# Water Quality Assessment and Proposed Objectives for Burrard Inlet: Microplastics Technical Report

November 2019

Tsleil-Waututh Nation
səlilwətaɬ

BRITISH COLUMBIA

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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**Cover Photograph:**
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 discusses microplastic (MP) pollution in Burrard Inlet and the data required to establish marine water quality objectives. Background information, a literature review of toxicity studies, and an overview of current knowledge about MP levels in sediment, water, and marine biota within and around Burrard Inlet are provided.

The use of plastics in consumer products has led to an increase in plastic waste that can break down into smaller fragments, known as microplastics (MPs). MPs are particles smaller than 5 mm and are made of organic polymers derived from petroleum products, including polyvinylchloride (PVC), low density polyethylene (LDPE), nylon, polystyrene (PS), polyethylene (PE), and polypropylene (PP). There are two categories of MPs: primary and secondary.

Due to the small size of MP particles, they can be ingested by various marine organisms and potentially cause both physical and chemical adverse effects. There are three suggested mechanisms by which MPs can present significant risks to marine biota:

Physical interactions: entanglement and ingestion of plastics

Indirect toxicity through release of toxic additives or bound chemicals

As a vector for pathogenetic microorganisms and parasites

Sources of MP pollution into Burrard Inlet include personal care products, marine coatings, plastic pellets, vehicle tires, road markings, and plastic shoreline waste. These sources are summarized in the sections below. The main transport pathways between these MP sources and the marine environment are discussed further in Section 2.

A few studies have investigated MPs in marine samples from British Columbia to date. In the north-eastern Pacific Ocean and along the British Columbia coast, MPs in subsurface seawater were quantified according to their size and shape. MPs were four to 27 times more abundant at nearshore sites, consistent with proximity to land-based human activities; sizes ranged between 62-5000 µm, and the majority of MP particles identified were fibres/filaments and angular plastic fragments (Desforges et al., 2015). At the Annacis Island WWTP near Vancouver, the majority of MPs being discharged to the marine environment were observed to be fibres (Gies et al., 2018).

Higher concentrations of MPs in sediments were associated with urban development, with fibres and fragments being the most dominant types of MPs found (Ocean Wise, 2018). In Burrard Inlet mussels, fibres and fragments were also observed to be the most common MP types (Ocean Wise, 2018). In studies by Boucher et al. (2016) and Munier and Bendell (2018), MPs in Burrard Inlet were also found to act as sorption sites for lead, cadmium, copper and zinc.

Water quality benchmarks for the protection of marine life are not available for MPs, and there is currently insufficient toxicological information to establish quantitative water quality objectives for the MPs outlined in this report. Until marine-related toxicity data are available, MP management strategies should focus on source control and monitoring, with the goal of reducing concentrations of MPs in water, sediment, and biota over time.

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## ACRONYMS

| | |
|---|---|
| B.C. | British Columbia |
| CSO | Combined sewer overflow |
| ENV | Ministry of Environment and Climate Change Strategy |
| HDPE | High density polyethylene |
| IDZ | Initial dilution zone |
| ISMP | Integrated Storm water Management Plan |
| LDPE | Low density polyethylene |
| MP | Microplastics |
| PE | Polyethylene |
| PET | Polyethylene terephthalate |
| PP | Polypropylene |
| PS | Polystyrene |
| PVC | Polyvinylchloride |
| SBR | Styrene butadiene rubber |
| UV | Ultraviolet |
| WWTP | Wastewater treatment plant |

## 1. INTRODUCTION

This chapter presents proposed water quality objectives for microplastics in Burrard Inlet. It includes relevant background information, an overview assessment of current status and trends in microplastics levels in Burrard Inlet, comparison to benchmarks, and a rationale for the proposed objectives. Recommendations for future monitoring as well as management options to help achieve these objectives are also included.

Plastics have been in use since 1907. The development of inexpensive manufacturing techniques in the 1940s resulted in mass production of a wide variety of lightweight, durable, inert, and corrosion-resistant plastics (PlasticsEurope, 2010). Mass production of plastics has continued to increase globally, and while plastics are a valuable commodity, they have sparked major environmental concerns due to their durability and resistance to degradation in the environment. The use of plastics in consumer products has led to an increase in plastic waste that can break down into smaller fragments, known as microplastics (MPs) (Cole et al., 2011). MPs are plastic particles smaller than 5 mm and are made of organic polymers derived from petroleum products, including polyvinylchloride (PVC), low density polyethylene (LDPE), nylon (polyamide (PA)), polystyrene (PS), polyethylene (PE), and polypropylene (PP) (Anderson et al., 2016). The most common plastic polymers include PP, PE, and LDPE (Imhof et al., 2013; Hidalgo-Rus et al., 2012). Biodegradable plastics may also contribute to MPs from often incomplete decomposition, leaving behind various synthetic polymers that were composites of starches, vegetable oils or specialist chemicals (designed to accelerate decomposition) (Cole et al., 2011).

There are two categories of MPs:

Primary MPs originate from various sources, including consumer products (e.g., microbeads in cosmetics) and virgin resin pellets (nurdles) used in plastic manufacturing (GESAMP, 2016).

Secondary MPs are derived from the breakdown of larger plastic debris, at sea or on land (Cole et al., 2011). When these plastic pieces are exposed to physical, biological, or chemical processes, their structural integrity breaks down and results in fragmentation (Cole et al., 2011).

Due to their small size, MPs can be ingested by various marine organisms, potentially causing adverse physical and/or chemical effects.

This chapter presents current information on MPs in Burrard Inlet. It includes relevant background information, a literature review of toxicity studies, an overview of current information about MP levels in water, sediment and biota in and around Burrard Inlet, and a rationale for an approach to develop water quality objectives. Recommendations for future monitoring as well as management options to help reduce MP levels in Burrard Inlet are also provided.

# 2. BACKGROUND

## 2.1 Values and Potential Effects

There are three suggested mechanisms by which MPs can present significant risks to marine biota:

1. Physical effects: entanglement and ingestion of plastics
2. Indirect toxicity through release of toxic additives or bound chemicals
3. As a vector for pathogenetic microorganisms and parasites

### *2.1.1 Physical Effects of Microplastics*

MPs are similar in size to sediment and some planktonic organisms, which makes them particularly bioavailable to many marine organisms. Once an organism interacts with MPs, several adverse physical effects can occur. These include internal and/or external abrasion, blockages of the digestive tract, entanglement, starvation, and physical deterioration. Physical effects can also reduce reproductive fitness, reduce predator avoidance, and cause drowning and feeding impairment (Barboza et al., 2018; Wright et al., 2013). Lower trophic level organisms are especially susceptible to MP ingestion, since many of them are indiscriminate feeders and will mistake MP particles for food fragments (Cole et al., 2011). Cole et al. (2013) showed that a range of zooplankton from the north east Atlantic, ingest MPs ranging between 1.4-30.6 µm in diameter, with the capacity for uptake varying between species, life stage, and MP size. Desforges et al. (2015) also reported ingestion of particles in zooplankton collected off the coast of British Columbia (BC): 1 MP particle for every 34 copepods, and 1 MP particle for every 17 euphausiids (krill). MPs were also found to accumulate on dead zooplankton (Cole et al., 2013).

