biota, and the Tsleil-Waututh Nation's goal of harvesting traditional seafood species from the Inlet in the future, a better understanding of food chain transfer and potential effects of PPCPs in humans is imperative.

2.2 Potential Sources of Pharmaceuticals & Personal Care Products Pollution

PPCP sources are entirely anthropogenic. PPCPs are typically released into the marine environment via sewage, landfill and aquaculture/agriculture waste and run-off. Since there is no aquaculture/agriculture or landfill directly adjacent to Burrard Inlet, these potential PPCP sources are not discussed in this report (Metro Vancouver, 2017; Department of Fisheries and Oceans, 2016) (**Figure 1**). The main potential source of PPCPs in Burrard Inlet is from sewage releases.

Sewage releases into Burrard Inlet originate from the Lions Gate WWTP, as well as from illegally released sewage effluent from boats moored or anchored in the inlet. Other sources include CSOs, as well as streams and rivers, which receive surface and storm water runoff.

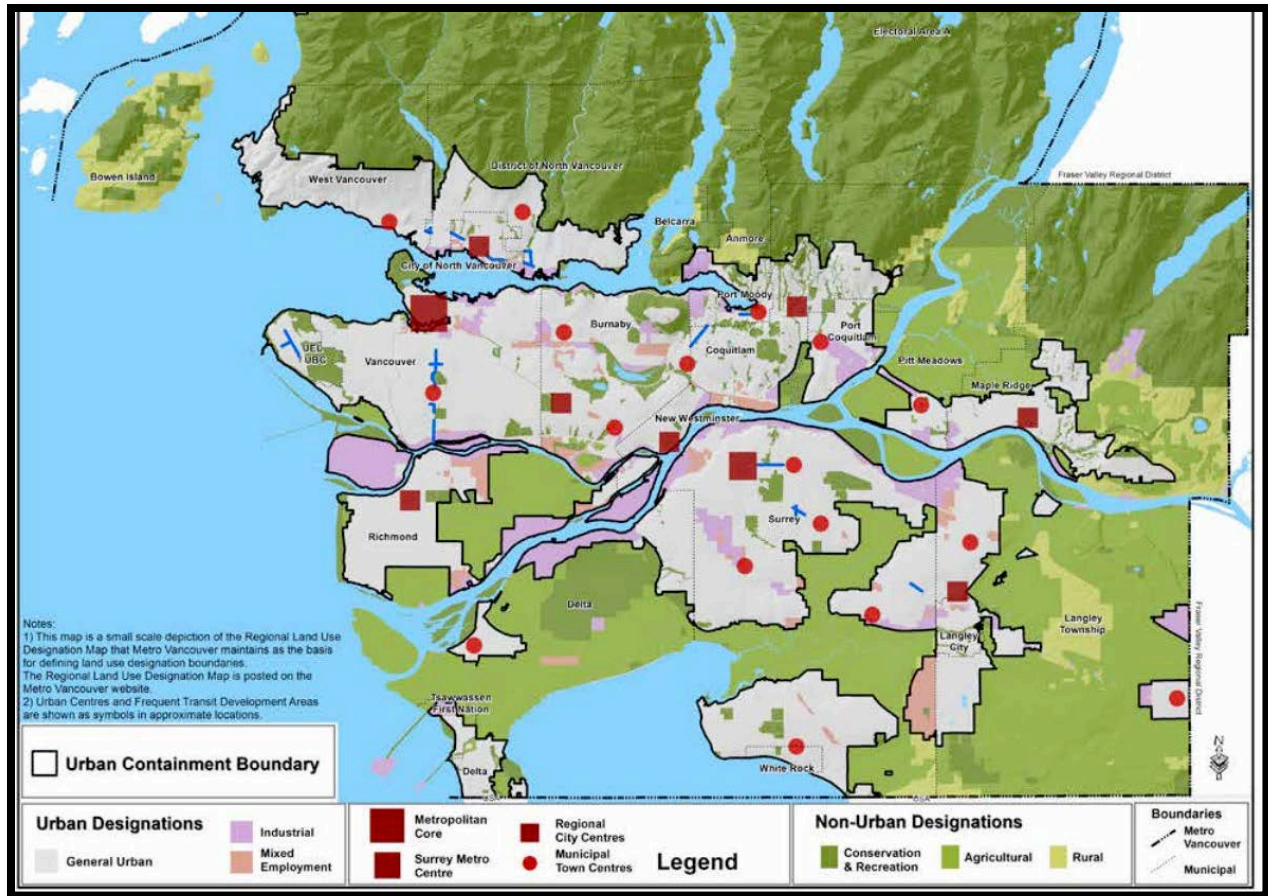


Figure 1. Regional land use around Burrard Inlet (Metro Vancouver Regional District, 2017)

2.2.1 Sewage

The Lions Gate WWTP is located in Burrard Inlet near the Lions Gate Bridge, east of the Capilano River. The WWTP discharges primary treated effluent into the turbulent First Narrows area of the Inlet through an outfall and diffuser located just west of the Lions Gate Bridge. The outfall is about 184 m offshore, and the average diffuser depth is approximately 20 metres (Metro Vancouver, 2017). The effluent is dispersed at the initial dilution zone (IDZ) throughout inner and outer Burrard Inlet before entering the Strait of Georgia (Metro Vancouver, 2017).

