Hydrodynamic modelling of microplastic transport

A case study on microplastics from traffic emissions in the Göta River

Master's thesis in the Master Programme Infrastructural and Environmental Engineering

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Cover: A visualization of microplastic transport in the Göta River, constructed in MIKE Powered by DHI.

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Abstract

The consequences of plastic debris are not just what the eyes can see but also the small particles – microplastics – caused by degradation of plastic items. Microplastics are particles with size $\leq$ 5 mm.

Since plastics have a wide range of applications, there are multiple possible emission sources of microplastics to water. According to the literature, the greatest land-based source of microplastic is road traffic with 13 500 tonnes annually only in Sweden. The Göta River is surrounded by the most trafficked roads in Gothenburg. Therefore, it is interesting to study the transport and fate of microplastic particles entering the river.

The aim of this thesis is to study microplastic transport through hydrodynamic modelling and investigate the behaviour of microplastic particles once they are released into the Göta River. In order to carry out the study, three different scenarios have been simulated with the software MIKE 3 Flow Module FM (MIKE Powered by DHI). The simulated scenarios differ in settling velocity and the number of emission sources.

Considering the high density, the microplastic particles (from traffic related sources) are likely to settle at the bottom of the Göta River. The simulations conducted in this thesis confirm this; the harbour and the moat are shown to be the areas with a higher risk of microplastic sedimentation. However, particles in smaller size will still end up in the Kattegat sea.

Microplastic and its properties can pose a health problem for humans and marine organisms. Thus, increased awareness of own plastic consumption, reduction of plastic and rubber use and finding replacement materials for plastics will be the most important questions in the future.

Keywords: Göta River, hydrodynamic modelling, microplastics, MIKE Powered by DHI, stormwater, traffic-related sources.

Hydrodynamisk modellering av mikroplasttransport
En fallstudie om mikroplaster från trafikutsläpp till Göta älv.
Examenarbete inom mastersprogrammet Infrastruktur och Miljöteknik
AI LINH NGUYEN
Institutionen för Arkitektur och samhällsbyggnadsteknik
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Sammanfattning

Konsekvenserna av nedskräpning av plast är inte bara vad ögat kan se utan även de små partiklarna - mikroplaster - som uppstår genom nedbrytning av plastföremål. Mikroplast är partiklar med diameter ≤ 5 mm.

Eftersom plast har ett brett användningsområde finns det flera möjliga utsläppskällor som leder till mikroplasters förekomst i vatten. Enligt litteraturen är vägtrafik den största landbaserade källan till mikroplaster med 13 500 ton årligen enbart i Sverige. Göta älv är omgiven av de mest trafikerade vägarna i Göteborg. Därför är det intressant att studera mikroplast-partiklarnas transport i Göta älv.

Syftet med detta examensarbete är att studera mikroplast transport med hydrodynamisk modellering och mikroplastpartiklas beteende när det släpps ut i Göta älv. För att genomföra studien har tre olika scenarier simulerats med mjukvaran MIKE 3 Flow Module FM (MIKE Powered by DHI). Skillnaden mellan scenarierna är sedimenteringshastigheten och antal utsläppspunkter.

Med tanke på höga densitet kommer partiklarna (från traffik relaterad källor) att sedimentera i Göta älv. Resultaten från simuleringarna styrker detta; hamnen och vallgraven visar sig vara de områden med högst risk för mikroplast sedimentering. Partiklarna i mindre storlek kan emellertid transporteras ut i havet.

Mikroplast och dess egenskaper kan utgöra hälsoproblem för människor och marina organismer. Därmed är ökad medvetenhet om vår egna plastförbrukning, minskad användning av plast och gummi, samt att hitta ersättningsmaterial för plast de viktigaste frågor i framtiden.

Nyckelord: Göta älv, hydrodynamisk modellering, mikroplast, MIKE Powered by DHI, trafik-relaterade källor.