To some degree, MPs are also able to accumulate through the food chain, with low concentrations of MP particles being detected in various marine mammal species (Nelms et al., 2018). In the Desforges et al. (2015) study, juvenile salmon in the Strait of Georgia were estimated to ingest 2-7 MP particles/day, with returning adult salmon potentially ingesting ≤ 91 particles/day. Estimates were also made for marine mammals that feed heavily on zooplankton. A humpback whale (*Megaptera novaengliae*) in coastal BC, consuming 1.5% of its body weight in krill and zooplankton daily, would ingest > 300,000 MP particles/day (excluding the amount of plastics that are taken up directly from the water) (Desforges et al., 2015).

Available chronic effects data for marine species exposed to MPs and the endpoints of potential effects are summarized in **Table 1**.

*Table 1. Chronic effects of MPs on selected marine species (Everaert et al., 2018)*

| **Phylum** | **Species** | **Most Sensitive Endpoint** | **Type of Plastic (μm)**[1] | **NOEC (particles/ml)** | **Reference** |
|---|---|---|---|---|---|
| Ochrophyta | *Skeletonema costatum* | Growth | PVC 1 | $3.4 \times 10^6$ | Zhang et al 2017 |
| Mollusca | *Mytilus edulis* | Metabolic rate | PS 10-90 | 110 | Van Cauwenberghe et al 2015 |
| | *Crossostrea gigas* | Reproduction | PS 2-6 | 96.8 | Sussarellu et al 2016 |
| | *Ostrea edulis* | Abundance and biomass | HDPE 0.48-316 | 0.075 | Green 2016 |
| | *Perna viridis* | Filtration and respiration rates | PVC 1-50 | $6 \times 10^5$ | Rist et al 2016 |
| | *Brachionus koreanus* | Reproduction and life span | PS 0.05-6 | $7.3 \times 10^8$ | Jeong et al 2016 |
| | *Scrobicularia plana* | Antioxidant capacity and DNA damage | PS 20 | 2 | Ribeiro et al 2017 |
| | *Pinctada margartifera* | Energy balance and gametogenesis | PS 6-10 | 0.16 | Gardon et al 2018 |
| Arthropoda | *Tigriopus japonicus* | Mortality | PS 0.05-6 | $2.1 \times 10^5$ | Lee et al 2013 |
| | *Centropges typicus* | Ingestion rate | PS 0.4-30.6 | 2,000 | Cole et al 2013 |
| | *Calanus helgolandicus* | Feeding | PS 20 | 37.5 | Cole et al 2015 |
| | *Parvocalanus crassirostris* | Reproduction | PET 5-10 | 5,000 | Heinder et al 2017 |
| Echinodermata | *Tripneustes gratilla* | Growth | PE 10-45 | 100 | Kaposi et al 2014 |
| | *Paracentrotus lividus* | Fertility | PS | 500 | Martinez-Gomez et al 2017 |

### *2.1.2 Indirect Toxicity of Microplastics*

MPs can also act as vectors for chemical contaminants, either by binding to pollutants in the surrounding water and transferring them to biota, or by releasing toxic additives from the plastic itself (Cole et al., 2011 and Sussarellu et al., 2016).

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[1] Plastics used are polystyrene (PS), polyethylene terephthalate (PET), high density polyethylene (HDPE), polyvinyl chloride (PVC), and polyethylene (PE)

### *Release of chemical additives*

MPs can contain a wide variety of additives, such as heat stabilizers, UV stabilizers, plasticizers, processing aids, impact and thermal modifiers, fillers, flame retardants, biocides and smoke suppressors (Munier and Bendell, 2018). In the marine environment, this cocktail of contaminants can become bioavailable, penetrating cells and chemically interacting with biologically important molecules. Adverse effects may include changes in behaviour, liver toxicity, and endocrine disruption (Bergmann et al., 2015).

Lithner et al. (2009) evaluated the effects of leachate (hydrophobic organics and cationic metals) from PVC, polyurethane, and epoxy products and observed that these compounds were acutely toxic to *Daphnia magna* at concentrations between 2 to 235 g of plastic per litre of water (48h EC50[2]). Another study looked at 500 plastic products exposed to UV radiation, microwave radiation and heat in saline conditions. This study found that most of the plastics leached chemicals, such as bisphenol A, 1,4-cyclohexanedimethanol, styrene, dimethyl terephthalate, 1,4-bis(4-chlorophenyl) sulfone, and 1,4-dihydroxybenzene, and had estrogenic activity in cell proliferation assays (Yang et al., 2011). PVC materials, such as piping, can also contain phthalate plasticizers to improve performance, which can be mechanically broken down in the environment into increasingly smaller pieces. By doing so, the chemical toxicity of the tubing becomes of greater concern as smaller particles can be ingested by marine organisms and thus expose them to phthalate plasticizers (Anderson et al., 2016). Many factors such as the concentration gradient, matrix, physical and chemical properties of the MPs, and degradation processes acting on the MP particles will determine the amount of exchange between additives in the MP particle and that of the surrounding water (Anderson et al., 2016).

### *Adsorption of organic contaminants*

In addition to the chemical additives present in MP particles, MPs can also adsorb organic pollutants from the marine environment. Some of these organic pollutants can include persistent organic pollutants (POPs) that are adsorbed from marine waters, which can be re-released when taken up by marine organisms, causing adverse effects. The dose of organic contaminants delivered through a MP particle will be dependent not only on the volume of MPs ingested by marine organisms, but also on the amount of time the MP resides within the organisms and the transfer rate between the MP-associated pollutant and the organisms' tissues (Andrady et al., 2011). However, information on the bioavailability of sorbed POPs to organisms subsequent to ingestion of tainted MPs is lacking.

### *Adsorption of metals*

Metals can associate with plastics in the environment, where they can potentially accumulate at concentrations equivalent to or greater than those of the surrounding marine water and sediment (Anderson et al., 2016). Boucher et al. (2016) found that microbeads, the dominant type of MPs recovered in intertidal sediment from Burrard Inlet, acted as sorption sites for lead (Pb) and cadmium (Cd). Similarly, Munier and Bendell (2018) concluded that plastic polymers are the site of sorption for copper (Cu) and Pb, and are an inherent source of zinc (Zn) and Cd in Burrard Inlet intertidal sediment. **Table 2** shows the results for extracted metals recovered from five field samples.

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[2] Concentration at which 50% of the test population showed effects after 48 hours of exposure.