The Lions Gate WWTP treated a total of 30,419 million litres (ML) in 2017, with an average daily flow of 83 million litres per day (MLD) for 2016 and 2017 (Metro Vancouver, 2017). The plant receives residential and commercial wastewater, as well as wastewater from large institutions such as hospitals and laboratories (Metro Vancouver, 2017). Most of the PPCPs that enter the Lions Gate WWTP come from human excretion, while some come from other waste sources.

Currently, the Lions Gate WWTP is using a primary treatment system; however, it is currently in the process of being upgraded from a primary to a secondary waste water treatment system (to be completed in 2020). For the primary treatment system, wastewater is passed through several tanks and filters that separate the water from solids and organic matter producing a sludge. While some PPCPs are therefore reduced, eliminated or sorbed to biosolids at the WWTP, the rest are not removed completely and are then discharged into Burrard Inlet. The resulting sewage sludge is often used by Metro

Vancouver in parks to provide nutrients and organic matter for soils in landscaping (Metro Vancouver, 2019). However, this sludge contains various PPCPs as described in the Metro Vancouver biosolids risk assessment report (Kennedy Jenks Consultants, 2017). This risk assessment detected several PPCPs in the biosolids from the Lions Gate WWTP, which included SSRI's, antimicrobials, analgesics, and estrogens (Kennedy Jenks Consultants, 2017). This contaminated sludge or biosolids can potentially reach the marine environment of Burrard Inlet via surface water or groundwater runoff.

2.2.2 Removal Efficiency of PPCPs in WWTPs

The Lions Gate waste water treatment process has variable effectiveness in removing PPCPs, since each compound has differing physico-chemical properties. For example:

- Analgesics are excreted unchanged or as active metabolites. Both of these tend to have high solubility and low rates of removal during sediment/flocculation removal in WWTPs (Nesbitt, 2011). The rate of removal for these pharmaceuticals is also temperature dependent, where low water temperatures decrease the rate of removal. This creates a seasonal spike in analgesics during the winter months, which also coincides with increased use of NSAIDs for flu treatments (Nesbitt, 2011).
- For antimicrobials and anti-hypertensives there is only partial elimination in sewage treatment plants (Kummerer, 2009). If they are not eliminated during the purification process, they pass through the sewage system and end up mostly within the water compartment, with residual amounts reaching groundwaters or sediments (Kummerer, 2009). For antimicrobials, triclocarban is known to accumulate in sludges produced during the WWTP process. However, significant residual concentrations have been observed in receiving environment sediment samples, presumably a result of high inputs from widespread use in consumer products (Ogunyoku and Young 2014). Macrolids have a very low removal rate in WWTPs, and sometimes are even found at higher concentrations in effluents. This was observed by Lin et al (2009), who studied the removal efficiency of macrolids in a secondary WWTP in Teipei, China. The results of this study also agree with those of Gros et al (2007), who also found higher concentrations of macrolid antibiotics in the majority of secondary WWTP effluent samples in Spain. Tetracycline on the other hand was shown to consistently have a high removal rate in all WWTPs (between 66 and 91%).
- WWTPs can eliminate some caffeine, although at variable rates. These variations can come from the age of activated sludge and environmental conditions, such as temperature and light intensity, as well as the adsorption capacity of compounds in the sludge (Ogunyoku and Young, 2014).
- For SSRI's, primary treatment plants have a limited capacity to remove antidepressants from sewage (Lajeunesse et al., 2012). In a study done by Lajeunesse et al (2012), fourteen antidepressants along with their respective metabolites were studied in five different WWTPs across Canada. Results indicated that primary treatment has limited capacity to remove antidepressants from sewage, while activated sludge, biological aerated filtering, and biological nutrient removal processes indicated mean removal of 30%. Parent compounds were removed to a greater degree than metabolites of antidepressants.
- Removal of illicit drugs, such as cocaine and amphetamines, was generally found to be less than 50% in WWTPs that utilize primary treatment systems (Castiglioni et al., 2011).
- Estrogens, such as EE2 are not completely broken down in WWTP processes, and therefore can be discharged into Burrard Inlet (Kidd et al., 2007). However, EE2 can be removed via the activated sludge process, since it is a non-polar and hydrophobic compound, which allows it to be strongly adsorbed onto particles (Feng et al., 2010).

Lions Gate WWTP also disinfects the waste water between April and September with chlorine (Metro Vancouver, 2017). This additional step may result in unwanted reaction and transformation of some PPCPs (Westerhoff et al., 2005).

