Evaluating and Reducing Microplastics in Metro Vancouver Wastewater Treatment Plants

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Disclaimer Statement

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This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Metro Vancouver or the University of British Columbia.

Executive Summary

Introduction

The objectives of this project are to assess the sources of microplastics in wastewater in Metro Vancouver, and to determine the potential fate of microplastics following the land application of biosolids. Microplastics are an emerging contaminant of environmental concern, which are not currently regulated at the federal, provincial, or regional level. Biosolids are recovered from wastewater treatment and are high in organic matter and nutrients. Metro Vancouver beneficially uses biosolids as a soil amendment, fertilizer and ingredient in landscaping soils.

The first part of this study is a review of the existing literature, to determine the fate of microplastics after the land application of biosolids, as well as the environmental effects to terrestrial ecosystems when microplastics are introduced to soils. The literature review also identified commercial, industrial, and domestic sources of microplastics to the wastewater stream. Concentrations of microplastics in wastewater treatment plant (WWTP) influent, effluent, and sludge products have been reported in the literature, and the available data is included in this report.

The second part of this study aims to develop a database of businesses that are potential emitters of microplastics to the wastewater stream in Metro Vancouver. The database was generated by performing a business directory search using codes from the North American Industry Classification System (NAICS). The codes used in the search were chosen based on the results of the literature review, described above, which identified potential commercial and industrial sources of microplastics.

Research Approach

The literature review was conducted between May and July 2020. Some references were found and supplied by Metro Vancouver staff. Further references were found by conducting searches in the Web of Science database, using combinations of keywords including “microplastics,” “microfibres,” “biosolids,” “wastewater,” and “environmental effects.” The results from the literature review are summarized in two Excel documents, “Literature review A” and “Literature review B,” and in the current report. Published journal articles were accessed through the UBC Libraries “EZproxy” system.

The database of potential emitters was generated using the results from a business directory search, conducted by Suzanne McBeath, Metro Vancouver corporate librarian, on June 18th, 2020. The business directory search was done using NAICS codes identified as corresponding to potential commercial or industrial sources of microplastics. The list of NAICS codes used in the search is given in this report. The business directory search resulted in a list of 1,810 businesses. This list was refined by performing a Google search for each business to determine whether their business activity aligned with their reported NAICS code. Businesses were removed if they were not engaged in business activity likely to result in emission of microplastics. The refined list includes 1,252 businesses. Each business in the final database was assigned a weight in three categories. The categories represent the likely impact to the environment from microplastics emissions, and whether Metro Vancouver has an existing relationship with that business. The total weight assigned to a business represents priority for intervention from Metro Vancouver.

Summary

The literature review concludes that biosolids may be a significant source of microplastics to agricultural soils. Further, it finds that microplastics will accumulate in soils and persist for long periods of time. Microplastics affect the physical properties of soils, and also impact the organisms living in those soils. The literature review shows that WWTPs are very efficient in removing microplastics from the liquid waste stream and transfer the microplastics to the solid stream. A limited number of studies have examined the industrial and domestic sources of microplastics to WWTPs or to the environment. The existing studies have identified tire wear, laundering of textiles, and fabrication and transportation of plastic pellets as some important emission sources of microplastics.

The final database includes 1,252 businesses. The final weight assigned to each business represents the priority for intervention from Metro Vancouver. Businesses that emit primarily microfibres (instead of other plastic shapes), businesses with a large number of employees, and businesses with an existing relationship with Metro Vancouver have the highest cumulative weight. The majority of businesses that received a high weight score are involved in laundering textiles. This suggests that businesses involved in laundering of textiles may be a priority area for intervention by Metro Vancouver.

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Introduction

This document is primarily composed of two major sections. Section 1 is a literature review and Section 2 is a database of businesses. Both are described briefly here.

The literature review aims to summarize the available literature on the topic of microplastics which is relevant to the Residuals Management Program within the Liquid Waste Services Department of Metro Vancouver. Studies in multiple jurisdictions have shown that microplastics enter Wastewater Treatment Plants (WWTPs) via the wastewater stream in large numbers. Inside WWTPs, a large majority of the microplastics are retained in the solid stream, referred to as sludge, or after treatment, biosolids. Microplastics that are not retained in the solid fraction are released to the environment in the WWTP effluent. To understand the potential environmental effects as well at the effects on WWTPs themselves, the amount of microplastics entering WWTPs via the influent, exiting WWTPs via the effluent, and being retained in biosolids should be quantified. Metro Vancouver applies biosolids to land as a fertilizer, soil amendment or as an ingredient in landscaping soil. The potential environmental effects of the microplastics contained in the land-applied biosolids must be considered.

The literature review is separated into two parts. In Section 1.1 the motivation for the current project will be outlined, by summarizing the fate and subsequent environmental impacts of land-applied biosolids to agricultural soils. In Section 1.2, reported concentrations of microplastics in WWTP influent, effluent, and biosolids from jurisdictions across North America, Europe, and Asia will be summarized. The effects that different WWTP technologies have on microplastics concentrations and properties will be discussed. Potential sources of microplastics to the wastewater stream will also be identified. Finally, some of the challenges associated with identifying and quantifying microplastics in WWTPs will be discussed.

The database of businesses is presented in the accompanying Excel document “Microplastics Dischargers Database” and is described in Section 2 of this document. The database was generated to identify priority businesses for intervention from Metro Vancouver. The database was generated by performing a business directory search using NAICS codes. NAICS codes represent the type of activity in which a business participates and allow us to determine whether a business is likely to emit microplastics.

Some background information regarding microplastics is necessary to understand this document. There is no formal definition of microplastics, though in the literature microplastics most often refers to pieces of plastic smaller than 5 mm in each dimension, and plastics in this size range will be the focus of this review. Microplastics can be classified as either primary or secondary. Primary microplastics are intentionally manufactured with a size of 5 mm or smaller. Secondary microplastics are formed by fragmentation or wear of large plastics and can be produced either while a plastic product is in use, or in the environment after a large plastic has been discarded. Plastics can be made from a variety of polymers, all of which have slightly different properties, making them useful for different applications. Here, we do not often refer to the specific polymer type of a microplastic, and the environmental effects of microplastics as a function of polymer type have not been extensively studied in the literature. We will, however, distinguish between different morphologies of microplastics. Microplastic fibres, also referred to as microfibres, are emitted to WWTPs from different sources and have different environmental effects as compared to other microplastic shapes, such as beads or fragments.

1 Literature Review

1.1 Fate and environmental impacts of microplastics in land-applied biosolids

In Metro Vancouver, the presence of microplastics in biosolids may have important environmental and ecological considerations when biosolids are applied as a soil amendment or fertilizer to soils. Though the amount of microplastics applied to agricultural soils through the application of biosolids has not been measured on a national or global scale, it has been estimated that there is a total yearly input of 44,000−300,000 tons of microplastics to North American farmland and 63,000−430,000 tons of microplastics to European farmland through the application of biosolids and sludge (Nizzetto et al., 2016). Another study estimated that there is a total yearly input of 2,800-19,000 tons of microplastics to Australian farmland through the application of biosolids (Ng et al., 2018). Another source of microplastics to soils is the breakdown of plastic mulching films used in agriculture to generate secondary microplastics. Evidence for additional sources of plastic is found in Piehl et al. (2018), who detected microplastics in agricultural soils which had never been subjected to microplastic containing fertilizers (e.g. biosolids or sludge) or agricultural plastic applications such as the use of mulching films.

It is important to note that the terms biosolids and sludge cannot be used interchangeably. Biosolids are a product made by treating sludge and must meet certain quality criteria to be labeled "biosolids." However, in the European Union, the term "sludge" is often used to refer to treated products. This literature review includes both studies that have used biosolids, treated sludge, and untreated sludge. Throughout this review, whichever term was used in a specific study will be used when referencing that study.

Following the land application of biosolids or sludge, microplastics may be retained in soils for long periods of time. Following sludge application, microfibres from sludge products were detectable in experimental soil columns 5 years after application, and in soil samples from field application sites up to 15 years after sludge application (Zubris and Richards, 2005). There is also some evidence that microplastics concentrations in soils will increase with successive applications. In a study examining agricultural soils where 1, 2, 3, 4, and 5 applications of sludge had been performed (on average 40 tonnes per hectare dry weight per application), the soils had a median of 1.1, 1.6, 1.7, 2.3, and 3.5 microplastics g^{-1} of dry soil, respectively (Corradini et al., 2019). All of the sludge used in that study came from the same WWTP and was stabilized prior to application by either solar desiccation or centrifugation. The sludge contained a median microplastics concentration of 34 microplastics per gram.

Following the land application of biosolids as fertilizers, microplastics can move through the soil environment. They may move vertically through the soil through agricultural practices such as soil tillage, or through biological activity. For example, earthworms (*Lumbricus terrestris*) have been shown to have a significant positive effect on microplastic transport away from the soil surface, transporting spherical polyethylene microspheres from the soil surface to a depth of 10.5 cm over a 21-day study period. Four sizes of polyethylene spheres were used, with diameters of 710-850 µm, 1180-1400 µm, 1700-200 µm, and 2360-2800 µm. 750 mg of microplastics was added directly to the surface of 2.5 kg of soil. For the different sizes of polyethylene spheres this translated to 2,625, 424, 203, and 75 particles. In a control sample without worms, those same microplastics stayed on the surface of the soil. The authors hypothesize that the transport mechanisms for microplastics in this study include attachment of microplastics to the outside of the worms, movement through the burrows with water, and passage through the gut of earthworms (Rillig et al., 2017). The experiments described in this paragraph did not involve the application of biosolids or sludge to soils. Rather, the microplastics were added directly to the soil. This should be considered when extrapolating results from these studies to soils treated with biosolids.