*Table 2. Metal concentrations recovered from 5 field samples (refer to Figure 4 for general sample areas) from intertidal regions of Burrard Inlet (Munier and Bendell, 2018)*

| Metal | Sample Number | Polymer | Mg metal/g polymer |
|---|---|---|---|
| Copper | 116 | PVC | 12.18 |
| Copper | 47 | PVC | 0.188 |
| Copper | 134 | LDPE | 0.16 |
| Zinc | 47 | PVC | 66.9 |
| Zinc | 123 | PVC | 15.57 |
| Lead | 47 | PVC | 698 |
| Cadmium | 47 | PVC | 0.09 |
| Cadmium | 61 | PS | 0.02 |

MPs in Burrard Inlet can potentially act as a point source of metal pollution to the coastal ecosystem, with all types of plastic recovered (50% made up of PVC and LDPE) able to accumulate similar concentrations of metals. Wang et al. (2017) indicated that concentrations of Cu, Zn, Pb and Cd increased in concentration on MP particles over a 12-month period. The results of this study also concur with a 12-month study on metal accumulation increasing on recently manufactured PET, HDPE, PVC, LDPE and PP MP particles in San Diego Bay, USA (GESAMP, 2016). Values for Zn, Cd and Pb (copper was not measured) concentrations on MPs, were also within the range found by Munier and Bendell (2018). In another study by Brennecke et al. (2016), adsorption of Cu and Zn were examined during a 14-day experiment looking at antifouling paint containing MPs, virgin polystyrene (PS) beads, and aged PVC fragments in seawater. The study indicated that heavy metals were being released from antifouling paint to the marine waters, with both MP types adsorbing Cu and Zn (Brennecke et al., 2016). The study concluded that MPs have a high affinity to adsorb heavy metals.

### 2.1.3 Microplastics as Vectors for Pathogens

All surfaces within the marine environment are rapidly colonized by bacteria which build complex biofilms and act as highly heterogenous environments with diverse and variable taxa (Kirstein et al., 2016). By acting as a substrate, MPs can also become vectors for pathogenic micro-organisms and parasites. In a recent study, DNA sequencing results from biofilms on MPs indicated that a potentially pathogenic *Vibrio parahaemolyticus* bacterium was present on a number of floating MPs (PE, PP and polystyrene) in the North Baltic Sea (Kirstein et al., 2016). In addition, a study by Viršek et al. (2017) identified 28 bacterial species on MP particles in the North Adriatic Sea, which included the pathogenic fish bacterium *Aeromona salmonicida,* which causes septicemia, haemorrhages, muscle lesions, and inflammation of the intestine in salmon (Viršek et al., 2017).

### 2.1.4 Human Exposure

The effects of MPs on human health are largely unknown at this time. However, there are some studies that suggest possible pathways by which MPs can exert harmful effects in humans (Wright and Kelly, 2017). Once MPs are consumed, they pass into the gut where they are able to release associated toxins and plastic additives, exerting oxidative stress or carcinogenic reactions (Wright and Kelly, 2017). MPs can also be taken up in the gut via cellular or paracellular uptake, which varies according to the size and properties of the MP particle. Smaller MP particles that are a few microns in size can be taken up directly by cells, while larger particles can be taken up by specialized cells in the ileum (Cox et al., 2019; Wright and Kelly, 2017).

Research into MP exposure in humans via the consumption of seafood is still in its infancy; however, the transfer of MPs from fish and shellfish to humans is possible. Dietary MP exposure via consumption of fish (muscle tissue) is possible if MPs can translocate across the gastro-intestinal tract or gill surface of fish, via transcellular uptake or paracellular diffusion, and enter the circulatory fluid (Wright and Kelly, 2017). Given the structure of the respiratory epithelium of the gill, uptake across the fish gut is the most likely pathway (Wright and Kelly, 2017). Consumption of whole fish, such as herring and anchovies, increases the potential for human exposure to MPs, as the intestinal tracts of these fish retain most of the MPs. MPs have been found in small freshwater species such as the gudgeon *Gobio gobio* (Sanchez et al., 2014) and in small marine pelagic species such as silversides (*Stolephorus commersonnii*) (Kripa et al., 2014), anchovies (*Stolephorus heterolobus)* (GESAMP, 2016), Pacific anchovy (*Engraulis japonicus*) (GESAMP, 2016; Tanaka and Takada, 2016), and European anchovy (*Engraulis encrasicolus*) (Collard et al., 2017). Shellfish may also constitute an important source of MP exposure in humans, as the entire organism is typically consumed (Davidson and Dudas, 2016). Van Cauwenberghe et al. (2015) reported an average concentration of MPs in mussels of 0.36 particles/g wet weight.

Since MPs can adsorb chemicals from the surrounding environment, there is also the potential for chemical toxicity associated with incidental MP consumption (Smith et al., 2018).

## 2.2 Potential Sources of Microplastics Pollution

Burrard Inlet is surrounded by dense urban and industrial development, with multiple sources of both primary and secondary MPs. Studies in Europe have identified numerous MP sources in urban environments, such as personal care products (microbeads), marine coatings, vehicle tires, road markings, and city dust (Lassen et al., 2015; Magnuson et al., 2016; Sundt et al., 2014; Essel et al., 2015). These sources are equally applicable to the Metro Vancouver region, and are summarized in the sections below. The main transport pathways between these MP sources and the marine environment are discussed further in Section 2.3.

### *2.2.1 Primary Microplastics*

Microbeads and nurdles are considered the main types of primary MPs, and are discussed in the following sections. Primary MPs mainly enter the marine environment via waste water treatment plants, though some input occurs through spills during transport.

#### *Microbeads*

Microbeads are used in cosmetics and other personal care products as sorbents, exfoliants, cleaners, and thickening agents. Although Canada banned the use and sale of personal care products containing microbeads in 2018 (Microbeads in Toiletries Regulations, effective January 1, 2018), Boucher et al. (2016) indicated that the MP particles recovered from sediment samples from Cates Park (Burrard Inlet) and Horseshoe Bay contained approximately 75% microbeads. Li et al. (2017) determined through Fourier transform-infrared spectrometry analysis (FTIR), that PE accounts for 93% of the total amount of MPs used in personal care products in Beijing, China, where PE is added directly to products and cosmetics to strengthen their cleansing and exfoliating properties. These MPs are also added to toothpastes, soaps, shampoos, deodorants, and sunblock sticks (Lei et al., 2017). It is estimated that in Norway and Switzerland, the daily use of personal care products containing MPs is about 2.4 mg of MPs/person/day, which is equal to an average of 212 g/yr/capita (Boucher and Friot, 2017). Currently, the use and sale of microbeads in consumer products is permitted in Norway and Switzerland.

#### *Nurdles*

Nurdles are another type of primary MP found in the marine environment. Nurdles are pre-production plastic pellets typically 2-5 mm in diameter and are used to make nearly all plastic products. Through transport and mishandling, many end up in the marine where they can travel long distances. Nurdles have been identified in marine systems worldwide (Cole et al., 2011). Nurdles can also breakdown further into smaller fragments, as well as attract and concentrate pollutants in the water. They can be ingested by organisms, which mistake them for prey items. Nurdles may be a source of MPs in Burrard Inlet if spilled during their transport, recycling, or processing.

### *2.2.2 Secondary Microplastics*

Secondary MPs result from the breakdown of larger plastic items and enter the marine environment via several different pathways, including: direct input to the marine environment, input through wind or wave action, dust deposition, and/or waste water releases. The main types of secondary plastics are listed in the following sections.

#### *Marine Coatings*

Marine coatings that are applied to parts of marine vessels during pre-treatment, coating applications, and equipment cleaning may result in the release of MPs to surface waters. These include solid coatings and anticorrosive or antifouling paints that can contain several types of plastics, such as polyurethane, epoxy, vinyl, and lacquers (Boucher and Friot, 2017).