Overflow of sanitary sewers can also occur, contributing to the input of PPCPs to Burrard Inlet. Such combined sewer overflows (CSOs) occur during wet weather when there is insufficient combined sewer capacity to handle additional storm water inflows. As a result, excess combined sewage and storm water flow directly into Burrard Inlet rather than being treated at the WWTP (Metro Vancouver, 2017).

In addition to sewage directly entering Burrard Inlet, rivers and streams that flow into the inlet, including the Capilano and Seymour Rivers, receive storm water runoff from urban areas in North Vancouver, as well as other urban locations surrounding Burrard Inlet. Sources of PPCPs also include direct runoff from on-ground fecal material from pets and livestock (Cooper et al., 2008). This on-ground fecal material can potentially originate from areas such as equestrian centers (i.e., North Shore and Laura Lynn equestrian centers), and farms (Maplewood Farm), as well as from dog feces. Domestic animals and livestock are often treated with pharmaceuticals that are subsequently excreted and washed into nearby water bodies, to be transported into Burrard Inlet.

2.3 Factors Influencing PPCP Levels in Burrard Inlet

When PPCPs reach the marine receiving environment, photodegradation, biodegradation and other abiotic transformation processes, such as hydrolysis occur, which can reduce their concentrations (Ebele et al., 2016). PPCPs can also be transported in the marine environment, depending on their physico-chemical properties and environmental factors (e.g., pH, temperature, and the amount of sunlight exposure) (McEneff et al., 2015). For example, studies have shown that the physico-chemical and biological properties of antibiotics may change drastically with variation in pH (Kummerer et al., 2009). PPCPs have low volatility, and are highly polar and hydrophilic which suggests that their distribution and movement through marine waters is primarily via aqueous transport and food chain dispersal (Ebele et al., 2016).

While environmental degradation and transformation can sometimes reduce or eliminate a compound, these processes also often make PPCP transformation products more toxic than their original forms. Naproxen, for example, can undergo high rates of photodegradation resulting in photo products (1-(6-methoxynaphthalene-2-yl) ethylhydroperoxide, 2-methoxy-6-vinylnaphthalene, 1-(2-Methoxynaphthalene-6-yl)ethanone) (Aranay et al., 2013) that are more toxic than the original compound (McEneff et al., 2015). Other studies have reported data for PPCP transformation products, such as erythromycin-H₂O, which is the most commonly found transformation product in many waste waters. These products can be present in WWTP effluent and surface waters at concentrations that are similar or higher than their parent compounds (Gaw et al., 2013).

Adsorption of PPCPs to sediment particles can remove them from the water column, although there is great variation in this process among different types of PPCPs. Some, like various forms of antibiotics, show a high tendency to adsorb to sediment particles, while other compounds demonstrate a tendency to stay in solution. Sediments therefore have the potential to store PPCPs and release them back into the water column from the surface layer when there are changes in the physical or chemical environment, such as tidal changes, heavy storm events or changes in salinity and pH (Gaw et al., 2013; Hektoen et al., 1995). Once in the sediment, some PPCPs will persist, such as the antibacterial agent triclocarban.

2.4 1990 Provisional Water Quality Objectives for PPCPs

There were no water quality objectives developed in 1990 for PPCPs in Burrard Inlet.

3. WATER QUALITY ASSESSMENT

3.1 Benchmarks Used in this Assessment

Water quality benchmarks are used to evaluate data for thresholds and probable negative effects on the marine ecosystem in Burrard Inlet. However, water quality benchmarks for the protection of marine life were not found for the PPCPs discussed in this report. Nevertheless, a few select pharmaceutical benchmarks have been developed or proposed in Canada (CCME, 2018 and Environment and Climate Change Canada, 2017), and the Netherlands (National Institute for Public Health and the Environment, 2014).

The Canadian Council of Ministers of the Environment (CCME), have derived a freshwater guideline for carbamazepine (CBZ), a commonly prescribed antiepileptic (CCME, 2018). This was developed using different toxicity endpoints (i.e., molecular marker result from in vitro assays) that are normally used in developing CCME guidelines (i.e., survival, growth and reproduction) (CCME, 2018). The endpoint from this critical study was then divided by a safety factor of 10 to derive the exposure guideline value for CBZ at 10 µg/L (CCME, 2018). In addition, Environment and Climate Change Canada (ECCC) has developed a Canadian Federal Environmental Quality Guideline (FEQG) for triclosan, an antimicrobial compound. For this compound, sufficient chronic toxicity data were available to meet the minimum requirement for a CCME guideline, although to date no CCME water quality guideline exists for triclosan (ECCC, 2017). The FEQG for triclosan is 0.38 µg/L for freshwater aquatic life (ECCC, 2017).