Once in the soil environment, microplastics are expected to persist over long periods of time, though they are susceptible to some degree of degradation. Photo-oxidative and thermo-oxidative degradation processes rely on oxygen and UV light, and will therefore only occur at or near the soil surface. These degradation processes will result in the embrittlement, cracking and weakening of plastics, and cause chemical changes to the polymer material itself (Ng et al., 2018). Following extensive photo-oxidative and/or thermo-oxidative degradation, biodegradation is important. Soil-dwelling microorganisms can convert microplastics into either CO_2 and H_2O (under aerobic conditions), or CO_2 and CH_4 (under anaerobic conditions). Many properties of the microplastics, including molecular weight, chemical structure, morphology, hydrophobicity, water absorption, and surface roughness will all influence the extent to which a microplastic is susceptible to biodegradation (Ng et al., 2018). Again, these experiments did not involve the application of biosolids or sludge to soils; rather, microplastics were added directly to the soil.

Biosolids and soils have both been found to contain microplastics of many different shapes. Microfibres are one of the most common shapes and may be preferentially retained in soils following the land-application of biosolids. For example, Corradini et al. (2019) determined the quantity of microplastics in both sludge and soil from fields where sludge had been applied between 1-5 times, at a rate of 40 dry tonnes per hectare per application.. They found that 90% of the total microplastics in the sludge were fibres, while 97% of the total microplastics in the soil were fibres. In another study, Crossman et al. (2020) found that the proportion of polyester fibres was higher in soils (41–45%) than in biosolids (8–21%). While these results may indicate that soils preferentially retain microfibres over other shapes of microplastics, an alternative explanation is that there may be additional sources of microfibres to agricultural soils.

With the knowledge that microplastics are added to agricultural soils through sludge or biosolids, and that microplastics may accumulate following successive applications, it is necessary to assess the environmental and ecological risks posed by those microplastics. First, microplastics can affect the physical properties of soil itself. Wan et al. (2019) have shown that plastic films (2, 5, and 10 mm size fragments, added at 0.5% and 1.0% by weight) create channels for water movement through soil, leading to increased water evaporation. de Souza Machado et al. (2018) have shown that four types of polymer (polyacrylic fibres, polyamide beads, polyester fibres, polyethylene high-density fragments) affect soil bulk density when added in concentrations up to 0.40% by weight (fibres) or 2.0% by weight (particles). Further, increasing concentrations of polyester fibres significantly enhanced water holding capacity. Soils contaminated with polyester fibres and polyacrylic fibres show a significant decrease in water stable aggregates. This shows that the effects of microplastics on soil properties cannot be reduced to simply "microplastic" concentrations, as plastics with specific morphologies (e.g. fibres vs. fragments) have different effects (de Souza Machado et al., 2018). Microplastics concentrations in soils, biosolids, and sludge are generally reported in the literature in number concentration (# of microplastics per weight of soil) rather than mass concentrations, so it is difficult to determine whether the weight concentrations used in the two studies above are comparable to a typical agronomic rate. However, Wan et al. (2019) compared the concentrations used in their experiments to results from Fuller and Gautam (2016), who reported microplastics concentrations of between 0.03 and 6.7% by weight in soils taken from industrial areas. Further, these experiments did not involve the application of biosolids or sludge to soils; rather, microplastics were added directly to the soil.

Microplastics concentrations have been measured in sediment cores from two water bodies in Metro Vancouver: Orchid Lake, in the Seymour Watershed, and Boundary Bay (Morra, 2018). Surprisingly, microplastics concentrations were higher at Orchid Lake, which is further removed from industrial and commercial centres. This suggests that aerial transportation and deposition are a potential source of microplastics to the environment in this region. That study also suggested that microplastics concentrations may have been higher in Orchid Lake sediment due to the greater organic carbon content of that sediment. (Maes et al., 2017) have previously reported a correlation between microplastics concentrations and organic carbon content of sediments in aquatic environments. Whether microplastics concentrations correlate with organic carbon content in terrestrial ecosystems has not been studied.

Beyond impacting soil physical properties, microplastics also affect soil-dwelling organisms when they are present in soils. Zhu et al. (2018) found that a soil-dwelling collembolan (*Folsomia candida*), exposed to polyvinyl chloride particles (80-250 µm in diameter) applied directly to the soil surface at a concentration of 1 g of microplastics per kg of soil for 56 days, exhibited a decrease in reproduction by 28.8% compared to a control treatment without microplastic. Huerta Lwanga et al. (2016) exposed earthworms (*Lumbricus terrestris*) to low density polyethylene microplastics (sizes ranging from <50 µm to > 100 µm in diameter) applied directly to the soil surface at concentrations of 0.2, 0.4, 0.5 and 1.2 weight percent in soil. They found that over 60 days, mortality was higher in the 0.4, 0.5, and 1.2% conditions, while growth rate was higher in the control (0%) and 0.2% conditions. Reproduction was not significantly affected (Huerta Lwanga et al., 2016). As a final example, another earthworm species (*Eisenia fetida*) was exposed to polystyrene microspheres (58 µm in diameter) at concentrations from 0.25 - 2 weight percent. Microplastics exposure at lower concentrations (0.25 and 0.5%) had no obvious effect on the weight of worms, while at 1 and 2% concentrations, earthworm weights were reduced by an average of 27.6% and 29.8% compared to the control. Mortality was significantly greater in the 2% exposure condition compared to the control (Cao et al., 2017). As mentioned above, it is difficult to determine whether the weight concentrations used in the studies described here are comparable to a typical agronomic rate. The experiments described in this paragraph did not involve the application of biosolids or sludge to soils. Rather, the microplastics were added directly to the soil. This should be considered when extrapolating results from these studies to soils treated with biosolids.

Another study examined the effects of polyester microfibres on soil organisms (Selonen et al., 2020). Both short (12 µm – 2.9 mm) and long (4 – 24 mm) fibres were added to soils at 5 concentrations ranging from 0.02 – 1.5 weight percent and effects were tested on four types of organisms: enchytraeids (*Enchytraeus crypticus*), springtails (*Folsomia candida*), isopods (*Porcellio scaber*) and oribatid mites (*Oppia nitens*). There was no observable effect on survival or reproduction for either *Folsomia candida* or *Oppia nitens* for any treatment conditions. The survival and reproduction of *Enchytraeus crypticus* were negatively impacted by exposure to long fibers at some concentrations, but a concentration dependence was not observed. For *Porcellio scaber* a non-statistically significant, concentration dependent decrease in feeding activity was observed upon exposure to short fibres. Again, it is difficult to determine whether the weight concentrations used in the studies described here are comparable to typical agronomic rates. These experiments did not involve the application of biosolids or sludge to soils. Rather, the microplastics were added directly to the soil.

When considering the environmental effects of microplastics from land-applied biosolids, it is important to consider whether microplastics can accumulate over trophic levels in the soil environment. To our knowledge only one study has addressed this question, by measuring the concentrations of microplastics in soils, earthworm casts, chicken feces, and chicken organs sampled in home gardens in the southeastern state of Campeche, Mexico (a terrestrial ecosystem) (Huerta Lwanga et al., 2017). In this ecosystem the worms and chickens eat the soil, and the chickens also eat the worms. The number of microplastics per gram of soil, worm casts, and chicken feces was increasing in the order: soil (0.87 #/g) < earthworm casts (14.8 #/g) < chicken feces (129.8 #/g). These results can also be reported as concentration factors, as follows: 12.7 ± 9.5 for earthworm casts/soil, 105 ± 39.2 for chicken feces/soil, and 18.4 ± 22.2 for chicken feces/earthworm casts. The data support biomagnification of plastic through the tropic layers in this terrestrial ecosystem (Huerta Lwanga et al., 2017).

Microplastics are expected to further breakdown in the environment to produce nanoplastics, defined as plastic pieces with dimensions between 1 and 1000 nm. Understanding the concentrations and effects of nanoplastics in soil environments is difficult due to lack of analytical methods capable of quantifying nanoplastics (Awet et al., 2018). The same challenge applies to quantifying nanoplastics in sludge or soil samples. Technological advances capable of quantifying nanoplastics are necessary, as nanoplastics concentrations are expected to increase over time, and are expected to have environmental effects due to their small size and large surface area.

One study has investigated the effects of polystyrene nanoplastics on soil microorganisms and enzyme activity (Awet et al., 2018). Polystyrene nanoplastics with a mean diameter of 32.6 nm were added to soils in concentrations of 10, 100 and 1,000 ng per g dry weight with total experimental times of 28 days. The microbial biomass was measured to be less for the 100 and 1,000 ng per g treatments than for the 10 ng and control (0 ng) treatments at 28 days. Microbial activity was also measured and showed a positive effect (increased activity) at 100 and 1,000 ng per g after 14 days, but a negative effect (decreased activity) at 100 and 1,000 ng per g after 28 days. Measured enzyme activity did not show a consistent trend with increased concentration of nanoplastics, but all conditions (10, 100 and 1,000 ng per g dry weight) showed a decreased enzyme activity as compared with the control after 28 days. These results suggest that further research to understand the potential for negative environmental effects from nanoplastics in soil environments is warranted.

Finally, it must be noted that in addition to the direct effects of microplastics on soil properties and soil-dwelling organisms, the environmental effects of microplastics also include effects due to heavy metals, persistent organic pollutants, and other contaminants that may be associated with microplastics. Microplastics can concentrate organic contaminants because of 1) the hydrophobicity and lipophilicity both microplastics and the organic contaminants and 2) the high surface area-to-volume ratio of microplastics. The polymer material will influence the extent to which organic contaminants adsorb or absorb to microplastics, while the conditions of the surrounding environment also regulate the relationship between microplastics and contaminants. In the context of marine ecosystems there is currently no consensus as to whether microplastics are an important vector for persistent organic pollutants to marine organisms (Hartmann et al., 2017; Rodrigues et al., 2019). Chemical additives to plastics including a group of compounds called phthalates, which are used to modify the physical properties of a plastic, can also have negative environmental effects. These additives are not tightly bound in plastics, and so can leach out of microplastics and end up in the environment. Phthalates have been shown to bioaccumulate in organisms (Oehlmann et al., 2009). A more in-depth review of the relationship between contaminants, chemical additives, and microplastics is beyond the scope of the current project.