#### *Plastic Shoreline Waste*

Plastics items[3] can be either directly discarded into Burrard Inlet, or washed into the waters via overland flow, or through rivers and streams. Once in the ocean, if the plastic items remain in the water column or sink to the bottom, they will not typically undergo significant weathering, due to the lack of photedegradation processes (Andrady et al., 2011). However, plastic items that are discarded on beaches are exposed to high levels of photodegradation, which can break down the plastic to create MP particles that are then transported into marine waters via wind or wave action.

#### *Vehicle Tires and Crumb Rubber*

Wear and tear of tires on road surfaces can contribute to the flow of MPs into Burrard Inlet, from tires eroding over time, and emitting particles from the outer part of the tire. The MP components are styrene butadiene rubber (SBR) mixed with additives and natural rubber (Nelms et al., 2018). This erosion of the tire creates dust that can either be transported to Burrard Inlet via wind, or washed off the road by rain events into nearby storm drains, streams and/or rivers that contribute to MPs in the marine environment (Boucher and Friot, 2017). Global estimated per capita emissions range from 0.23 to 4.7 kg/year, with a global average of 0.81 kg/year (Boucher and Friot, 2017). Kole et al (2017) estimated the relative contribution of tire wear to the global amount of MPs ending up in our oceans at 5-10%.

Another tire-related source of MPs is from recycled tires that are ground up and used as infill in artificial turf grass (Kole et al., 2017). As an example, for a football field in Denmark, 100-120 tonnes of rubber infill was used, and an additional 3-5 tonnes of infill was required each year for maintenance (Kole et al., 2017). Lassen et al. (2015), estimated that 1.5 - 2.5 tonnes of infill were lost from such turf fields per year from 254 artificial football fields, ending up in waterways, soils, and on people's clothes (Kole et al., 2017). Ground up tire particles are also used for playgrounds, rubber mats, and running lanes around the Lower Mainland. In the Lower Mainland, almost 100% of the scrap tires generated are collected and recycled in Delta, B.C., where the majority are processed into crumb rubber, granules of rubber with the steel and fibre removed, and also into coloured mulch (Government of British Columbia, 2019). This crumb is used to create a variety of products including playground safety surfacing; athletic tracks;

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[3] Discarded plastics can include a variety of items, such as plastic bottles, straws, bottle caps, fishing gear, straws, rope, six pack rings, plastic utensils, food containers, floats and bait boxes.

synthetic turf fields; and mats for agricultural and industrial use (Government of British Columbia, 2019). Artificial turf fields have an infill that is often made of this crumb rubber, and sand for shock attenuation and ballast (Vancouver Board of Parks and Recreation, 2016). The cities surrounding Burrard Inlet, such as Vancouver, Burnaby, Coquitlam, North and West Vancouver all use some synthetic turf fields (Vancouver Board of Parks and Recreation, 2016; City of Burnaby, 2018; City of Coquitlam, 2013; North Vancouver District, 2017; District of West Vancouver, 2012). Over time, crumb rubber surfaces release particles that can break down into MPs and be transported into Burrard Inlet via wind, storm drains and through rivers and/or streams (Lassen et al., 2015 and Hüffer et al., 2018). In addition, recycled tire materials have complex compositions that are known to leach toxic substances, such as PAHs and zinc into the receiving environment (Hüffer et al., 2018). **Figure 1** shows released crumb rubber particles from a synthetic track and playground surface in the Lower Mainland.

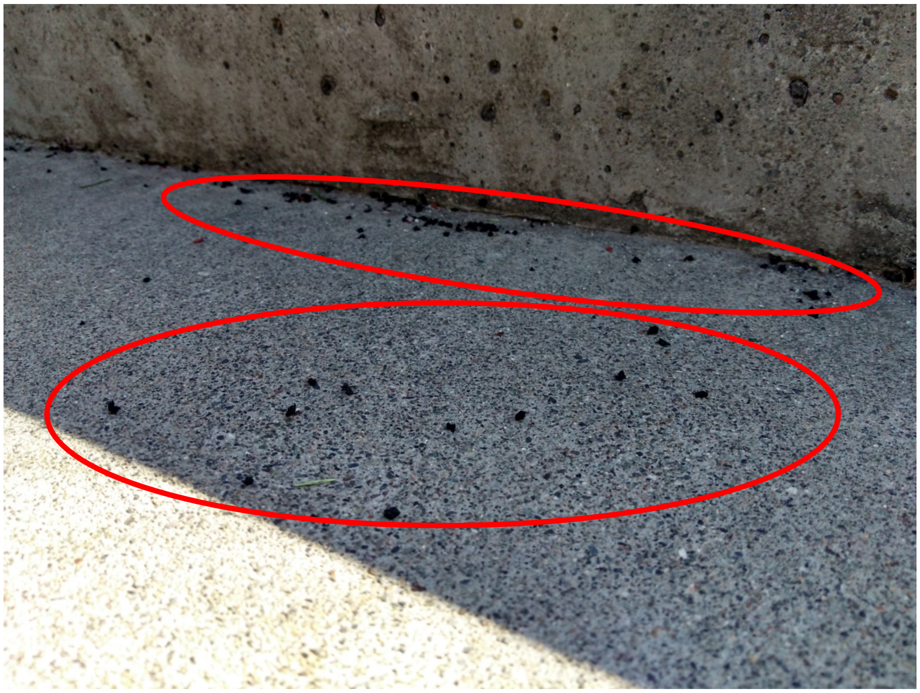

*Figure 1. Crumb rubber particles released from synthetic turf fields and playground surfaces (indicated within the circled areas).*

### Road Markings

Road markings, which are made up of paint, thermoplastics, preformed polymer tape, and epoxy, are another potential source of MPs to marine environments (Boucher and Friot, 2017). The loss of MPs from such paints occurs through weathering or abrasion from vehicle tires and salt applied to roads in the winter (Boucher and Friot, 2017; Kole et al., 2017). The paint particles that are released from road markings can be transported to Burrard Inlet by wind, by rivers/streams, or storm drains.

### Textile Microfibres

Washing synthetic textiles creates MPs through the shedding and abrasion of fibres in clothing. The microfibres from washing machine wastewater are transported to the Lions Gate WWTP, some of which may pass through the WWTP filters and into Burrard Inlet. In a study done by Gies et al. (2018) at the Annacis Island treatment plant, influent, primary and secondary effluent wastewater samples were shown to be dominated by fibres (65.6%), which are defined as particles that are fibrous in shape, with no clear definition or diameter.

## 2.3 Transport of Microplastics

MPs can be transported from the source into Burrard Inlet through various pathways, including wind (atmospheric deposition), waste water treatment plants, storm drains and combined sewer overflows, and rivers and streams.

### *2.3.1 Atmospheric Deposition*

Burrard Inlet is surrounded by highly populated urban areas, which can generate a significant amount of dust from various sources, such as abrasion of infrastructure from wind and rain, clothing and textile wear, disposal and breakdown of larger plastics, and from sandblasting activities (forcibly propelling a stream of abrasive material against a surface under high pressure) (Boucher and Friot, 2017). In a study of MPs in Dogguan City, China, MPs from city dust contained various polymers made of PE, PP, and PS. They were mostly comprised of fibres, foams, fragments and film, with fibres being the most dominant shape detected (Cai et al., 2017). The study suggested that MPs generated from cities can be transported via the atmosphere and deposited directly to land or aquatic surfaces (Cai et al., 2017).