In the Netherlands, a water quality standard has been proposed for three pharmaceuticals in fresh and marine surface waters: carbamazepine, metropol, and metformin. Based on monitoring data from Dutch surface waters, these chemicals have been put on a watch list. The methods that were used to develop these standards were based on literature reviews of different toxicity endpoints (using relevant endpoints such as consequences at the population level of the test species) (National Institute for Public Health and the Environment, 2014).

Although EE2 was not detected in any sediment and water sampling (IDZ sampling of Lions Gate treatment plant), the BC Ministry of Environment has developed a freshwater ambient water quality guideline for EE2 protective of aquatic life. The recommendation is that the 30-day average EE2 concentration in water should not exceed 0.5 ng/L, with no single value to exceed 0.75 ng/L (Nagpal and Meays, 2009). Marine water quality guidelines were not recommended due to a lack of relevant data from the literature (Nagpal and Meays, 2009).

3.2 Data Sources

Data from recent sampling efforts that tested for PPCPs were collected for this assessment. A summary of the datasets that were analyzed for this assessment is presented in **Table 2**. The locations of PPCP sample sites in Burrard Inlet are provided in Appendix B.

Table 2. Studies and/or monitoring programs contributing data used in this assessment

Source	Study/Monitoring Program	Year(s) Sampled	No. of Samples	No. of Sites	Sampling Frequency	Parameters Sampled
Klosterhaus et al (2013)	Pharmaceuticals and personal care products in surface waters in San Francisco Bay, USA	2009 - 2010	3 water, sediment and mussel tissue samples	5	December 2009; January 2010.	PPCPs
Krogh et al (2017)	Pharmaceuticals and personal care products in municipal waste water and the marine receiving environment near Victoria, Canada.	2009-2016	2 waste water; 3 marine sediment; 4 marine water; 2 benthic tissues	14	Waste water Nov 2009 & quarterly 2014-2016; sediment Sept 2010; marine water Oct 2012; benthic tissue Sept 2015	PPCPs
Enkon (2012)	Monitoring of receiving environment in initial dilution zone boundary of Lions Gate WWTP, for Metro Vancouver	2011	For PPCP analysis: 1 effluent; 2 samples from IDZ: 1 IBI reference site.	28	November, 2011	PPCPs + other water quality parameters
Golder (2013)	Sediment sampling around receiving environment of Lions Gate WWTP outfall, for Metro Vancouver	2011	For PPCP analysis: 3 sediment samples, 1 duplicate site	16	March 2011	PPCPs + other sediment parameters
Meador et al (2016)	Contaminants of emerging concern in large temperate estuary in Puget Sound, Washington USA	2013 –2014	8 fish samples; 2 WWTP; 3 estuary water	15	September 2014	PPCPs (included several industrial compounds)
Ocean Wise (2018)	<i>PollutionTracker</i> -within Burrard Inlet	2015-2017	12 sediment; 6 mussel samples	13	2015-2017	PPCPs + other contaminants

3.3 Assessment Results

3.3.1 Seawater

Only a handful of marine environmental monitoring studies have been conducted for PPCPs in seawater along the northwest coast of North America. These include sampling in 2011 by Metro Vancouver, which sampled eight sites within the IDZ of the effluent plume from the Lions Gate WWTP, as well as two reference sites located in outer Burrard Inlet and Vancouver Harbour. Studies on PPCP monitoring in Victoria (British Columbia, Canada), Puget Sound (Washington, USA), and San Francisco Bay (California, USA) will also be discussed in this section (Klosterhause et al., 2013; Meador et al., 2016; Krogh et al., 2017).

Results from the Metro Vancouver monitoring study are listed in **Table 3**. Of the 117 PPCPs analyzed, only 13 were detected (Enkon, 2012)⁶. Acetaminophen, caffeine, cocaine and its metabolite, benzoylecgonine, were detected in all samples with concentrations 4 to 10 times higher in the IDZ boundary samples than in the reference areas (Enkon, 2012).

Most of the PPCPs detected in Burrard Inlet were also found in Victoria Harbour (Krogh et al., 2017), Puget Sound (Klosterhause et al., 2013), and San Francisco Bay (Meador et al., 2016), with the exception of 1,7-dimethylxanthine, a caffeine metabolite.

Table 3. Maximum and minimum PPCP concentrations detected in seawater from the IDZ of Lions Gate WWTP (Enkon, 2012)

Compound	Class	Min. Concentration found in Burrard Inlet Seawater (µg/L)	Max. Concentration found in Burrard Inlet Seawater (µg/L)
Acetaminophen	Analgesic	0.143	0.182
Naproxen	Analgesic	0.00698	0.00929
Clarithromycin	Antimicrobial	0.0034	0.00574
Ciprofloxacin	Antimicrobial	<0.00565	0.00624
Erythromycin-H2O	Antimicrobial	0.000524	0.000608
Desmethyldiltiazem	Antihypertensive (metabolite)	0.000161	0.000214
Diltiazem	Antihypertensive	0.00059	0.000622
Diphenhydramine	Antihistamine	0.000657	0.000698
Benzoylecgonine	Recreational drug (metabolite)	0.00325	0.00331
Cocaine	Recreational drug	0.000785	0.000988
N,N-Diethyl-meta-toluamide (DEET)	Personal care product	0.00218	0.00381
Caffeine	Stimulant	0.0989	0.0249
1,7-dimethylxanthine	Stimulant	<0.0565	0.0705