1.2 Sources of microplastics to WWTPs and concentrations of microplastics in WWTP influent, effluent, and biosolids

In the context of Metro Vancouver, it is important to understand the sources of microplastics to WWTPs, and their concentrations in wastewater influent, effluent, and biosolids. These concentrations of microplastics have been measured in other jurisdictions as well as in Metro Vancouver, and those data are summarized here. The effects of different treatment types on both microplastics concentrations and microplastics physical properties are also reported here. While this is a growing field of research, the identification and quantification of microplastics in a complex matrix such as biosolids remains challenging, and no standard method for their identification and quantification exists in the literature. Different strategies for analyzing microplastics in complex organic matrices, as well the ongoing challenges regarding microplastics identification and quantification will be briefly covered here.

Because there is currently no standard protocol for the quantification of microplastics in biosolids, it is difficult to compare results from studies from multiple jurisdictions, where different methods of detection and quantification have been used to measure concentrations of microplastics in biosolids (Wang et al., 2018). Each study measuring microplastics concentrations in biosolids has included plastics of slightly different size ranges. Studies which do not account for the smallest microplastics might underestimate the concentrations of microplastics by failing to count small microplastic particles or fibres. Microplastics concentrations in biosolids or sludge have been measured in multiple studies and range from ~10^3 microplastics per kg of solids to ~10^5 microplastics per kg of solids. The results from those studies are summarized in Table 1.

Table 1. Concentration of microplastics detected in biosolids or sludge samples in jurisdictions across North America, Europe, and Asia. Also included are the treatment methods used in each WWTP, and the size range of microplastics that were included in the study.

Sample	**Treatment type**	**Location**	**Size range of MPs**	**Concentration (# of microplastics per kg of sample)**	**Note about concentration**	**Population served**	**Volume wastewater treated per year (m^3)**	**Reference**
Biosolids	Anaerobic digestion	Ireland	250 µm – 4 mm	3,950	Average (mean) of 2 WWTPs	179,000 – 2.36M [b]	Not available	(Mahon et al., 2017)
Biosolids	Thermal drying	Ireland	250 µm – 4 mm	9,027	Average (mean) of 4 WWTPs	6,500 – 2.36M [b]	Not available	(Mahon et al., 2017)
Biosolids	Lime stabilization	Ireland	250 µm – 4 mm	12,038	Average (mean) of 2 WWTPs	31,788-101,000 [b]	Not available	(Mahon et al., 2017)
Biosolids	Secondary plant, not specified	Southern California	20 – 400 µm	1,000	Average of 2 or 3 replicates	Not available	387M	(Carr et al., 2016)
Dried sludge	Conventional activated sludge (activated sludge)	Finland	> 250 µm	23,000	Average (assumed this is a mean)	Not available	3.65M	(Lares et al., 2018)
Dried sludge	Conventional activated sludge (digested sludge)	Finland	> 250 µm	170,900	Average (assumed this is a mean)	Not available	3.65M	(Lares et al., 2018)
Dried sludge	Membrane bioreactor	Finland	> 250 µm	273,000	Average (assumed this is a mean)	Not available	1,000	(Lares et al., 2018)
Primary sludge	Primary treatment, Gravity thickeners	Canada	> 1µm	14,900	Average (mean) of 6 replicates	1.3M	180M	(Gies et al., 2018)
Secondary sludge	Secondary treatment, Dissolved air flotation	Canada	> 1µm	4,400	Average (mean) of 6 replicates	1.3M	180M	(Gies et al., 2018)
Dewatered sludge	Primary and secondary treatment [a]	China (11 provinces)	37 µm – 5 mm	22,700	Average (mean) from 28 WWTPs	51,900 – 7.05M	7.3M – 730M [c]	(Li et al., 2018)
Dewatered sludge	Not specified	Denmark	20 – 500 µm	169M	Average, median of 5 WWTPs	Not available	7,500 – 55,000	(Vollertsen and Hansen, 2017)

[a] Secondary treatment types in this study were anaerobic/aerobic processes, oxidation ditch processes, and other.

[b] Population equivalents.

[c] Represents a treatment capacity per year rather than a volume treated per year.

The level of treatment has an effect on the efficiency of a WWTP for removal of microplastics from the liquid stream (effluent) to the solid stream (sludge or biosolids) (Mahon et al., 2017; Michielssen et al., 2016). For example, Mahon et al. (2017) found when comparing biosolids treated using thermal drying, anaerobic digestion, and lime stabilization (without controlling for differences in influent) the concentration of microplastics in biosolids increased in the following order: anaerobic digestion < thermal drying < lime stabilization. A different study determined the total removal efficiency from the final effluent of different treatments and found that efficiencies decreased in the following order: anaerobic membrane bioreactor > tertiary WWTP > secondary WWTP. There was a 10-fold reduction in the number of fibres released in the final effluent following an anaerobic membrane bioreactor treatment vs. a tertiary treatment (Michielssen et al., 2016).

The efficiency of a WWTP for removing microplastics from the liquid stream might depend on the size of the microplastics. For example, in one study the median size of microplastic particles in the effluent was approximately 20% smaller than in the influent, possibly indicating that large particles preferentially end up in biosolids or sludge (Vollertsen and Hansen, 2017).

There is evidence that some treatments will degrade microplastics, reducing the combined amount of microplastics in the liquid and solid streams. For example, Mahon et al. (2017) have measured concentrations of microplastics in biosolids from a WWTP that treated the same influent with two different processes: a thermal drying treatment or an anaerobic digestion treatment. They were able to compare results from the two methods and found that the biosolids sample collected after the anaerobic digestion treatment had a lower total concentration of microplastics, suggesting anaerobic digestion may reduce the concentration of microplastics in biosolids. This could be due to fragmentation of plastics into pieces that are too small to detect, or chemical breakdown of plastics into small molecules.

Microplastics with different morphologies (e.g. fibres vs. fragments) may have different environmental impacts. It is therefore useful to know the proportion of microplastics with each morphology found in biosolids samples. Mahon et al. (2017) found that on average, 78.5% of microplastics identified in biosolids were fibres. Gies et al. (2018) found that in Metro Vancouver, the percentage of microplastics that are fibres in the influent is 70%, while the percentage of fibres in the effluent following secondary treatment is 60%. This may suggest a preferential retainment of fibres over other plastic shapes in the biosolids during treatment. Those results differ from results from a Danish study, which found that the distribution of the different polymer types was similar in the influent and effluent but was different in the sludge. The authors suggest that these results could indicate that the anaerobic digestion process affects the microplastic, either by breaking it down into particles too small to detect or by biological degradation (Vollertsen and Hansen, 2017).

The results of Mahon et al. (2017) suggest that treatment type may affect the proportion of microplastic fibres relative to other microplastic shapes found in biosolids. That study found the greatest proportion of microplastics fragments to fibres in biosolids treated using lime stabilization (as compared to thermal drying or anaerobic digestion). The lime stabilization biosolids samples also contain a greater number of small microplastics (again compared to thermal drying or anaerobic digestion). This may be due to elevated pH and mechanical mixing during lime stabilization, which could break existing microplastic fragments into multiple, smaller pieces.

In addition to affecting the concentrations of microplastics in effluent and biosolids, the treatment type inside a WWTP can affect the physical properties of microplastics. A polymer fibre from thermal drying treatment showed distinct blistering and fracturing, while a fragment from the same treatment showed wrinkling, melding and some fracturing. The physical appearance of the fragment from the thermal drying treatment was distinct from a polymer sample that had not been treated in a WWTP. In the same study, microplastics from a lime stabilization treatment had a more shredded and flaked appearance (Mahon et al., 2017).

Gies et al. (2018) have summarized the concentrations of microplastics in wastewater influent that have been reported in the literatures. Those data are reproduced in Table 2 here. Included in Table 2 is information on the smallest mesh size used to collect microplastics. Studies using larger mesh sizes may underestimate the number concentration of microplastics in wastewater influent, as they are not accounting for the smallest microplastics. To evaluate WWTP efficiency in removing microplastics from the liquid stream, concentrations of microplastics in the effluent must also be evaluated. This has been done in many studies, the results of which have been summarized by both Gies et al. (2018) and Lares et al. (2018), and those data are reproduced in Table 3 here.

By measuring the concentration of microplastics in both wastewater influent and effluent, researches have determined the microplastics removal efficiency of several WWTPs. In these cases, as in the literature more generally, removal efficiency refers to removal of microplastics from the final effluent. An increased removal efficiency will then lead to a greater number of microplastics in the solid product. A summary of microplastics removal efficiencies taken from the literature are given in Table 4.

Table 2. Number concentration of microplastics in WWTP influent.

Location	**# of microplastics/L in influent**	**Smallest mesh size (μm)**	**Reference**
Metro Vancouver, Canada	31.1 ± 6.70	1	(Gies et al., 2018)
Helsinki, Finland	380-900	20	(Talvitie et al., 2017)
Detroit, USA	133 ± 35.6	20	(Michielssen et al., 2016)
Northfield, USA	367	20	(Michielssen et al., 2016)
Glasgow, Scotland	15.7 ± 5.23	65	(Murphy et al., 2016)
Mikkeli, Finland	57.6 ± 12.4	250	(Lares et al., 2018)
Lysekil, Sweden	15.1 ± 0.89	300	(Magnusson and Norén, 2014)
Los Angeles County, USA	1 [a]	N/A	(Carr et al., 2016)

[a] The authors report this value as an estimate. It is not clear how this number is determined.

Table 3. Number concentration of microplastics in WWTP effluent following treatment.