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Preface

First and foremost, I would like to thank my examiner, Karin Björklund, and my supervisor, Mia Bondelind, with whole my heart for their continuous support. This master's thesis could not have been done without their guidance och inspiration. They were always patient and helpful. The journey has been fun and instructive thanks to them.

Furthermore, I would like to thank Kretslopp och Vatten, for providing me with the completed hydrodynamic model and Ekaterina Sokolova, for her help with software MIKE Powered by DHI.

Lastly, I want to thank my family and my partner, Svante Karlsson, for their unwavering trust and support to me.
I am grateful!

Ai Linh Nguyen, Gothenburg, November 2018

Abbreviations

Brominated flame-retardant	BFR
Dibutylphthalate	DBP
Ecology and water quality module	ECO lab
High density	HD
Perfluorinated compounds	PFC
Hexabromocyclododecane	HBCD
Low density	LD
Low density polyethylene	LDPE
Microplastic	MP
Polybrominated biphenyls	PBB
Polybrominated diphenyl ether	PBDE
Polybutadiene Rubber	BR
Polycarbonate	PC
Polyethylene	PE
Polytetrafluoroethylene	PTFE
Polyisoprene Rubber	IR
Polypropylene	PP
Polystyrene	PS
Polyvinylchloride	PVC
Styrene-Butadiene Rubber	SBR
Tetrabromobisphenol A	TBBPA

1 Introduction

Plastic is a material with very long degradation time, it could take a millennium for plastic to completely degrade. Over time, plastic may be decomposed into microplastic particles. According to the definition by the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), the size of microplastics ranges from 1 nm - 5 mm. Due to its size, microplastic is easily consumed by organisms and therefore easily transferred between food chains. The effects of consuming microplastic are different between different organisms but the effects are all negative and in the worst case could lead to disease and/or decrease of reproduction of one species (Kärrman et al., 2016).

The first study of microplastics was published in 1983. Since then, only a few studies have been published each year up until the last couple of years. Research on the subject has increased drastically, but there is still no specific method to collect or prevent the entering of microplastics into the marine environment (Kärrman et al., 2016). As knowledge on the subject is limited and because of the risk of great environmental impact, it is interesting to study microplastics from sources to final fate, which is often sediment burial.

It is estimated that 70–80 % of marine microplastics originates from land-based sources, transported mainly via rivers (Dehghani et al., 2017). A report on microplastic by the Swedish Water & Wastewater Association presented that the most significant source of microplastics is road traffic, for example, wear of roads and tires (Svenskt Vatten, 2016). The emitted amount of MP in Sweden alone adds up to thousands of tonnes every year and in 2016 the total emissions from wear of tires in the Netherlands, Norway, Sweden, Denmark, Italy, Germany, United Kingdom, Japan, China, India, Australia, America and Brazil together were estimated to 3.4 million tonnes (Kole et al., 2017). At second place comes emissions from artificial grass, and even daily hygienic products, such as toothpaste and cleaning products contribute to a large proportion of microplastic emissions (Svenskt Vatten, 2016).

This study focuses on microplastic emissions from traffic-related sources to a receiving freshwater body. The study area is a part of the Göta River, the longest watercourse in Sweden. The Göta River starts at the lake Vänern, continues through the city of Gothenburg then flows out to the sea (Eklund, 2010). The Göta River is used for many different purposes, one being a source of drinking water for about 700 000 people (Water Quality Association of the Göta älv, 2016). In order to prevent health issues with water ingestion, it is important to keep the water in the Göta River free from pollution, including microplastics.

1.1 Aim and objectives

The aim of this thesis is to study microplastic transport through hydrodynamic modelling and investigate the behaviour of microplastic particles once they are released into the Göta River. To reach the goal, this study is divided into the following objectives:

- Review the behaviour of microplastic particles by literature study.
- Model three different scenarios of microplastic emissions into the river.
- Study and compare the results from different modelled scenarios.