⁶ Weekly water sampling at Lions Gate WWTP IDZ and at two reference sites over a five-week period (October 31st to November 2011). The IDZ boundary (\pm 100 m centered on the diffuser) and outside the IDZ is defined as the lesser of 100 m from the outfall, or 25% of the width of the water body. Reference sites: one reference area is situated in the inner harbour and the second is located in the outer harbour.

3.3.2 Sediment

Sediment was also sampled as part of the PPCP monitoring studies conducted in Burrard Inlet, where both Metro Vancouver and Ocean Wise have collected marine sediment for PPCP analysis (see Section 4.1). PPCP results for Victoria Harbour, Puget Sound, and San Francisco Bay are also discussed in this section.

Metro Vancouver conducted surface sediment sampling in 2011 at 16 stations: one in the Inner Harbour, east of the Lions Gate WWTP outfall; 13 stations in the Outer Harbour, west of the outfall, and at two stations west of Burrard Inlet between Point Atkinson and Eagle Harbour (Golder, 2013). A total of 118 PPCPs were analysed in 16 sediment samples, and 11 PPCPs were detected (**Table 4**). Four PPCPs were detected in all four sediment samples (clarithromycin, diphenhydramine, DEET, and triclocarban), with triclocarban detected at the highest concentration.

In 2015, Ocean Wise's *PollutionTracker* program collected nine subtidal surface sediment samples from the outer and inner harbour of Burrard Inlet, and from two sites in Indian Arm (Ocean Wise, 2018). Triclocarban was the only PPCP detected of the 12 PPCPs analyzed in Phase 1 of the *PollutionTracker* program (Ocean Wise, 2018). Triclocarban was detected in sediment from sites in the outer harbour, at three sites around the inner harbour, and at one site in Port Moody Arm. The number of PPCPs being analyzed has increased from 12 to 90 compounds at selected sites as part of *PollutionTracker* Phase 2 (2018-2020), with preliminary results indicating the presence of a SSRI, fluoxetine (Prozac), within the North Indian Arm sampling site. Additional analytical results will become available as the Phase 2 program continues.

Most of the PPCPs detected in Burrard Inlet sediment were also found in Puget Sound (Klosterhouse et al., 2013), San Francisco Bay (Meador et al., 2016), and Victoria Harbour (Krogh et al., 2017) studies, with the exception of clarithromycin and norverapamil, which were only detected in Burrard Inlet sediment.

Table 4. Maximum and minimum PPCP concentrations detected in Burrard Inlet sediment (Golder, 2013)

Compound	Class	Min. Concentration found in Burrard Inlet Sediments (µg/kg dry wt)	Max. Concentration found in Burrard Inlet Sediments (µg/kg dry wt)
Clarithromycin	Antimicrobial	1.36	1.58
Erythromycin-H2O	Antimicrobial	0.263	0.554
Miconazole	Antimicrobial	1.39	1.73
Norverapamil	Antihypertensive	0.134	0.269
Verapamil	Antihypertensive	0.136	0.201
Diphenhydramine	Antihistamine	0.942	1.76
DEET	Personal Care Product	0.622	1.18
Triclocarban	Personal Care Product	9.06	15.6
Cocaine	Recreational Drug	<0.123	0.27
Amphetamine	Stimulant	2.86	2.99
Sertraline	SSRI	0.354	0.453

3.3.3 Marine Biota

On the West Coast, monitoring of PPCPs in marine biota (mussels, fish) has been conducted as part of the *PollutionTracker* program (Ocean Wise, 2018), as well as in Victoria Harbour (Krogh et al., 2017), Puget Sound (Klosterhause et al., 2013) and San Francisco Bay (Meador et al., 2016).

One of the main concerns regarding PPCPs is their potential to accumulate in marine organisms; however, there is a lack of reliable accumulation data. One review paper found that antimicrobials and their metabolites were the most frequently reported PPCPs in marine biota, followed by antihypertensive agents (Gaw et al., 2014).

The antimicrobial triclocarban was detected in *PollutionTracker* mussel samples during Phase 1 sampling, but only in Victoria Harbour and Prince Rupert Harbour (Ocean Wise, 2018). Blue mussel (*Mytilus edulis*) tissue collected from around the untreated sewage outfall near Victoria Harbour contained naproxen, while horse mussels (*Modiolus modiolus*) collected from around the outfall diffuser and at reference stations contained virginiamycin (a veterinary antibiotic) (Krogh et al., 2017). In Puget Sound, antimicrobials were investigated in Chinook salmon (*Oncorhynchus tshawytscha*) and Pacific staghorn sculpin (*Leptocottus armatus*) from three local estuarine systems around WWTPs. Sixteen antimicrobial compounds were detected in fish tissues, likely resulting from elevated antimicrobial concentrations in water (Meador et al., 2016).