Location	**# of microplastics/L in effluent**	**Smallest mesh size/lower size limit (µm)**	**Highest level of treatment in WWTP**	**Reference**
Australia	1	N/A	Tertiary	(Browne et al., 2011)
Netherlands	9-91	0.7	7 WWTPs, variable	(Leslie et al., 2017)
Detroit, USA	5.9 [a]	20	WWTPs, Secondary	(Michielssen et al., 2016)
Northfield, USA	2.6 [a]	20	Tertiary	(Michielssen et al., 2016)
Northfield, USA	0.5 [a]	20	Pilot-scale anaerobic membrane bioreactor	(Michielssen et al., 2016)
Germany	0.1-10.05	20	12 WWTPs, mostly secondary and tertiary	(Mintenig et al., 2017)
Helsinki, Finland	13.5 [a]	20	Tertiary	(Talvitie et al., 2015)
Helsinki, Finland	0.005-0.3	20	4 WWTPs, tertiary	(Talvitie et al., 2017)
Australia	0.28	25	Tertiary	(Ziajahromi et al., 2017)
Australia	0.48	25	Secondary	(Ziajahromi et al., 2017)
Australia	1.54	25	Primary	(Ziajahromi et al., 2017)
Los Angeles County, USA	0	45	Tertiary	(Carr et al., 2016)
Metro Vancouver	0.5 ± 0.2	64	Secondary	(Gies et al., 2018)
Glasgow, Scotland	0.25	65	Secondary	(Murphy et al., 2016)
USA	0.02	125	Tertiary	(Dyachenko et al., 2017)
USA	0.05	125	17 WWTPs, variable	(Mason et al., 2016)
San Fransisco Bay area, USA	0.022-0.19	125	Secondary	(Sutton et al., 2016)
Mikkeli, Finland	1.05	250	Secondary	(Lares et al., 2018)
Lysekil, Sweden	0.00825	300	Mechanical, chemical, and biological	(Magnusson and Norén, 2014)

[a] Value includes all textile fibres, which may include natural as well as synthetic fibres.

Table 4. Microplastics removal efficiencies from the liquid stream of several WWTPs reported in the literature.

Location	**Microplastics removal efficiency (from liquid stream) (%)**	**Reference**
Helsinki, Finland	99.9	(Talvitie et al., 2017)
Lysekil, Sweden	99.9	(Magnusson and Norén, 2014)
Los Angeles County, USA	99.9	(Carr et al., 2016)
Northfield, USA	99.4 [a]	(Michielssen et al., 2016)
Glasgow, Scotland	98.4	(Murphy et al., 2016)
Metro Vancouver, Canada	98.3	(Gies et al., 2018)
Mikkeli, Finland	98.3 (99.1 for fibres) (89.8 for other shapes)	(Lares et al., 2018)
Northfield, USA	97.2 [b]	(Michielssen et al., 2016)
Detroit, USA	93.8	(Michielssen et al., 2016)

[a] Pilot-scale anaerobic membrane bioreactor.

[b] Tertiary WWTP.

To control the amount of microplastics entering WWTPs, we must assess both industrial and domestic sources as potential emitters of microplastics to the wastewater stream. The data in the literature in this area are somewhat limited. Attempts to quantify the amount of microplastics emitted from different sources have largely been informed by a marine ecosystem perspective, meaning that such studies have examined all potential emitters of microplastics to ocean waters. From those studies we can identify which emitters may be relevant in the context of the wastewater stream.

One study looking specifically at the concentration of microplastics in WWTP influent streams found greater concentrations of microplastics in WWTPs in East China than in West China, possibly due to higher population density and total investment in fixed assets in East China. The average microplastic concentration also tended to increase with an increase in the proportion of industrial wastewater in WWTP influent (Li et al., 2018). Specific industrial or domestic sources of microplastics were not identified in that study.

As mentioned above, some studies quantifying microplastics in WWTP wastewater streams and biosolids have noted a very high ratio of microfibres relative to other microplastic shapes. The shedding of small synthetic fibres from synthetic textiles during the laundering process has been noted by researchers. For example, an Ocean Wise study conducted in Metro Vancouver found that the number of microfibres shed during a single wash cycle in a top-loading washing machine ranged from 9,766 to 4,315,371 microfibres per kg of textile per wash (Vassilenko et al., 2019). Using those measurements, they estimated that an average household in Canada or the U.S. releases 533 million microfibres (135 g) from laundry into WWTPs every year. This leads to a total of 22 ktonnes of microfibres being released to wastewater in Canada and the U.S. combined. Approximately 4 ktonnes go untreated (e.g. enter septic tanks) while the rest, approximately 18 ktonnes, enter WWTPs in influent (Vassilenko et al., 2019).

A few European countries have identified relevant emitters of microplastics to the marine environment, and in some cases estimated the quantity of microplastics released from each of those sources on an annual basis. The data from those studies are included in Table 5. One study from Denmark has estimated both total emissions and emissions to the WWTP stream (Lassen et al., 2015). Total emissions include emissions that enter marine ecosystems directly from the source of emission, avoiding WWTPs, while emission to the WWTPs stream indicate microplastics that pass through WWTPs before entering the marine environment. Other studies have estimated total emissions only, with direct emissions to the marine environment and emissions that pass through WWTPs being reported together (Essel et al., 2015; Magnusson et al., 2016; Sundt et al., 2014). Some entries included in Table 5 are likely not relevant to the entire Metro Vancouver region. Microplastics from tires, for example, would be washed from roads as stormwater and into the stormwater sewer system. This stormwater is normally discharged directly into the nearest body of water. However, in older parts of the region, some stormwater drains into combined sewers, which carry both stormwater and wastewater to Annacis Island and Iona Island WWTPs.

Gies et al. (2018) have estimated the total daily load of microplastics to WWTPs in Metro Vancouver and report a value of between 10.6 and 19.9 billion suspected microplastics entering WWTPs daily. Based on Table 5, the largest contributor to that total is likely to be the laundering of textiles. This suggests that reducing the amount of microplastics emitted from domestic washing machines as well as commercial laundering services could significantly reduce the amount of microplastics entering WWTPs in Metro Vancouver. In addition to fibres from laundering textiles, microplastics may enter the wastewater stream through the use of personal care products (i.e. toiletries such as body wash or toothpaste). Although Canadian law prohibits the manufacture, import, and sale of toiletries containing microplastics, a bodywash sold in Metro Vancouver in May 2020 lists as an ingredient “acrylates copolymer.” It is unclear whether or not microplastics from personal care products are an important source of microplastics entering WWTPs in Metro Vancouver. Microplastics shed from household cleaning materials, such as synthetic cloths or sponges, may also be a contributor of microplastics to the wastewater stream.

Table 5. Summary of emissions of primary and secondary microplastics in four European countries with the potential to enter wastewater streams. Data come from Essel et al., (2015), Lassen et al., (2015), Magnusson et al., (2016) and Sundt et al., (2014). N/A indicates that information was not reported.

Estimated emissions of microplastics (tonnes/year)	**Denmark**	**Germany**	**Norway**	**Sweden**
Primary sources				
Personal Care Products: Emissions to WWTPs	10-22	N/A	N/A	N/A
Personal Care Products: Total emissions	9-29	496	40	69 (from liquid soap only)
Pellets/raw materials for production: Emissions to WWTPs	3-56	N/A	N/A	N/A
Pellets/raw materials for production: Total emissions	3-56		200	298
Pellets/raw materials transportation/handling: Emissions to WWTPs	N/A	N/A	N/A	N/A
Pellets/raw materials transportation/handling: Total emissions	N/A	21,000-210,000	250	12-235
Paints (primary, refers to manufacturing of paints): Emissions to WWTPs	2-7	N/A	N/A	N/A
Paints (primary, refers to manufacturing of paints): Total emissions	2-7	N/A	N/A	N/A
Blasting abrasives: Emissions to WWTPs	0.03-1.3	N/A	N/A	N/A
Blasting abrasives: Total emissions	0.05-2.5	N/A	N/A	N/A
Rubber granules: Emissions to WWTPs	20-330	N/A	N/A	N/A
Rubber granules: Total emissions	450-1,580	N/A	N/A	2,300-3,900 (turf fields)
Secondary sources				
Tires: Emissions to WWTPs	1,600-2,500	N/A	N/A	N/A
Tires: Total emissions	4,200-6,600	60,000-111,000	4,500	13000
Textiles laundering (domestic): Emissions to WWTPs	200-1,000	N/A	N/A	N/A
Textiles laundering (domestic): Total emissions	200-1,000	N/A	600	195-2,216
Textiles laundering (commercial): Emissions to WWTPs	N/A	N/A	N/A	N/A
Textiles laundering (commercial): Total emissions	N/A	N/A	100	N/A
Paints (secondary, excluding ships, refers to abrasion and wear of painted surfaces): Emissions to WWTPs	14-220	N/A	N/A	N/A

Paints (secondary, excluding ships, refers to abrasion and wear of painted surfaces): Total emissions	150-810	N/A	130	128-251
Road markings: Emissions to WWTPs	40-260	N/A	N/A	N/A
Road markings: Total emissions	110-690	N/A	320	504
Building materials: Emissions to WWTPs	30-150	N/A	N/A	N/A
Building materials: Total emissions	80-480	N/A	N/A	N/A
Footwear: Emissions to WWTPs	40-380	N/A	N/A	N/A
Footwear: Total emissions	100-1,000	N/A	N/A	N/A
Cooking utensils/cleaning materials (e.g. sponges): Emissions to WWTPs	20-180	N/A	N/A	N/A
Cooking utensils/cleaning materials (e.g. sponges): Total emissions	20-180	N/A		N/A
Household dust: Total emissions	N/A	N/A	400-450	1-19
Public and commercial indoor air dust: Total emissions	N/A	N/A	200	N/A

The final portion of this review will discuss the analytical methods used to identify and quantify microplastics in complex matrices such as biosolids and describe the challenges regarding the identification and quantification of microplastics in biosolids and sludge samples. Currently, there is no uniform protocol for quantification of microplastics in biosolids, making it difficult to compare results from different studies where different methods of quantification were used (Wang et al., 2018). Microplastics concentrations are almost always reported in units of number of microplastics per amount of sample (e.g. # per litre of wastewater or # per gram or kilogram of biosolids). Only a few researchers have also attempted to estimate and report mass concentrations of microplastics in biosolids or the wastewater stream. This is a problem in part because the number concentration (i.e. the concentration measured in number of microplastics per amount of sample) of microplastics is affected by physical breakdown, meaning that a WWTP system could 'produce' microplastics by breaking down large particles into smaller particles during treatment. For this reason, the mass of microplastics could provide a more meaningful unit to evaluate efficiencies of WWTPs. However, the number concentration of microplastics is important in terms of environmental impact. Vollertsen and Hansen (2017) therefore suggest that microplastics mass should be used to assess treatment efficiencies while particle number concentrations should be reported to support environmental impact assessment. Another issue not addressed in many microplastics sampling studies is that microplastics concentrations can vary substantially in both water and sludge samples depending on time of day and season. Samples should therefore be collected over long campaigns and at different times of day to assess both seasonal and diurnal variation (Lares et al., 2018).