### *2.3.2 Waste Water Treatment Plants*

One of the main potential sources of secondary MP contamination in Burrard Inlet is the Lions Gate WWTP, located near the Lions Gate Bridge, east of the Capilano River. The WWTP receives residential and commercial wastewater from North Vancouver, and as an example of volume, 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). It discharges primary treated effluent into the turbulent First Narrows area of Burrard Inlet through an outfall and diffuser located just west of the Lions Gate Bridge in West Vancouver. The outfall is about 184 m offshore, and the average diffuser depth is approximately 20 metres (Metro Vancouver, 2017). The effluent is dispersed throughout inner and outer Burrard Inlet before entering the Strait of Georgia (Metro Vancouver, 2017). In a study done by Gies et al. (2018) at the Annacis Island treatment plant, influent, primary and secondary effluent wastewater samples were shown to be dominated by fibres (65.6%), followed by fragments (28.1%) and pellets (5.4%).

Currently, the Lions Gate WWTP is using a primary treatment system, where wastewater is passed through several tanks and filters that separate the water from solids and organic matter, producing a sludge. The resulting sewage sludge is often used by Metro Vancouver to create a fertilizer called Nutrifor$^{TM}$. This fertilizer is applied in parks, forests, hayfields and rangelands to provide nutrients and organic matter for soils in landscaping (Metro Vancouver, 2019), where it can potentially reach the marine environment via surface water or groundwater runoff.

Upgrades to secondary treatment are underway at the Lions Gate WWTP, with completion scheduled for December 2020. For such secondary WWTPs, the estimated retention capacity for MPs ranges between 97.1 and 99.1% (Gies et al., 2018). However, despite this high reduction ability, many conventional WWTPs may still actually be a significant source of MPs given the large volumes of effluents that are discharged. For the Annacis Island WWTP, such daily discharge rates are between 32 and 97 million MPs into the receiving environment (Gies et al., 2018 and Talvitie et al., 2017).

### *2.3.3 Storm Drains, Combined Sewer Overflows, and Rivers/Streams*

Storm water drains and overflow of sanitary sewers can also contribute MPs to Burrard Inlet. Combined sewer overflows (CSOs) occur during wet weather events 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).

Storm water drains provide a pathway for secondary MPs on roadways and parks (e.g., from vehicle tires, road markings, and crumb rubber used on playing fields and playgrounds). Rivers and streams that flow into the inlet, including the Capilano and Seymour Rivers and other streams within urban areas, also receive storm water runoff, which transport MPs into the inlet.

### 2.4 Factors Influencing Microplastics Levels in Burrard Inlet

Plastics from either land or marine sources undergo several physical, chemical, and biological processes which determine their ultimate form and distribution in the marine environment. MPs may deposit directly onto beaches, drift or settle, where they reach beaches, tidal wetlands, and in marine sediments (Zhang et al., 2017). The distribution of MPs in Burrard Inlet is influenced by the location and nature of the source, as well as these complex physical, chemical, and biological processes. Since MPs have varying polymers, composition, density, and shape, they will either be buoyant, neutrally buoyant, or sink in the water column (Law et al., 2014). The attachment of fouling agents onto MPs can also change their buoyancy and cause them to sink (Andrady, 2011). In addition, research indicates that sheltered marine environments, such as Burrard Inlet, provide low energy environments where particle deposition is more favourable, resulting in an accumulation of easily transported, low density MPs (Mathalon and Hill, 2014). The opposite has been observed in exposed rocky shorelines, where high energy environments are likely to suspend and flush MPs from the area. Boucher et al. (2016) demonstrated that higher concentrations of MPs were present in Cates Park, a protected portion of Burrard Inlet (5,560 per kg of wet sediment), compared to Horseshoe Bay, a more exposed area outside of Burrard Inlet (3,120 particles/kg wet sediment) (Boucher et al., 2016).

### 2.5 1990 Provisional Water Quality Objectives for Microplastics

MPs have only been investigated in the marine environment since the early 2000s (Wagner et al., 2014). Since MP research is fairly new and the consequences of MPs in the marine environment are only starting to be investigated, water quality objectives have not yet been developed for MPs in Burrard Inlet.

## 3. WATER QUALITY ASSESSMENT

### 3.1 Benchmarks Used in this Assessment

There is currently no water quality benchmark for MPs in the marine environment.

### 3.2 Data Sources

Data from recent sampling efforts that tested for MPs in the marine environment were compiled for this assessment and are presented in **Table 3**.

*Table 3. MP monitoring and research in and around Burrard Inlet*

| Source | Study/Monitoring Program | Year(s) Sampled | No. of Samples | No. of Sites | Sampling Location and Frequncy | Parameters Sampled |
|---|---|---|---|---|---|---|
| Desforges et al (2014) | Widespread distribution of MP in subsurface seawater in the NE Pacific Ocean | 2012 | 34 water samples; Seawater collected at 4.5m below surface | 34 | August 2012 and September 2012<br>Coastal to 1200km offshore in the NE Pacific Ocean, and samples off coastal Vancouver Island. | Composition and distribution of MP in seawater |
| Boucher et al 2016 | The influence of cosmetic microbeads on the sorptive behaviour of cadmium and lead in intertidal sediments: A laboratory study | 2015 | 8 intertidal sediment | 2 | April and July 2015. Sampled in Horseshoe bay and Cates Park (Burrard Inlet) | Concentration of MPs and influence of microbeads on lead and cadmium sorption. |
| Ocean Wise (2018) | MP contamination in mussels (*Mytilus sp.*) and marine sediments along the coast of BC | 2015-2017 | 51 sediment samples; 33 mussel samples along the BC coast, including Burrard Inlet. | 55 | Phase 1 of *PollutionTracker,* 2015 to 2017 | MP in mussels and sediment |
| Geis et al (2018) | Retention of MPs in a major secondary waste water treatment plant in Vancouver, Canada | 2016 | Processing stream of major WWTP | 6 | September 16, 29th and October 28th, 2016. | MPs collected from WWTP in Vancouver. Influent, primary effluent, secondary effluent and primary and secondary sludge. |
| Dimitrijevic (2018) | Application of the Blue Mussel (*Mytilus edulis*) as an indicator of MP pollution within the Salish Sea | 2017 | 171 mussels sampled | 11 | Sampling on day 0, 30 and 60 from first deployment in Strait of Georgia and southern BC waters. | Quantification of the accumulation of MPs in mussels. |
| Munier and Bendell (2018) | Macro and micro plastics sorb and desorb metals and act as point source of trace metals to coastal ecosystems | 2018 | 150 beach samples collected | 9 | No sampling dates available.<br>Beaches sampled within Burrard Inlet. | Characterized specific polymer and analyzed for metals – zinc, copper, cadmium and lead. |

## 3.3 Status and Trends

### *3.3.1 Seawater*

In the Desforges et al. (2014) study, abundance, composition and distribution of MPs in the subsurface seawaters of the northeastern Pacific Ocean and coastal BC were documented (**Figure 2**). The study quantified MPs according to their size and shape in subsurface seawater, and found that MPs were four to 27 times more abundant at nearshore sites, consistent with proximity to land-based human activities (Desforges et al., 2014). Locally, the inland waters of the Queen Charlotte Islands and the Strait of Georgia had higher MP levels than the west coast of Vancouver Island (Desforges et al., 2014). Microplastic sizes ranged between 62-5000 µm and were detected in all sampled areas[4]. The majority of the identified MP particles were fibres/filaments and angular plastic fragments which accounted for approximately three quarters of the MPs found (Desforges et al., 2014).