PPCPs have also been detected in numerous other marine biota globally, including squid from the central Pacific, herring from the northeast Atlantic, and shark from the eastern central Atlantic (Fedora et al., 2014). In Sweden, a study of juvenile rainbow trout revealed high levels of ibuprofen and naproxen in tissues (McEneff et al., 2015).

Although there are currently no studies that provide bioconcentration or bioaccumulation factors for the uptake of pharmaceuticals in marine finfish, it is possible that there is trophic transfer of PPCPs to top level predators in coastal marine environments (Gaw et al., 2014). Some personal care products have been found in plasma samples from Atlantic bottlenose dolphins (*Tursiops truncatus*), and UV-filtering chemicals have been found in Franciscana dolphins (*Pontoporia blainvillei*) (Gaw et al., 2013).

The presence of PPCPs in edible marine organisms and consequent human exposure through the diet has been investigated in China. Twenty-two antimicrobials were detected in fish, molluscs, shrimp and crabs collected from the marine waters of South China (Fabbri and Franzelitti, 2015). Although there are limited studies, the antibiotic erythromycin was found to bioaccumulate in adult shrimp, representing a potential health risk to humans who consume these species (Fabbri and Franzelitti, 2015).

3.4 Knowledge Gaps and Research Needs

The following key research gaps have been identified:

1. Monitoring of Burrard Inlet for PPCPs
 - Additional monitoring of PPCPs and their active transformation products in sediment, water, and biota is recommended for Burrard Inlet. Sampling should be conducted year-round to account for potential seasonal variability in PPCP concentrations associated with variations in WWTP discharges and consumption/use patterns of PPCPs in humans and animals.
 - Source monitoring program to establish concentration and rate of PPCP discharge in Burrard Inlet.
2. Improving laboratory methods for the detection of PPCPs in marine matrices

- Lower laboratory detection limits are needed to better understand PPCP inputs to the marine environment and potential effects.
3. Increasing knowledge of PPCP toxicity
- Additional studies are required to better understand the long-term chronic effects of PPCP exposure in marine biota and humans, including food chain effects and the effects of long-term environmental exposures to PPCP mixtures and transformation products.

4. PROPOSED OBJECTIVES FOR PHARMACEUTICALS & PERSONAL CARE PRODUCTS IN BURRARD INLET

4.1 Proposed Objectives

Table 5. Proposed objectives for PPCP levels in Burrard Inlet

All sub-basins	Short Term	Long Term
Water	No increase from current levels	Decrease from current levels
Sediment		
Tissue		

4.2 Rationale

There is currently insufficient toxicological information to establish quantitative water quality objectives for the PPCPs outlined in this report. Until marine-relevant toxicity data are available, management priorities should be source control and monitoring, with the goal of reducing concentrations of PPCPs in water, sediment, and biota over time.

5. MONITORING RECOMMENDATIONS

Sampling for PPCPs in Burrard Inlet has been limited to date. The following recommendations are provided to help guide future monitoring programs, and to inform the future development of water quality objectives for Burrard Inlet:

1. Monitor potential sources of PPCPs for Burrard Inlet (listed as highest priority to lowest):
 - Evaluate the presence and concentrations of PPCPs in sludge and biosolids and how this affects the marine environment when applied to soils.
 - Continue sampling for PPCPs in Burrard Inlet to inform on spatial and temporal trends. A combination of sampling sites near point sources and at background locations will be essential to better understand the sources of PPCPs to Burrard Inlet.
 - Currently, the Lions Gate WWTP is being upgraded from primary to secondary treatment, which will be completed by the end of 2020. Monitoring of the WWTP effluent should be conducted to measure any changes in PPCP concentrations as a result of this upgrade.
 - Ocean Wise is currently analyzing for up to 90 PPCPs in *PollutionTracker* Phase 2 sediment and tissue samples in Burrard Inlet (see Appendix A for list of PPCPs being analyzed). Once Phase 2 is complete, the results can be used to inform a priority list of PPCPs to monitor in Burrard Inlet.

2. Monitor potential PPCP accumulation in the food chain:
 - Evaluate PPCPs in the local marine food web to better understand their potential for biomagnification and impacts on marine top predators
 - *PollutionTracker* is currently conducting further sampling on sediment and mussels within Burrard Inlet as part of the Phase 2 sampling program. Data on PPCPs will become available as the program continues.
 - Analyze for PPCPs and relevant metabolites in water.
3. Monitor potential adverse effects on the marine environment:
 - Increase our understanding of potential adverse effects on marine biota by conducting long-term toxicity assessments using environmentally-relevant concentrations.
 - Based on toxicity test results, conduct human health and ecological risk assessments for PPCPs.