Multiple approaches to separate microplastics from biosolids or sludge have been reported in the literature. These methods may also be used to separate microplastics from soil samples. Perhaps the most common method is density flotation. Flotation methods using dense solutions (e.g. $ZnCl_2$ solution, NaCl solution) to separate microplastics from other components of a biosolid, sludge, or soil sample (Li et al., 2018; Wang et al., 2018). In these solutions, microplastics are expected to float to the top of the liquid, because of the low density of many polymer types. One study evaluated the extraction efficiency for polystyrene spheres from soil and biosolids samples using the flotation method. They found that the efficiency is low for spheres < 100 µm in diameter (Wang et al., 2018). Microplastics can be made of many different polymer types, with varying densities, and so one drawback of density separation is the loss of high-density microplastics. Another drawback of density separation when using biosolids or sludge samples is that cellulose fibres are one of the most abundant non-plastic groups in WWTP samples. Cellulose fibres have a density of 1.5 g cm^{-3}, which overlaps with the densities with some polymers, meaning the it can be difficult to separate plastics from cellulose fibres using density separation (Lares et al., 2018). Other methods to separate microplastics form soil samples are oil extraction (Crichton et al., 2017) an electrostatic method (Felsing et al., 2018), and a pressurized fluid extraction method (Fuller and Gautam, 2016). These methods have been evaluated to a lesser extent in the literature.

Chemical treatments of biosolids or soil samples can be used to oxidize organic material, potentially making it easier to separate microplastics from those complex matrices. Perhaps most commonly used chemical for this purpose is H_2O_2, as used by Gies et al. (2018) and others. Hurley et al. (2018) have compared NaOH, KOH, H2O2 and Fenton's reagent for the removal of organic material in soil and suggest Fenton's reagent. These results may or may not extend to biosolids and sludge. Unfortunately, there is evidence that treatment of biosolids or soils with H_2O_2 to digest organic material may decrease the efficiency of flotation methods to isolate microplastics from those samples (Wang et al., 2018).

Following separation from the biosolids or sludge matrix, microplastics must be positively identified. Most studies recommend visual identification using an optical microscope as a first step. However, visual identification can lead to false positive results, as it can be difficult to distinguish between natural and synthetic (plastic) fibres by eye. Suspected microplastics should therefore be confirmed using a spectroscopic technique such as Fourier Transform Infrared (FT-IR) spectroscopy, attenuated total reflectance spectroscopy, or Raman spectroscopy (Carr et al., 2016; Gies et al., 2018; Lares et al., 2018; Li et al., 2018; Mahon et al., 2017; Vollertsen and Hansen, 2017). Generally, only a subset of suspected microplastics are examined using one of these spectroscopic techniques, allowing for an estimate of the number of false positive microplastics identifications. These spectroscopic techniques also indicate the type of polymer used to make each microplastic. Mahon et al. (2017) also tested ambiguous particles using the tip of a hot needle to determine whether a particle was plastic. A positive (plastic) result was indicated if the particle melted.

2 Database of potential commercial and industrial microplastics emitters in Metro Vancouver

2.1 Business directory search using North American Industry Classification System (NAICS) Codes

A database of potential microplastics emitters was generated by performing a business directory search using North American Industry Classification System (NAICS) codes (Statistics Canada, 2018). The full list of NAICS codes was reviewed, and codes corresponding to industries that have the potential to emit microplastics were identified. The potential for industries to emit microplastics was determined based on the literature review in Part 1, which identified sources of microplastics.

The NAICS codes which were identified as corresponding to industries with the potential to emit microplastics are listed in Table 2.1. Those NAICS codes are further described in Appendix A. Metro Vancouver's corporate librarian used the Dun and Bradstreet Hoovers business directory database to perform the search using that list of NAICS codes (June 18th, 2020). The search produced 1,810 businesses which became the starting point for generating the database of potential microplastics emitters and is included in the Microplastics Dischargers Database Excel document in the Sheet "Business Directory Results." The details of the business directory search are included in the Sheet "Search Details." The database was refined by doing a Google search for each business on the list to confirm that the business activity aligned with its NAICS code. Based on the Google search results, businesses that were not potential microplastics emitters were deleted from the database as described in the following paragraphs.

Businesses corresponding to all NAICS codes were deleted from the database if they did not work with plastic materials. Businesses corresponding to all NAICS codes were deleted from the database if they were found to be permanently closed. Businesses engaged in manufacturing plastic products were kept in the database as it is assumed that the manufacturing process involves the generation of wastewater into the Metro Vancouver's sewer system.

Businesses corresponding to NAICS codes associated with manufacturing of textiles or textile products (313XXX, 314XXX, 315XXX) were deleted from the database if they were found to be a retailer, wholesaler, or importer of textiles rather than a manufacturer of those products. Businesses corresponding to the NAICS code 339930 (Doll, Toy, and Game Manufacturing) were deleted if they were not found to be engaged in the manufacturing of plastic toys (e.g. they were engaged in retail, wholesale, or videogame development). Businesses corresponding to NAICS codes 562211 (Hazardous Waste Treatment and Disposal) and 562212 (Solid Waste Landfill) that store waste (e.g. landfills) were kept in the database, while businesses that only transport waste materials were deleted from the database.

Businesses corresponding to the NAICS code 562920 (Materials Recovery Facilities) were deleted if they were found to be engaged in the recovery of non-plastic materials (e.g. auto or scrap metal recovery). In cases where it was unclear whether a business was engaged in activities that could result in the emission of microplastics due to a lack of available information (e.g. it could not be determined whether manufacturing was performed in Metro Vancouver), the business was kept in the database. The list of businesses that were removed from the database are included in the Microplastics Dischargers Database Excel document in the Sheet “Removed from Business Directory.”

A list of businesses with Waste Discharge Permits (current as of June 25, 2020) was obtained by Metro Vancouver staff. This list is included in the Microplastics Dischargers Database Excel document in the Sheet “List of Permits.” There are 286 businesses on that list. Each business with a Waste Discharge Permit was considered for its potential to emit microplastics. This process identified 15 additional potential microplastics emitters that were not identified via the business directory search. Among those businesses were 12 landfills, two hotel laundry facilities, and one plastic container manufacturer. Those businesses were added to the database and are also listed on the Sheet “Cross ref. permits and results.” The total annual discharge volume from 2019 for each of those businesses is included on the Sheet “Cross ref. permits and results.” The final database contains 1,252 businesses. In the Sheet “Dischargers database_NAICS” businesses are grouped by NAICS code in ascending order.

The 1,252 businesses in the final database have been evaluated to determine priority opportunities for intervention by Metro Vancouver. Three categories have been chosen and a weight for each category has been assigned to each business. The categories represent:

1) the likely impact to the environment based on the shape of microplastic being emitted;
2) the ability of Metro Vancouver to influence a business based on existing relationships and;
3) the number of employees working at each business.

In the Sheet “Dischargers database_Weight” businesses are grouped by their total weight. In the database, businesses are also colour-coded according to their total weight. These categories used to assign weight are expanded on in Section 2.2.

Table 2.1. NAICS codes corresponding to industries with the potential to emit microplastics and which were included in the business directory search.

NAICS 2017 Code	**NAICS 2017 Description**
31311/313110	Fibre, yarn and thread mills
31321/313210	Broad-woven fabric mills
31322/313220	Narrow fabric mills and Schiffli machine embroidery
31323/313230	Nonwoven fabric mills
31324 /313240	Knit fabric mills
31331/313310	Textile and fabric finishing
31332/313320	Fabric coating
31411/314110	Carpet and rug mills
31412/314120	Curtain and linen mills
31491/314910	Textile bag and canvas mills
31499/314990	All other textile product mills
31511/315110	Hosiery and sock mills
31519/315190	Other clothing knitting mills
31521/315210	Cut and sew clothing contracting
31522/315220	Men's and boys' cut and sew clothing manufacturing
31524	Women's, girls' and infants' cut and sew clothing manufacturing
315241	Infants' cut and sew clothing manufacturing
315249	Women's and girls' cut and sew clothing manufacturing
31528/315289	All other cut and sew clothing manufacturing
31599/315990	Clothing accessories and other clothing manufacturing
31621/316210	Footwear manufacturing
32521/325210	Resin and synthetic rubber manufacturing
32522/325220	Artificial and synthetic fibres and filaments manufacturing
32551/325510	Paint and coating manufacturing
32552/325520	Adhesive manufacturing
32611	Plastic packaging materials and unlaminated film and sheet manufacturing
326111	Plastic bag and pouch manufacturing
326114	Plastic film and sheet manufacturing
32612	Plastic pipe, pipe fitting, and unlaminated profile shape manufacturing
326121	Unlaminated plastic profile shape manufacturing
326122	Plastic pipe and pipe fitting manufacturing

32613/326130	Laminated plastic plate, sheet (except packaging), and shape manufacturing
32614/326140	Polystyrene foam product manufacturing
32615/326150	Urethane and other foam product (except polystyrene) manufacturing
32616/326160	Plastic bottle manufacturing
32619	Other plastic product manufacturing
326191	Plastic plumbing fixture manufacturing
326193	Motor vehicle plastic parts manufacturing
326196	Plastic window and door manufacturing
326198	All other plastic product manufacturing
32621/326210	Tire manufacturing
32622/326220	Rubber and plastic hose and belting manufacturing
32629/326290	Other rubber product manufacturing
33993/339930	Doll, toy and game manufacturing
56221/562210	Waste treatment and disposal
56292/562920	Material recovery facilities
81231/812310	Coin-operated laundries and dry cleaners
81232/812320	Dry cleaning and laundry services (except coin-operated)
81233/812330	Linen and uniform supply
81293/812930	Parking lots and garages

2.2 Database weighting categories

Each business in the database has been assigned a weight for each of the following three categories. The weights assigned for each category are multiplied to determine an overall weight for each business in the database. A higher overall weight represents a higher priority business, based on either potential environmental impact, ability for influence from Metro Vancouver, or both.