1.2 Research questions

To give a clearer picture over the properties and fate of microplastics released into the Göta River, the following questions were studied:

- The size of microplastics could be between 1 nm - 5 mm, what is the typical size of microplastic generated by traffic? What is the dominant type of plastics in traffic-related runoff?
- Research the density of microplastic particles: will the particles sink or float?
- If the particles sink, will they settle at the bottom of Göta River?
- If the particles do not sink, at which depth could the particles be found?
- How does the flow affect the settling of microplastics in the Göta River?
- How will the location of emission sources affect the behaviour of particles?

1.3 Limitations

- The study area is limited to stretch between Lärjeholm and the old fort of Älvsborg with focus on microplastic from traffic-related sources.
- The input-data used for simulations are based on assumptions with the support of the literature study as no measurements of microplastics were performed in this study. Analysis of microplastic occurrence in the Göta River is not possible due to lack of resources. Thus no validation of simulation results has been performed.

2 Literature review

In this chapter, the theory about microplastics and their environmental impact are presented.

2.1 Emission sources of microplastics

Since the beginning of mass production of plastic in the mid-19th century, the production of plastic has steadily increased each year (Barnes et al., 2009). In 2016, the global plastic production (plastic materials such as thermoplastics, polyurethanes, thermosets, adhesives coatings and sealants) increased to 335 million tonnes, and 18% of it is produced in Europe. This data does not include polyethylene terephthalate (PET), polyamide (PA), polypropylene (PP) and polyacrylic fibres (PlasticsEurope, 2017). In a study from 2010, it was estimated that there are approximately 12.7 million tonnes of microplastics in the sea, with polyethene (PE) and polypropylene (PP) being the most common plastic types (Jambeck et al., 2015).

Plastics have a wide range of applications, which leads to a wide range of possible emission sources (Table 2.1). According to a study by Svenskt Vatten (2016), the greatest source of microplastic emission is road traffic with around 13500 tonnes annually. Approximately 58% of the total emission is wear of tires (Magnusson et al., 2016). From the city of Gothenburg, approximately 178 - 543 tonnes of microplastics are released annually (Kole et al., 2017). Another important source is artificial grass with 3900 tonnes of microplastic emissions per year (Svenskt Vatten, 2016). Microplastics are also emitted from households, for example through the wear of clothes during laundry or from detergents and cosmetic products. The volume of household emissions may reach up to 19 tonnes each year (Svenskt Vatten, 2016). For the most significant sources of emissions mentioned, it is possible to track the number of microplastics produced each year. However, there are only a few sources where it is possible to quantify the number of microplastics that end up in water. These trackable sources all share the same property: the wear of plastics occurs directly in the marine waters. Examples of sources with direct emissions to the sea are wear of paint on boat hulls and wear of fishery products. These are not classified as a dominant emission source of microplastics, yet release between 4 and 1360 tonnes of microplastics per year to the sea (Svenskt Vatten, 2016).

Mermaid tears, plastic pellets and nibs are all the same thing: plastic particles before it is melted and moulded to different plastic products. It is not just pre-made plastic products that pollute the environment. Loss of plastic pellets during transport and production causes tonnes of microplastic emissions (Magnusson et al., 2016).

Table 2.1 Estimated emitted loads (in tonnes) of microplastics from different sources.

Emission source	Quantity of MP [tonnes]	Quantity of MP that reach the marina waters [tonnes]	Geographical scale	Reference
Plastic in total	335000000	no data	Global	PlasticsEurope (2017)
Plastic in total	60300000	no data	Europe	PlasticsEurope (2017)
Road traffic	13500	no data	Sweden	Svenskt Vatten (2016)
Road traffic	178 - 543	no data	Gothenburg	Jannö (2016)
Artificial grass	2300 - 3900	no data	Sweden	Svenskt Vatten (2016)
Wear of paint on boat hulls & fishery products	4 - 1360	4 - 1360	Sweden	Svenskt Vatten (2016)
Plastic pellets lost	300 - 530	no data	Sweden	Magnusson et al. (2016)
Household	1.4 - 19	no data	Sweden	Magnusson et al. (2016)