6. MANAGEMENT OPTIONS

The following are recommendations to reduce the flow of PPCPs into Burrard Inlet:

1. Promote public education initiatives
 - Public health and health care practitioners can provide education regarding the environmental hazards of pharmaceuticals.
 - There are several drug return initiatives that exist throughout Canada. In British Columbia, the B.C. Medication Return Program (BCMRP) (BC Pharmacy, 2019) allows the public to return any unused or expired medications to participating pharmacies free of charge. A Vancouver city bylaw currently bans the disposal of medications in the garbage; however, only 49% of British Columbian's surveyed are aware of this program (Green Care Community 2019).
2. Limit or ban the use of triclocarban and other potentially harmful PPCPs in consumer products (e.g., soaps and deodorants).
 - There is currently no ban on triclocarban in Canada. Triclosan, a similar antimicrobial, has had a voluntary deregistration in effect since 2014, under the *Pest Controls Products Act* (Environment and Climate Change Canada, 2016).

The following are initiatives that are already in progress:

1. Complete the separation of CSOs within the City of Vancouver and the City of Burnaby
 - This will eliminate combined sanitary and stormwater discharges to Burrard Inlet, and will decrease the amount of PPCPs reaching marine species and habitats. In Metro Vancouver, combined sewers are still present, but separation is in progress. Metro Vancouver's strategy is to work with Burnaby and Vancouver to eliminate CSOs by 2050. CSO separation is a provincial goal, with each municipality working under the same target of 2050 in the Vancouver Sewage Area (Metro Vancouver, 2017).
2. Strengthen pre-treatment requirements for hospital waste discharge

- Metro Vancouver has a Hospital Pollution Prevention bylaw that came into effect in October 2018. This bylaw requires Metro Vancouver hospitals to develop a pollution prevention plan by 2020, to eliminate or reduce pollutants at the source (Metro Vancouver, 2019).
3. Develop and implement Integrated Stormwater Management Plans (ISMPs) for all developed watersheds that flow into Burrard Inlet
 - The ISMP will address erosion, drainage, flooding, stream health and remediation of any potential water quality issues within watersheds.
 - Under the federal *Fisheries Act*, Metro Vancouver and its member municipalities (Vancouver, West and North Vancouver, Burnaby, Richmond, New Westminster, Surrey, White Rock, Delta, Coquitlam, Port Coquitlam, Langley, Maple Ridge, Port Moody, etc.) are not allowed to discharge storm or rain water that would negatively impact fish and their habitat. Metro Vancouver facilitates the Stormwater Interagency Liaison Group (SILG), which shares information on the development and implementation of each municipality's storm water management (Metro Vancouver, 2017).

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**APPENDIX A: POLLUTIONTRACKER PHASE 2 LIST OF PPCPS CURRENTLY BEING ANALYZED FOR
IN SEDIMENT AND TISSUE**

Analyte
<i>List 1</i>
Acetaminophen
Azithromycin
Caffeine
Carbadox
Carbamazepine
Cefotaxime
Ciprofloxacin
Clarithromycin
Clinafloxacin
Cloxacillin
Dehydronifedipine
Digoxigenin
Digoxin
Diltiazem
1,7-Dimethylxanthine
Diphenhydramine
Enrofloxacin
Erythromycin-H2O
Flumequine
Fluoxetine
Lincomycin
Lomefloxacin
Miconazole
Norfloxacin
Norgestimate
Ofloxacin
Ormetoprim
Oxacillin
Oxolinic acid
Penicillin G
Penicillin V
Roxithromycin
Sarafloxacin
Sulfachloropyridazine
Sulfadiazine
Sulfadimethoxine
Sulfamerazine
Sulfamethazine
Sulfamethizole
Sulfamethoxazole
Sulfanilamide
Sulfathiazole
Thiabendazole
Trimethoprim

Tylosin
Virginiamycin
<i>List 3</i>
Bisphenol A
Furosemide
Gemfibrozil
Glipizide
Glyburide
Hydrochlorothiazide
2-hydroxy-ibuprofen
Ibuprofen
Naproxen
Triclocarban
Triclosan
Warfarin
<i>List 5</i>
Alprazolam
Amitriptyline
Amlodipine
Benzoylcegonine
Benzotropine
Betamethasone
Cocaine
DEET
Desmethyldiltiazem
Diazepam
Fluocinonide
Fluticasone propionate
Hydrocortisone
10-hydroxy-amitriptyline
Meprobamate
Methylprednisolone
Metoprolol
Norfluoxetine
Norverapamil
Paroxetine
Prednisolone
Prednisone
Promethazine
Propoxyphene
Propranolol
Sertraline
Simvastatin
Theophylline
Trenbolone
Trenbolone acetate
Valsartan
Verapamil

APPENDIX B - SAMPLING LOCATION COORDINATES

Table B1. 2011 Lions Gate WWTP Sampling Events and Sampling Locations for PPCPs (Enkon, 2012)