1. Impact to the Environment

Weight	Description	Associated Codes
2	Likely to emit primarily or exclusively fibres	313XXX, 314XXX, 315XXX, 316210, 812310, 812320
1	Likely to emit other microplastic shapes	All other codes

a. Key assumptions for the Impact to the Environment category:

- The literature review conducted for this project indicated that microfibres are preferentially retained in biosolids and soils and may have the greatest impact on soil physical properties. This review also suggested that microfibres have the greatest impact on aquatic ecosystems. The confidence of this being true is high.
- Businesses which manufacture textiles or textile products, or launder textiles, are assumed to release fibres to the wastewater stream. The confidence of this being true is high for businesses which launder textiles, but low for businesses that manufacture textiles or textile products.

b. Details regarding the Impact to the Environment category:

- Industry codes that correspond to businesses which are involved in manufacturing textiles or textile products have NAICS codes of 313XXX, 314XXX, and 315XXX. Businesses involved in footwear manufacturing, which may include the use of textiles, have the NAICS code 316210. The list of businesses matching these codes that was returned via the business directory search was reviewed. Some businesses were removed from the database, including businesses that do not use plastic materials, and businesses that only participate in the wholesale or retail of textiles or textile products.
- Industry codes that correspond to businesses which are involved in laundering of textiles have NAICS codes of 812310 and 812320. The list of businesses matching these codes that was returned via the business directory search was reviewed. Some businesses were removed from the database, including businesses providing home cleaning services. Businesses engaged in carpet cleaning were kept in the database.

- Some businesses (e.g. landfills) are expected to emit both microfibres and other shapes of microplastics. Those businesses have been assigned a weight of “1”, while a weight of “2” has been assigned only to businesses that are expected to emit exclusively or primarily fibres.

2. Relationship to Metro Vancouver

Weight	Description	Associated Codes
4	MV Waste Discharge Permit	N/A
3	MV Code of Practice	812310/812320 (Dry Cleaners)
2	MV Waste Management Guide	812320 (Carpet Cleaners)
1	No relationship	All other codes

a. Key assumptions for Number of Employees category:

- No assumptions were made for this category

b. Details regarding the Relationship to Metro Vancouver category:

- Permits, Codes of Practice, and Waste Management Guides are regulatory mechanisms that allow Metro Vancouver to regulate commercial and industrial liquid waste (Metro Vancouver, 2020). Although microplastics are not regulated by Metro Vancouver, the three regulatory mechanisms represent an existing relationship between the business community and Metro Vancouver.
- A list of businesses with Waste Discharge Permits was obtained by Metro Vancouver staff (current as of June 25, 2020) and this list was cross-referenced with the database of businesses from the business directory search using the VLOOKUP function in Excel. Those businesses are assigned a weight of 4 in this category because Metro Vancouver has exclusive ability to regulate discharge and enforce Permit requirements.
- There is a Code of Practice for Dry Cleaners using tetrachloroethylene and operating in Metro Vancouver. Dry Cleaners fall under the NAICS codes 812310 (Coin-Operated Laundries and Drycleaners) and 812320 (Drycleaning and Laundry Services (except Coin-Operated)). These categories also include laundromats and some other cleaning businesses, which do not operate under a Code of Practice. Businesses with these NAICS codes have therefore been examined individually to determine whether or not they are Dry Cleaners, and to determine whether the Code of Practice applies. Dry Cleaners are assigned a weight of 3 in this category because although Metro Vancouver has the ability to regulate and enforce Codes of Practices under Metro Vancouver’s Sewer Use Bylaw, this regulatory mechanism is less frequently enforced (Metro Vancouver, 2020).

- There is a Waste Management Guide for Carpet Cleaners operating in Metro Vancouver. Some businesses with NAICS codes 812310 and 812320 were identified as Carpet Cleaners. Those businesses are assigned a weight of 2 in this category because best management practices under these Guides are voluntary and not regulated or enforceable under the Sewer Use Bylaw.

3. Number of Employees

Weight	Description	Associated Codes
3	>50 employees (large business)	N/A
2	10-50 employees (medium business)	N/A
1	<10 (small business)	N/A

a. Key assumptions for Number of Employees category:

- The volume of discharge is positively correlated with the number of employees. The confidence of this being true is medium to low.

b. Details regarding the Number of Employees category:

- The number of employees in each weight category was chosen arbitrarily to differentiate between businesses of different sizes.
- For some businesses the number of employees was not reported. In those cases, the lowest possible weight for number of employees (weight = 1) was assigned to that business.

2.3 Results from database weighting

The highest possible weight a business can receive based on these weighting categories is 24. There were four businesses that received a weight of 24, all of which are engaged in the laundering of textiles with the NAICS codes 812331 “Linen Supply” and 812332 “Industrial Launderers.” Businesses which received a weight of 24 are colour-coded red in the Microplastics Dischargers Database.

There are 11 businesses which received the second-highest weight of 12. Eight of those businesses fall under the NAICS code 812320 “Drycleaning and Laundry Services (except Coin-Operated).” Two businesses fall under NAICS codes related to plastics manufacturing, and one business falls under the NAICS code 562212 “Solid Waste Landfill.” Businesses which received a weight of 12 are colour-coded orange in the Microplastics Dischargers Database.

There are nine businesses which received the third-highest weight of 8. Six of those businesses fall under NAICS codes related to the laundering of textiles. Businesses which received a weight of 8 are colour-coded yellow in the Microplastics Dischargers Database.

There are 253 businesses which receive a weight of 6. 245 of those businesses are Dry Cleaners. Businesses which received a weight of 6 are colour-coded green in the Microplastics Dischargers Database.

The remaining 974 businesses received a weight of 4, 3, 2, or 1. Businesses which received a weight of 4 are colour-coded blue, those which received a weight of 3 are colour-coded purple, and those which received a weight of 2 are colour-coded pink in the Microplastics Dischargers Database. Those which received a weight of 1 are not colour-coded.

The majority of businesses which received a high weight score (either 24, 12, 8, or 6) are involved in laundering textiles. The high scores are the results of these businesses releasing primarily microfibres over other plastic shapes, and existing relationships between Metro Vancouver and some industrial launderers, in the form of Permits, and between Metro Vancouver and Dry Cleaners, in the form of a Code of Practice. This suggests that businesses involved in laundering of textiles could be a priority area for intervention by Metro Vancouver.

Conclusions

The literature review, presented in Section 1, concluded that the use of biosolids as a soil amendment may be a large source of microplastics to agricultural soils. It also found that microplastics persist in soils for long periods of time and can accumulate with successive applications. Microplastics affect the physical properties of soils, and the effects depend on the shape of a microplastic. Specifically, microfibres have more significant effects on soil physical properties than other microplastic shapes, such as fragments. Microplastics also impact the organisms living in soils. For example, some studies showed increased mortality and decreased reproductive success for organisms living in soils treated with microplastics. There is also evidence that microplastics can bioaccumulate at higher trophic levels.

The literature review determined that WWTPs are very efficient in removing microplastics from the liquid waste stream, showing a removal efficiency greater than 90% when comparing microplastics concentrations in WWTP influent and effluent from multiple studies. This results in a high concentration of microplastics in the solid stream. Microfibres are more likely to be retained in biosolids than other microplastics shapes. Many studies point to the challenges regarding the identification and quantification of microplastics in biosolids and soil samples. Currently, there is no uniform protocol for quantification of microplastics in solid matrices, making it difficult to compare results from different studies where different methods of quantification were used.

There are a limited number of studies that have examined the industrial and domestic sources of microplastics to WWTPs or to the environment in European countries. The existing studies have identified tire wear, laundering of textiles, and fabrication and transportation of plastic pellets as some important emission sources of microplastics. The total daily load of microplastics to WWTPs in Metro Vancouver has been estimated to be between 10.6 and 19.9 billion suspected microplastics by Gies et al. (2018), though the contributing sources were not investigated in that work.

A database of potential industrial and commercial emitters of microplastics is described in Section 2. The database was generated using a business directory search using NAICS codes, which were identified as corresponding to business activities that could result in the emission of microplastics. The final database includes 1,252 businesses. Each business in the database has been assigned a weight for three categories, representing the likely extent of the environmental impact due to microplastics emissions, and whether there is an existing relationship between Metro Vancouver and that business. Businesses which emit primarily microfibres (instead of other plastic shapes), businesses which have a large number of employees, and businesses that have an existing relationship with Metro Vancouver have the highest cumulative weight. The cumulative weight for each business represents the priority for intervention from Metro Vancouver. The majority of businesses which received a high weight score are involved in laundering textiles. This suggests that businesses involved in laundering of textiles may be a priority area for intervention by Metro Vancouver.

References

Awet, T. T., Kohl, Y., Meier, F., Straskraba, S., Grün, A. L., Ruf, T., Jost, C., Drexel, R., Tunc, E. and Emmerling, C.: Effects of polystyrene nanoparticles on the microbiota and functional diversity of enzymes in soil, Environ. Sci. Eur., 30(1), doi:10.1186/s12302-018-0140-6, 2018.

Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T. and Thompson, R.: Accumulation of microplastic on shorelines woldwide: Sources and sinks, Environ. Sci. Technol., 45(21), 9175–9179, doi:10.1021/es201811s, 2011.

Cao, D., Wang, X., Luo, X., Liu, G. and Zheng, H.: Effects of polystyrene microplastics on the fitness of earthworms in an agricultural soil, IOP Conf. Ser. Earth Environ. Sci., 61(1), doi:10.1088/1755-1315/61/1/012148, 2017.

Carr, S. A., Liu, J. and Tesoro, A. G.: Transport and fate of microplastic particles in wastewater treatment plants, Water Res., 91, 174–182, doi:10.1016/j.watres.2016.01.002, 2016.

Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga, E. and Geissen, V.: Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal, Sci. Total Environ., 671, 411–420, doi:10.1016/j.scitotenv.2019.03.368, 2019.

Crichton, E. M., Noël, M., Gies, E. A. and Ross, P. S.: A novel, density-independent and FTIR-compatible approach for the rapid extraction of microplastics from aquatic sediments, Anal. Methods, 9(9), 1419–1428, doi:10.1039/c6ay02733d, 2017.