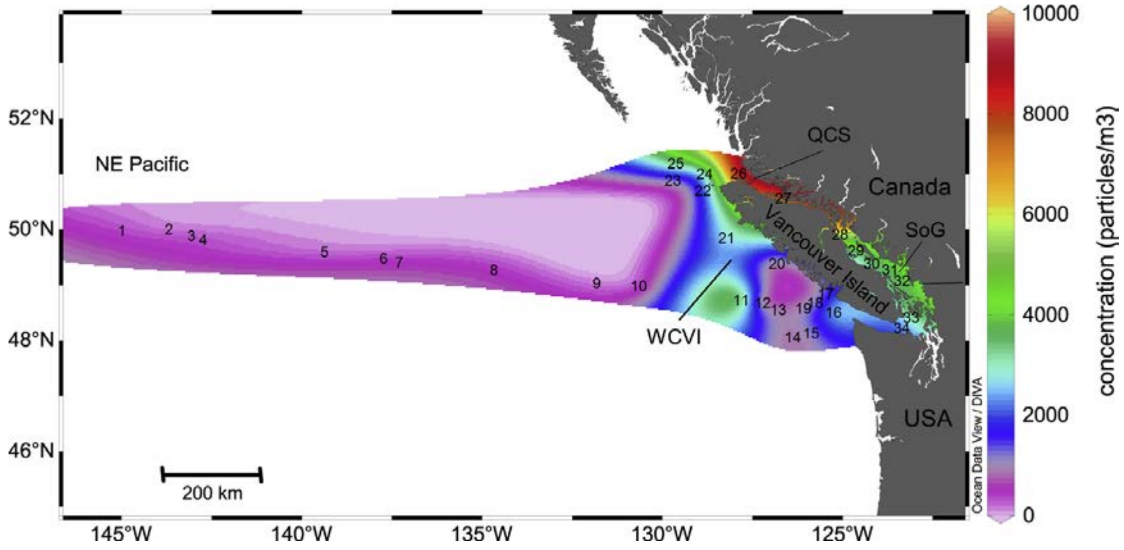

*Figure 2. Sampled locations (1-34) and concentration gradient of MP concentrations (particles/m3); detected particles >62 µm) in subsurface waters (4.5 m) of NE Pacific Ocean (Desforges et al., 2014)*

### *3.3.2 Sediment*

As part of Ocean Wise Conservation Association's (Ocean Wise) Phase 1 *PollutionTracker* program, nearshore subtidal sediment was collected from 51 sites along the BC coast between 2015 and 2017, with nine of these samples located within Burrard Inlet (**Figure 3**). MP analysis was conducted at these Burrard Inlet locations. Preliminary results suggest that the highest concentrations were found in urban areas, with fibres and fragments being dominant (Neuport, April 2018). However, differences across locations within Burrard Inlet were not discussed, since the study only described MP differences between urban and remote areas.

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[4] Samples were run through a series of copper sieves of pore sizes: 250 µm, 125 µm, and 62.5 µm (Desforges et al., 2014)

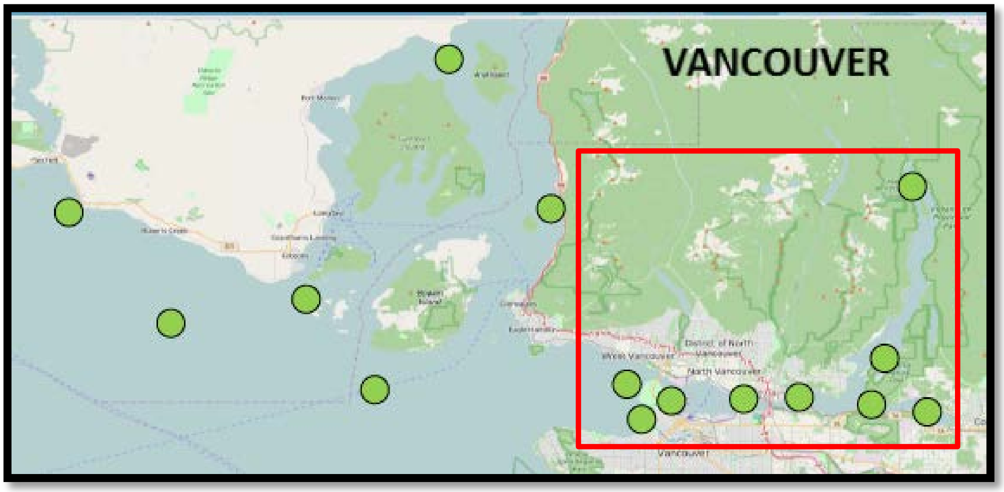

*Figure 3. PollutionTracker sediment sample sites, showing the 9 sites in Burrard Inlet (outlined in red)*

In the Munier and Bendell (2018) study, nine urban intertidal regions were sampled from the outer, inner, and central harbours of Burrard Inlet for plastic debris (large plastics and MPs) (**Figure 4**). In total, 26 km of beach was surveyed within Burrard Inlet, and 150 samples collected. This study indicated a wide variety of MPs, as well as macro plastics, with PVC and LDPE comprising 46% of all samples; however differences across locations where not discussed, since the study focused largely on the association of metals to MPs. The macroplastics collected ranged from toys, bicycle parts, personal hygiene items and food packaging, with about 50% of all collected samples being PVC and LDPE-based, as seen in **Figure 5** (Munier and Bendell, 2018).

Landsat: http://landsat.visibleearth.nasa.gov/

Map of Burrard Inlet (Wikimedia Commons 2011).

*Figure 4. Location of 9 urban intertidal regions sampled within Burrard Inlet (Munier and Bendell, 2018)*

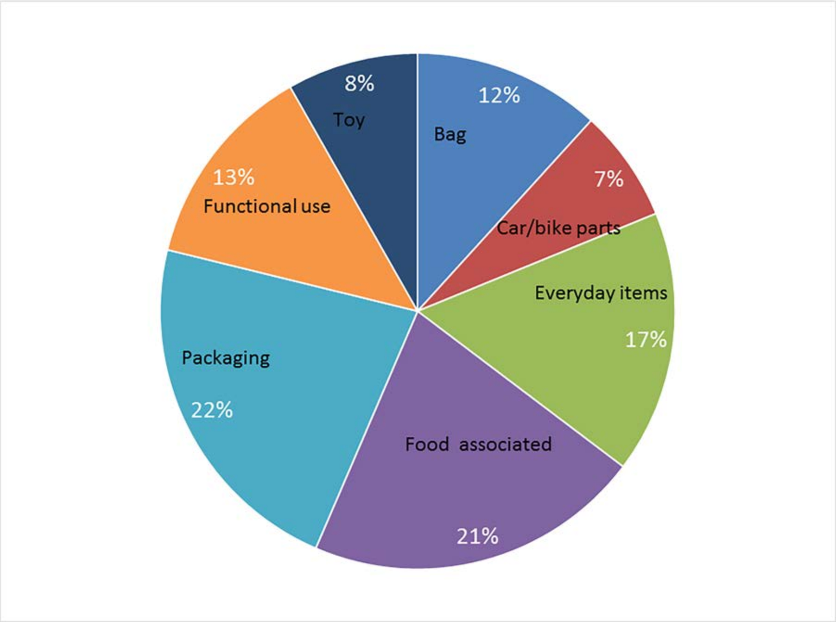

*Figure 5. Classification of collected macroplastics found in Burrard Inlet, based on original use (Munier and Bendell, 2018)*