Event	Date	Site	Northing	Easting
Ebb	Nov 28 th	W-100A	5462715	489811
	Nov 28 th	W-100B	5462707	489801
	Nov 28 th	W-100C	5462696	489794
	Nov 28 th	W-100D	5462689	489785

Table B2. 2011 Lions Gate Sediment Sampling Site Locations for PPCP (Golder, 2013)

Station No.	Date	Northing	Easting
1	March 2011	5464913	483392
45	March 2011	5466265	479793
46b	March 2011	5464200	484542

Table B3. Sampled sites from PollutionTracker Phase 1 (Ocean Wise, 2018)

Pollution Tracker Phase 1 - Burrard Inlet Sites (PPCPs)							
Site ID	Website Site ID	Medium	Analyzed for PPCPs?	PPCPs detected?	Notes	Sediment Coordinates	
						Lat	Long
IA1	Indian Arm 1	sediment	Y	N		49.462767	-122.885567
IA1	Indian Arm 1	mussels	Y	N			
IA2	Indian Arm 2	sediment	Y	N		49.323417	-122.910611
IA2	Indian Arm 2	mussels	Y	N			
PMV1	Burrard Inlet 1	sediment	Y	Y		49.2955	-122.885
PMV1	Burrard Inlet 1	mussels	N	N			
PMV2	Burrard Inlet 2	sediment	N	N	mussels not sampled	49.292983	-122.9373
PMV3	Burrard Inlet 3	sediment	Y	N		49.306867	-122.983933
PMV3	Burrard Inlet 3	mussels	N	N			
PMV4	Burrard Inlet 4	sediment	N	N		49.30175	-123.053167
PMV4	Burrard Inlet 4	mussels	N	N			
PMV5	Burrard Inlet 5	sediment	N	N		49.293033	-123.120583
PMV5	Burrard Inlet 5	mussels	N	N			
PMV6	Burrard Inlet 6	sediment	Y	N		49.292483	-123.175267
PMV6	Burrard Inlet 6	mussels	N	N			
PMV7	Burrard Inlet 7	sediment	N	N	mussels not sampled	49.287317	-123.152017

SOA4	Burrard Inlet 8	sediment	Y	Y		49.335881	-123.202851
MSL3	Burrard Inlet 8	mussels	Y	N			
MSL2	Burrard Inlet 9	mussels	Y	N	sediment not sampled	49.340459	-123.212850
SOA5	Burrard Inlet 10	sediment	Y	Y		49.281346	-123.190995
MSL4	Burrard Inlet 10	mussels	Y	N			
SOA6	Burrard Inlet 11	sediment	Y	N	mussels not sampled	49.30393	-123.062383
SOA7	Burrard Inlet 12	sediment	Y	Y	mussels not sampled	49.309446	-123.08696
SOA8	Burrard Inlet 13	sediment	Y	Y	mussels not sampled	49.288169	-123.10227
SOA9	Burrard Inlet 14	sediment	Y	Y	mussels not sampled	49.290634	-123.064566
MSL5	Burrard Inlet 15	mussels	Y	N	sediment not sampled	49.279828	-123.242507
17 locations total in Burrard Inlet for Phase 1 (2015-2017) 13 sites total were analyzed for PPCPs in Phase 1 6 sites had detected PPCPs in sediment (never detected in mussels)							

Table B4. Sampled sites from Krogh et al (2017).

Latitude (N)	Longitude (W)	Station Name
48°25'12	123°24.35	MAC
48°24'33	123°20.96	CLO
48°24.16	123°24.52	M0
48°24.16	123°24.44	M100E
48°24.16	123°24.99	M200E
48°24.16	123°20.76	M800E
48°23.66	123°20.59	C0
48°21.26	123°30.65	C200E
48°20.69	123°18.99	PB
48°27.44	123°13.60	CB
48°22.62	123°26.99	FC2
48°23.20	123°22.28	AH1
48°25.40	123°22.91	AH3
48°25.79	123°22.28	VH1

Table B5. Samples sites from Meador et al (2016)

Sample Dates	Puyallup estuary	Sinclair Inlet	Nisqually Estuary	Voight's Creek Hatchery
Water:	47°16'35.4N 122°24'58W	47°32'24.4N 122°39'44.3W	47°05'56.4N 122°42'01.8W	47°04'58.8N 122°10'40.8W

Table B6. Sampled sites from Klosterhause et al (2017)

Site	Bay Segment	Latitude/ Longitude
Richmond	Central Bay	37° 58.903' / -122° 21.898'
San Leandro Bay	Central Bay	37° 44.594' / -122° 12.460'
Eden Landing	South Bay	37° 35.697' / -122° 08.788'
Foster City	South Bay	37° 33.864' / -122° 14.983'
Cooley Landing	Lower South Bay	37° 28.582' / -122° 07.435'