Crossman, J., Hurley, R. R., Futter, M. and Nizzetto, L.: Transfer and transport of microplastics from biosolids to agricultural soils and the wider environment, Sci. Total Environ., 724, 138334, doi:10.1016/j.scitotenv.2020.138334, 2020.

Dyachenko, A., Mitchell, J. and Arsem, N.: Extraction and identification of microplastic particles from secondary wastewater treatment plant (WWTP) effluent, Anal. Methods, 9(9), 1412–1418, doi:10.1039/c6ay02397e, 2017.

Essel, R., Engel, L., Carus, M. and Ahrens, R. H.: Sources of microplastics relevant to marine protection in Germany., 2015.

Felsing, S., Kochleus, C., Buchinger, S., Brennholt, N., Stock, F. and Reifferscheid, G.: A new approach in separating microplastics from environmental samples based on their electrostatic behavior, Environ. Pollut., 234, 20–28, doi:10.1016/j.envpol.2017.11.013, 2018.

Fuller, S. and Gautam, A.: A Procedure for Measuring Microplastics using Pressurized Fluid Extraction, Environ. Sci. Technol., 50(11), 5774–5780, doi:10.1021/acs.est.6b00816, 2016.

Gies, E. A., LeNoble, J. L., Noël, M., Etemadifar, A., Bishay, F., Hall, E. R. and Ross, P. S.: Retention of microplastics in a major secondary wastewater treatment plant in Vancouver, Canada, Mar. Pollut. Bull., 133(March), 553–561, doi:10.1016/j.marpolbul.2018.06.006, 2018.

Hartmann, N. B., Rist, S., Bodin, J., Jensen, L. H. S., Schmidt, S. N., Mayer, P., Meibom, A. and Baun, A.: Microplastics as vectors for environmental contaminants: Exploring sorption, desorption, and transfer to biota, Integr. Environ. Assess. Manag., 13(3), 488–493, doi:10.1002/ieam.1904, 2017.

Huerta Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., Van Der Ploeg, M., Besseling, E., Koelmans, A. A. and Geissen, V.: Microplastics in the Terrestrial Ecosystem: Implications for Lumbricus terrestris (Oligochaeta, Lumbricidae), Environ. Sci. Technol., 50(5), 2685–2691, doi:10.1021/acs.est.5b05478, 2016.

Huerta Lwanga, E., Mendoza Vega, J., Ku Quej, V., Chi, J. de los A., Sanchez del Cid, L., Chi, C., Escalona Segura, G., Gertsen, H., Salánki, T., van der Ploeg, M., Koelmans, A. A. and Geissen, V.: Field evidence for transfer of plastic debris along a terrestrial food chain, Sci. Rep., 7(1), 1–7, doi:10.1038/s41598-017-14588-2, 2017.

Hurley, R. R., Lusher, A. L., Olsen, M. and Nizzetto, L.: Validation of a Method for Extracting Microplastics from Complex, Organic-Rich, Environmental Matrices, Environ. Sci. Technol., 52(13), 7409–7417, doi:10.1021/acs.est.8b01517, 2018.

Lares, M., Ncibi, M. C., Sillanpää, M. and Sillanpää, M.: Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology, Water Res., 133, 236–246, doi:10.1016/j.watres.2018.01.049, 2018.

Lassen, C., Hansen, S. F., Magnusson, K., Hartmann, N. B., Rehne Jensen, P., Nielsen, T. G. and Brinch, A.: Microplastics Occurrence , effects and sources of releases., 2015.

Leslie, H. A., Brandsma, S. H., van Velzen, M. J. M. and Vethaak, A. D.: Microplastics en route: Field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota, Environ. Int., 101, 133–142, doi:10.1016/j.envint.2017.01.018, 2017.

Li, X., Chen, L., Mei, Q., Dong, B., Dai, X., Ding, G. and Zeng, E. Y.: Microplastics in sewage sludge from the wastewater treatment plants in China, Water Res., 142, 75–85, doi:10.1016/j.watres.2018.05.034, 2018.

Maes, T., Van der Meulen, M. D., Devriese, L. I., Leslie, H. A., Huvet, A., Frère, L., Robbens, J. and Vethaak, A. D.: Microplastics baseline surveys at the water surface and in sediments of the North-East Atlantic, Front. Mar. Sci., 4, 1–13, doi:10.3389/fmars.2017.00135, 2017.

Magnusson, K. and Norén, F.: Screening of microplastic particles in and down-stream a wastewater treatment plant, IVL Swedish Environ. Res. Inst., C 55(C), 22, doi:naturvardsverket-2226, 2014.

Magnusson, K., Eliasson, K., Fråne, A., Haikonen, K., Hultén, J., Olshammar, M., Stadmark, J. and Voisin, A.: Swedish sources and pathways for microplastics to the marine environment. A review of existing data. [online] Available from: www.ivl.se, 2016.

Mahon, A. M., O'Connell, B., Healy, M. G., O'Connor, I., Officer, R., Nash, R. and Morrison, L.: Microplastics in sewage sludge: Effects of treatment, Environ. Sci. Technol., 51(2), 810–818, doi:10.1021/acs.est.6b04048, 2017.

Mason, S. A., Garneau, D., Sutton, R., Chu, Y., Ehmann, K., Barnes, J., Fink, P., Papazissimos, D. and Rogers, D. L.: Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent, Environ. Pollut., 218, 1045–1054, doi:10.1016/j.envpol.2016.08.056, 2016.

Metro Vancouver, Metro Vancouver Liquid Waste Regulatory Program, [online] Available from: http://www.metrovancouver.org/services/Permits-regulations-enforcement/liquid-waste/Pages/default.aspx (Accessed 31 July 2020), 2020.

Michielssen, M. R., Michielssen, E. R., Ni, J. and Duhaime, M. B.: Fate of microplastics and other small anthropogenic litter (SAL) in wastewater treatment plants depends on unit processes employed, Environ. Sci. Water Res. Technol., 2(6), 1064–1073, doi:10.1039/c6ew00207b, 2016.

Mintenig, S. M., Int-Veen, I., Löder, M. G. J., Primpke, S. and Gerdts, G.: Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging, Water Res., 108, 365–372, doi:10.1016/j.watres.2016.11.015, 2017.

Morra, J.: Microplastic Contamination at Orchid Lake in the Seymour Watershed., unpublished report prepared for MEtro Vancouver, 2018.

Murphy, F., Ewins, C., Carbonnier, F. and Quinn, B.: Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment, Environ. Sci. Technol., 50(11), 5800–5808, doi:10.1021/acs.est.5b05416, 2016.

Ng, E. L., Huerta Lwanga, E., Eldridge, S. M., Johnston, P., Hu, H. W., Geissen, V. and Chen, D.: An overview of microplastic and nanoplastic pollution in agroecosystems, Sci. Total Environ., 627, 1377–1388, doi:10.1016/j.scitotenv.2018.01.341, 2018.

Nizzetto, L., Futter, M. and Langaas, S.: Are Agricultural Soils Dumps for Microplastics of Urban Origin?, Environ. Sci. Technol., 50(20), 10777–10779, doi:10.1021/acs.est.6b04140, 2016.

Oehlmann, J., Schulte-Oehlmann, U., Kloas, W., Jagnytsch, O., Lutz, I., Kusk, K. O., Wollenberger, L., Santos, E. M., Paull, G. C., VanLook, K. J. W. and Tyler, C. R.: A critical analysis of the biological impacts of plasticizers on wildlife, Philos. Trans. R. Soc. B Biol. Sci., 364(1526), 2047–2062, doi:10.1098/rstb.2008.0242, 2009.

Piehl, S., Leibner, A., Löder, M. G. J., Dris, R., Bogner, C. and Laforsch, C.: Identification and quantification of macro- and microplastics on an agricultural farmland, Sci. Rep., 8(1), 1–9, doi:10.1038/s41598-018-36172-y, 2018.

Rillig, M. C., Ziersch, L. and Hempel, S.: Microplastic transport in soil by earthworms, Sci. Rep., 7(1), 1–6, doi:10.1038/s41598-017-01594-7, 2017.

Rodrigues, J. P., Duarte, A. C., Santos-Echeandía, J. and Rocha-Santos, T.: Significance of interactions between microplastics and POPs in the marine environment: A critical overview, TrAC - Trends Anal. Chem., 111, 252–260, doi:10.1016/j.trac.2018.11.038, 2019.

Selonen, S., Dolar, A., Jemec Kokalj, A., Skalar, T., Parramon Dolcet, L., Hurley, R. and van Gestel, C. A. M.: Exploring the impacts of plastics in soil – The effects of polyester textile fibers on soil invertebrates, Sci. Total Environ., 700, 134451, doi:10.1016/j.scitotenv.2019.134451, 2020.

de Souza Machado, A. A., Lau, C. W., Till, J., Kloas, W., Lehmann, A., Becker, R. and Rillig, M. C.: Impacts of Microplastics on the Soil Biophysical Environment, Environ. Sci. Technol., 52(17), 9656–9665, doi:10.1021/acs.est.8b02212, 2018.

Statistics Canada: North American Industry Classification System (NAICS) 2017 Version 3.0. [online] Available from: https://www.statcan.gc.ca/eng/subjects/standard/naics/2017/v3/index, 2018.

Sundt, P., Schultze, P. and Syversen, F.: Sources of microplastic- pollution to the marine environment., 2014.

Sutton, R., Mason, S. A., Stanek, S. K., Willis-Norton, E., Wren, I. F. and Box, C.: Microplastic contamination in the San Francisco Bay, California, USA, Mar. Pollut. Bull., 109(1), 230–235, doi:10.1016/j.marpolbul.2016.05.077, 2016.

Talvitie, J., Heinonen, M., Pääkkönen, J. P., Vahtera, E., Mikola, A., Setälä, O. and Vahala, R.: Do wastewater treatment plants act as a potential point source of microplastics? Preliminary study in the coastal Gulf of Finland, Baltic Sea, Water Sci. Technol., 72(9), 1495–1504, doi:10.2166/wst.2015.360, 2015.

Talvitie, J., Mikola, A., Setälä, O., Heinonen, M. and Koistinen, A.: How well is microlitter purified from wastewater? – A detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant, Water Res., 109, 164–172, doi:10.1016/j.watres.2016.11.046, 2017.