### 3.3.3 Marine Biota

Dimitrijevic (2018) evaluated MP accumulation in caged blue mussels on the west coast of BC (**Figure 6**). Blue mussels were placed in cages at 11 locations within the Strait of Georgia, Howe Sound, and Burrard Inlet. They were sampled at day 0, 30 and 60 and analyzed for MPs. Similar to previous studies (Catarino et al., 2017; Li et al., 2016), an average of 0.43 suspected MPs per mussel were found ranging between 25 µm and 5 mm in size, with 91% being microfibres. Results did not indicate MPs accumulated in blue mussels over the 60-day study period. However, based on a study done by Browne et al. (2008), MPs that are less than 1µm, can translocate to tissues and accumulate in soft body tissues of blue mussels. Research also indicates that MP particles within the size range of 1 µm to 24.9 µm increase in abundance, and are small enough to translocate to tissues and partition into lipid membranes (Browne et al., 2008). There was no significant difference when comparing sites for all time periods for suspected MPs per individual mussel and per mg of wet weight (GWW), except for the Campbell River site, which had significantly more suspected MPs. This difference was mainly attributed to this site's proximity to shellfish farming facilities and sewage outfalls (Dimitrijevic, 2018).

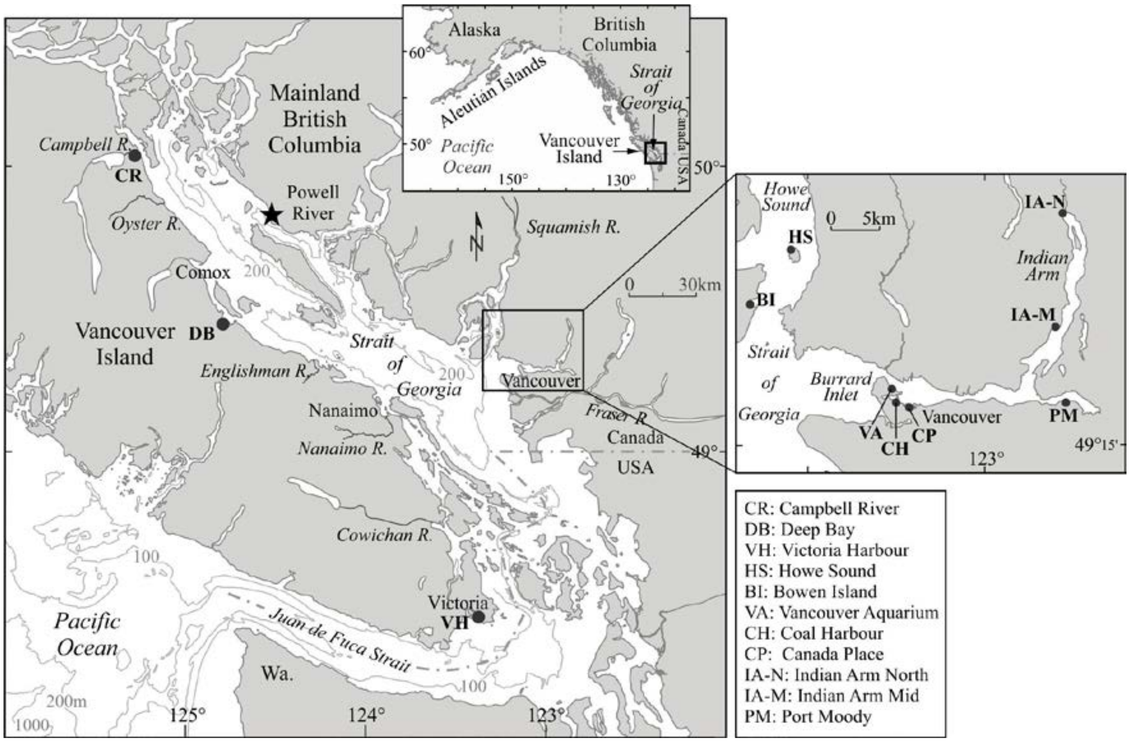

*Figure 6. Mussels were received from a shellfish farm (indicated by a star) and deployed at 11 locations at 1m depth (Dimitrijevic, 2018)*

As part of the *PollutionTracker* program, 33 blue mussel samples were collected from the coast of BC. Mussels were collected within 2 km of sediment sample sites and analyzed for the presence and type of MPs. Preliminary results indicate that fibres and fragments are the most common type of MPs in wild mussels (Ocean Wise, 2018).

### 3.3.4 Wastewater

A pilot study was conducted at the Annacis Island WWTP, the largest WWTP in the Metro Vancouver region that provides secondary treatment to the wastewater generated by 1 million residents (Gies et al., 2018). This WWTP treats approximately 180,044 ML/year of municipal wastewater and storm water from combined sewers. Influent, primary effluent, secondary effluent, and primary and secondary sludge samples were collected in the fall of 2016 (Geis et al., 2018). The results of this study indicated that primary and secondary effluent samples were dominated by fibres (65.6%), fragments (28.1%), and pellets (5.4%), with the rest being foam, granules and sheets (**Figure 7**). Based on a visual count of MPs, influent wastewater had 31.1 +/- 6.7 suspected MPs/L, which was reduced after primary clarification to 2.6 +/- 1.4 suspected MPs/L (Gies et al., 2018). Subsequent sedimentation and scum removal reduced the remaining suspected fibres and particles by 92.8% and 88.4%, respectively. The majority of MPs being discharged from this secondary WWTP to the marine environment were observed to be fibres, corresponding to Desforges et al. (2014), which reported that 75% of MPs in the Strait of Georgia were fibres.