Vassilenko, K., Watkins, M., Chastain, S., Posacka, A. and Ross, P. S.: Me, My Clothes and the Ocean: The role of textiles in microfiber pollution., Vancouver, BC., 2019.

Vollertsen, J. and Hansen, A. A.: Microplastic in Danish wastewater: Sources, occurrences and fate.

[online] Available from: https://www.researchgate.net/publication/316966942, 2017.

Wan, Y., Wu, C., Xue, Q. and Hui, X.: Effects of plastic contamination on water evaporation and desiccation cracking in soil, Sci. Total Environ., 654, 576–582, doi:10.1016/j.scitotenv.2018.11.123, 2019.

Wang, Z., Taylor, S. E., Sharma, P. and Flury, M.: Poor extraction efficiencies of polystyrene nano- and microplastics from biosolids and soil, PLoS One, 13(11), 1–13, doi:10.1371/journal.pone.0208009, 2018.

Zhu, D., Chen, Q. L., An, X. L., Yang, X. R., Christie, P., Ke, X., Wu, L. H. and Zhu, Y. G.: Exposure of soil collembolans to microplastics perturbs their gut microbiota and alters their isotopic composition, Soil Biol. Biochem., 116(November 2017), 302–310, doi:10.1016/j.soilbio.2017.10.027, 2018.

Ziajahromi, S., Neale, P. A., Rintoul, L. and Leusch, F. D. L.: Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics, Water Res., 112, 93–99, doi:10.1016/j.watres.2017.01.042, 2017.

Zubris, K. A. V. and Richards, B. K.: Synthetic fibers as an indicator of land application of sludge, Environ. Pollut., 138(2), 201–211, doi:10.1016/j.envpol.2005.04.013, 2005.

Appendix A. Hierarchy of NAICS codes. Descriptions for each code are included in the Excel document "NAICS codes hierarchy." Codes and descriptions are taken from North American Industry Classification System (NAICS) Canada, 2017, Version 3.0.

Two-digit code	**Three-digit code**	**Four-digit code**	**Five/six-digit code**	**Likely to discharge water?**	**Likely to produce/release fibres? If yes, synthetic or natural fibres?**	**Notes**
31-33 Manufacturing	313 Textile mills	3131 Fibre, yarn and thread mills	31311/313110 Fibre, yarn and thread mills	Unknown.	Yes, both natural and synthetic fibres.	
		3132 Fabric mills	31321/313210 Broad-woven fabric mills	Unknown.	Yes, both natural and synthetic fibres.	
			31322/313220 Narrow fabric mills and Schiffli machine embroidery	Unknown.	Yes, both natural and synthetic fibres.	
			31323/313230 Nonwoven fabric mills	Unknown.	Yes, both natural and synthetic fibres.	
			31324/313240 Knit fabric mills	Unknown.	Yes, both natural and synthetic fibres.	
		3133 Textile and fabric finishing and fabric coating	31331/313310 Textile and fabric finishing	Likely for some processes (bleaching, dyeing, washing).	Yes, both natural and synthetic fibres.	Processes like bleaching, dyeing, and washing would likely result in a wastewater being produced and discharged.
			31332/313320 Fabric coating	Unknown.	Yes, both natural and synthetic fibres.	
	314 Textile product mills:	3141 Textile furnishings mills:	31411/314110 Carpet and rug mills	Unknown.	Yes, both natural and synthetic fibres.	
			31412/314120 Curtain and linen mills	Unknown.	Yes, both natural and synthetic fibres.	
		3149 Other textile product mills	31491/314910 Textile bag and canvas mills	Unknown.	Yes, both natural and synthetic fibres.	

			31499 All other textile product mills	Unknown.	Yes, both natural and synthetic fibres.	
	315 Clothing manufacturing	3151 Clothing knitting mills	31511/315110 Hosiery and sock mills	Unknown.	Yes, both natural and synthetic fibres.	
			31519/315190 Other clothing knitting mill	Unknown.	Yes, both natural and synthetic fibres.	
		3152 Cut and sew clothing manufacturing	31521/315210 Cut and sew clothing contracting	Unknown.	Yes, both natural and synthetic fibres.	
			31522/315220/31524/315241/315249 Cut and sew clothing manufacturing: Men's, boy's, infant’s, women's, girl's	Unknown.	Yes, both natural and synthetic fibres.	
			315280 Other cut and sew clothing manufacturing	Unknown.	Yes, both natural and synthetic fibres.	Some businesses in this category do not work with synthetic fibres. For example, businesses who state they deal primarily in "leather and sheep-lined clothing" were deleted from the database.
		3159 Clothing accessories and other clothing manufacturing	31599/315990 Clothing accessories and other clothing manufacturing	Unknown.	Yes, both natural and synthetic fibres.	
	316	3162 Footwear manufacturing	31621/316210 Footwear manufacturing	Unknown.	Yes, both natural and synthetic fibres.	
	325	3252 Resin, synthetic rubber, and artificial and	32521 Resin and synthetic rubber manufacturing	Unknown.	Unlikely to produce fibres.	

	Chemical manufacturing	synthetic fibres and filaments manufacturing	325220 Artificial and synthetic fibres and filaments manufacturing	Unknown.	Yes, both synthetic fibres and artificial fibres (e.g. man-made fibres from natural materials such as cellulose).	
		3255 Paint, coating and adhesive manufacturing	32551/325510 Paint and coating manufacturing	Unknown.	Unlikely to produce fibres.	
			32552/325520 Adhesive manufacturing	Unknown.	Unlikely to produce fibres.	
		3259	325998 All Other Miscellaneous Chemical Product and Preparation Manufacturing	Unknown.	Unlikely to produce fibres.	Only two companies match this code, they don’t appear to manufacture chemicals relevant to MPs.
	326 Plastics and rubber products manufacturing	3261 Plastic product manufacturing	326111 Plastic bag and pouch manufacturing	Unknown.	Unlikely to produce fibres.	These companies could use plastic pellets (MPs) as their raw material - opportunities for spills.
			326112 Plastics Packaging Film and Sheet (including Laminated) Manufacturing	Unknown.	Unlikely to produce fibres.	These companies could use plastic pellets (MPs) as their raw material - opportunities for spills.
			326113 Unlaminated Plastics Film and Sheet (except Packaging) Manufacturing	Unknown.	Unlikely to produce fibres.	These companies could use plastic pellets (MPs) as their raw material - opportunities for spills.
			32612 Plastic pipe, pipe fitting, and unlaminated profile shape manufacturing	Unknown.	Unlikely to produce fibres.	These companies could use plastic pellets (MPs) as their raw material - opportunities for spills.
			326122	Unknown.	Unlikely to produce fibres.	These companies could use plastic pellets (MPs)

			Plastic pipe and pipe fitting manufacturing			as their raw material - opportunities for spills.
			326130 Laminated plastic plate, sheet (except packaging), and shape manufacturing	Unknown.	Unlikely to produce fibres.	
			326150 Urethane and other foam product (except polystyrene) manufacturing	Unknown.	Unlikely to produce fibres.	These companies could use plastic pellets (MPs) as their raw material - opportunities for spills.
			326191 Plastic plumbing fixture manufacturing	Unknown.	Unlikely to produce fibres.	These companies could use plastic pellets (MPs) as their raw material - opportunities for spills.
			326199 All Other Plastics Product Manufacturing	Unknown.		These companies could use plastic pellets (MPs) as their raw material - opportunities for spills.
		3262 Rubber product manufacturing	326211 Tire Manufacturing (except Retreading)	Unknown.	Unlikely to produce fibres.	
			326212 Tire Retreading	Unknown.	Unlikely to produce fibres.	
			326220 Rubber and plastic hose and belting manufacturing	Unknown.	Unlikely to produce fibres.	
			32629 Other rubber product manufacturing	Unknown.	Unlikely to produce fibres.	
			326291 Rubber Product Manufacturing for Mechanical Use	Unknown.	Unlikely to produce fibres.	

			326299 All Other Rubber Product Manufacturing	Unknown.	Unlikely to produce fibres.	
	339 Miscellaneous manufacturing:		339930 Doll, toy and game manufacturing	Unknown.	Unlikely to produce fibres.	May or may not use plastic as a material. Businesses have been examined individually and those that do not use plastics have been deleted from the database.
56 Administrative and support, waste management and remediation services	562 Waste management and remediation services	5621 Waste collection	562112 Hazardous Waste Collection	Unknown.	Unlikely to produce fibres.	Only 1 result returned for this code.
			562119 Other Waste Collection	Unknown.	Unlikely to produce fibres.	Only 1 result returned for this code.
		5622 Waste treatment and disposal	562211 Hazardous Waste Treatment and Disposal	Unknown.	Unlikely to produce fibres.	
			562212 Solid Waste Landfill	Yes, leachate is collected and sent to WWTPs.	Yes, synthetic and natural fibres and other microplastic shapes.	
			562219 Other Nonhazardous Waste Treatment and Disposal	Unknown.	Unlikely to produce fibres.	
		5629 Remediation and other waste management services	562920 Material recovery facilities		Unlikely to produce fibres.	It sounds like these facilities are only sorting recyclable material from other waste streams, not actually physically or chemically manipulating the materials. It is unclear whether these businesses are a source of MPs.

81 Other services	812 Personal and laundry services	8123 Dry cleaning and laundry services	812310 Coin-operated laundries and dry cleaners	Yes.	Yes, both natural and synthetic fibres.	
			812320 Dry cleaning and laundry services (except coin-operated)	Yes.	Yes, both natural and synthetic fibres.	
			81233 Linen and uniform supply	Yes.	Yes, both natural and synthetic fibres.	
			812331 Linen Supply	Yes.	Yes, both natural and synthetic fibres.	
			812332 Industrial Launderers	Yes.	Yes, both natural and synthetic fibres.	
		8129 Other personal services:	812930 Parking lots and garages	Yes, run-off from rain or from washing parking garages will result in discharge of water.	Unlikely to produce fibres.	If parking lot/garage is in a catchment area where storm run-off enters a WWTP, this may be a source of MPs from tire wear.