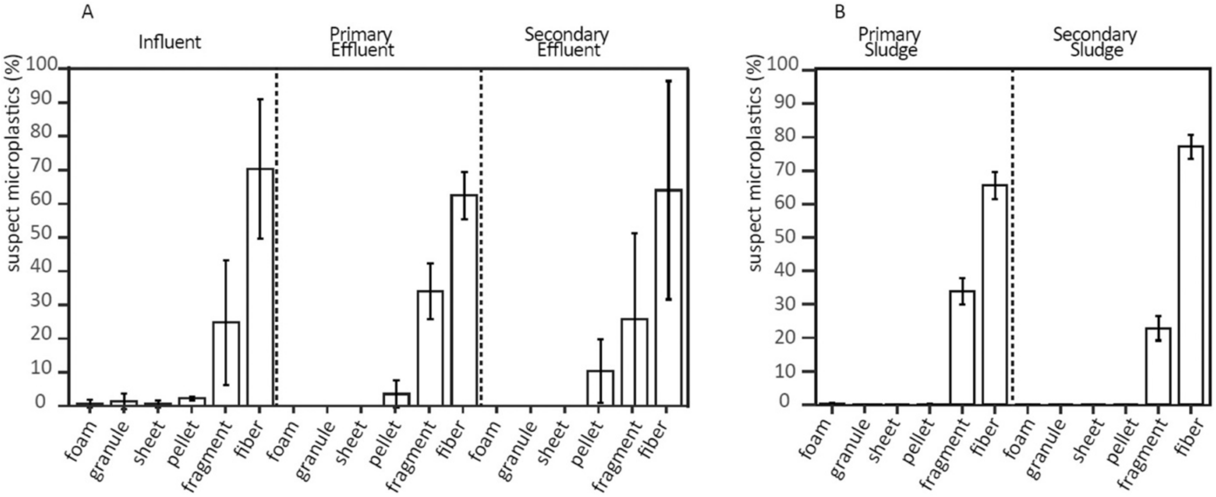

*Figure 7. Suspected MPs from liquid (A) and solid (B) waste water treatment sample matrices categorized into foam, granule, sheet, pellet, fragment and fibre (Gies et al., 2018)*

## 3.4 Knowledge Gaps and Research Needs

The following key research gaps have been identified:

1. Monitoring of MPs in Burrard Inlet:

- Monitoring of MPs in sediment, water, and biota is recommended for Burrard Inlet, with year-round sampling to account for potential seasonal variability in MP abundance associated with variations in WWTP discharges and plastic use. Currently, *PollutionTracker* is sampling sediment, mussels, and water for MP analysis during the winter months, every three years.
- Monitoring the amount of rubber crumb from synthetic tracks, fields and playgrounds that is potentially contributing MPs to Burrard Inlet.

2. Improving laboratory methods for the detection of MPs in marine matrices:

- Fourier transform infrared spectroscopy (FTIR), Raman spectroscopy, pyrolysis or thermal decomposition gas chromatography coupled with mass spectrometry are currently the main technologies for MP identification (Mai et al., 2018). Standardization of analytical protocols for MP analysis is required, and detection technologies identifying nano-sized particles still need to be developed (Mai et al., 2018).

3. Increasing knowledge of microplastic toxicity:

- Additional studies are required to better understand the long-term effects of MP exposure in marine biota and humans, including food chain effects and the effects of MP additives and plastic-bound chemicals.

## 4. PROPOSED OBJECTIVES FOR MICROPLASTICS IN BURRARD INLET

### 4.1 Proposed Objectives

*Table 4: Proposed Water Quality Objectives for Microplastics*

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

### 4.2 Rationale

MPs have environmental impacts as particulate pollutants and as transporters of toxic pollutants. There is currently insufficient toxicological information to establish quantitative water quality objectives for MPs. Until marine-relevant toxicity data are available, management priorities should include source control and monitoring, with the goal of reducing the amount of MPs in water, sediment, and biota over time. To inform the development of a Burrard Inlet water quality objective for MPs, the following questions need to be addressed:

1. What are the specific source(s) of MP pollution into Burrard Inlet?
2. How much MP pollution is currently in Burrard Inlet?
3. What are the risks associated with MP pollution to marine biota and human health in Burrard Inlet?
    - What is the ingestion rate by marine biota and subsequent human consumption rate of MPs?
    - Is there transfer of MPs between trophic levels?
    - What are the effects of toxic pollutants associated with MPs?

## 5. MONITORING RECOMMENDATIONS

Sampling for MPs 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 for potential MP sources to Burrard Inlet:
    - Conduct MP sampling in rivers and streams that flow into Burrard Inlet.
    - Evaluate the presence and concentration of MPs in sludge and biosolids and how this affects the marine environment when applied to soils.

- Sample Burrard Inlet for MPs 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 MPs to Burrard Inlet.
- Currently, the Lions Gate WWTP is being upgraded from primary to secondary treatment (completion by 2020). Monitoring of the WWTP effluent should be conducted to measure any changes in MP concentrations as a result of this upgrade.
- Determine the rates of plastic degradation for different types of MPs in sediment and on beaches, as well as the degradation rates of MPs into nanoplastics.
- Create a particle count balance for MPs in Burrard Inlet, to identify the main types of MP particles.

2. Monitor potential MP accumulation and transfer in the food chain:
   - Evaluate the local marine food web to better understand the potential for MPs to concentrate and transfer from prey to predator. *PollutionTracker* is currently conducting sampling of sediment and mussels within Burrard Inlet as part of the Phase 2 program. More data on MPs will become available as the program continues.
   - Analyze for MPs in the water column in Burrard Inlet.

3. Monitor potential adverse effects of MPs on the marine environment:
   - Conduct long-term toxicity experiments to look at the effects of MP additives and adsorption and desorption of pollutants, using environmentally relevant concentrations of MPs.
   - Monitor the potential physical effects of MPs, such as stress, starvation, entanglement, and smothering of sea beds.
   - Based on toxicity test results, conduct human health and ecological risk assessments for MPs. These should include examining the potential impact of cooking and/or processing seafood at high temperatures on the toxicity of MPs (Lusher et al., 2017).

## 6. MANAGEMENT OPTIONS

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

1. Complete the separation of CSOs within the City of Vancouver and the City of Burnaby:
   - This will eliminate combined sanitary and storm water discharges to Burrard Inlet, and will decrease the amount of MPs 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. Develop and implement Integrated Storm water Management Plans (ISMPs) for all developed watersheds that flow into Burrard Inlet:
   - ISMPs 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).

3. Promote public education initiatives:
    - Create a cost for plastic polluters and make plastic products more valuable to encourage reuse, repair and recycling (GESAMP, 2016).
    - Increase awareness campaigns and engage more stakeholders in reducing plastic use.
    - Invest in improved and new waste management infrastructure to deal with plastic wastes (GESAMP, 2016).
    - Create public awareness and education on ways to reduce MP pollution from washing textiles in residential laundry machines.
    - Reduce the use of recycled tires for rubber crumb in artificial turf, tracks and playground surfaces around the Lower Mainland, and determine other environmentally friendly options to recycle tires. The municipalities of North Vancouver, Burnaby, Coquitlam, Port Moody, West Vancouver, and Vancouver all plan to install additional artificial fields (North Vancouver District, 2017; City of Burnaby, 2018; City of Coquitlam, 2013; City of Port Moody, 2015; District of West Vancouver, 2012). In Vancouver, the use of artificial turf fields is planned to increase between 2019 and 2022 (per. comm. Tiina Mack, Vancouver Board of Parks and Recreation, April 5th, 2019).
    - Increase organized beach clean-ups. The removal of larger pieces of plastic debris from beaches can reduce MP inputs to Burrard Inlet.

4. Limit or ban the use of microbeads and single-use plastics in consumer products:
    - Currently there is no ban on single use plastics in Canada. However, the city of Vancouver has recently voted to ban the distribution of plastic straws as well as foam take–out containers and cups as part of its Zero-Waste 2040 Strategy (City of Vancouver, 2018).

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