2.2 Polymer and rubber types

The consumption of plastics is steadily increasing, and millions of tonnes of microplastic emissions end up in the sea every year (Jambeck et al., 2015). However, plastic is not a material but a collective name for many polymer based materials, which also makes rubber count as plastic. Common plastic materials include: Polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), polyester, polycarbonate (PC), nylon and polytetrafluoroethylene (PTFE) also known as Teflon. These materials can be found in many everyday products, such as water bottles, kitchen utensils, nappy bottles, disposable items, pans, plastic films, plastic bags and more (Livsmedelsverket, 2017).
Tires make up a majority of microplastics released from traffic, which is the largest source of microplastic emissions (Magnusson et al., 2016). More than half of the rubber content used during the manufacturing process of tires is synthetic rubber, a by-product of petroleum (Michelin, 2018). Synthetic rubbers used in tire manufacturing are, for example (Siemens AG, 2013):

- Styrene-Butadiene Rubber (SBR)
- Polybutadiene Rubber (BR)
- Polyisoprene Rubber (IR)

Although the weight of a tire could vary among manufacturers, the density of the common ingredients are the same. Table 2.2 presents the density of the rubber together with different types of plastics. The density of synthetic rubber and the most common plastic material (PE, PP, PS, PVC and PC) are close to each other, except for PTFE with a density of 2200 kg/m^3.

Table 2.2 The density of different types of plastic and rubber materials.

Polymwer/rubber	Density kg/m^3	Reference
High density black pellet	1055	Ballent et al. (2013)
Polycaprolactone (PCL)	1131	Khatmullina and Isachenko (2017)
Low density polyethylene (PE-LD)	930	Scherer et al. (2018)
Natural rubber	920	Scherer et al. (2018)
High density polyethylene (PE-HD)	970	Scherer et al. (2018)
PP	940	Scherer et al. (2018)
PS	1050	Scherer et al. (2018)
PVC	1385	PolymerProcessing.com (n.d.-c)
PC	1200	PolymerProcessing.com (n.d.-a)
PTFE	2200	AFT Fluorotec Limited (2016)
PE	855	PolymerProcessing.com (n.d.-b)
Styrene - butadiene Rubber	1010	MakeItFrom (2018)
Polybutadiene Rubber	1000	MATBASE (n.d.-b)
Polyisoprene Rubber	930	MATBASE (n.d.-a)
Tire wear particles	1700 - 2100	Vogelsang et al. (2018)

In a study at Terra Nova Bay, the most common material of microplastic found in the sediment is Styrene-Butadiene-Styrene (SBS) (Munari et al., 2017). The material shares similar functions as SBR and has both plastic and rubber features (Encyclopaedia Britannic, 2009).

2.2.1 Additives in plastic materials

The differences in the properties of plastics depend on polymer type and additives, and the variations are many (Naturskyddsföreningen, n.d.). According to Daun (2017), the four most common plastic additives are Bisphenol A, brominated flame retardants, phthalates, and highly fluorinated substances. Bisphenol A is an essential additive in the manufacturing of for example PVC. Bisphenol A exhibits adverse effects on human health, such as hormonal effects, higher risk of miscarriage and increased/decreased activity level of Thyroid. Bisphenol A in animals is carcinogenic, causes defects in the immune system and increases the risk of abnormalities and/or delayed development in the next generation (Daun, 2017).

Brominated flame-retardants (BFRs) are substances with the primary objective of protecting flammable products against fire. There are more than 70 BFR compounds on the market with polybrominated diphenyl ether (PBDE), tetrabromobisphenol A (PBBPA) and hexabromocyclododecane (HBCD) as the most common ones (Livsmedelsverket, 2016). Prohibition of BFRs has been an important issue since the discovery of their negative health impacts. Still, the only ban that has ever been reviewed in the EU is a ban on PBDE in 2004 (Cousins et al., 2015). In 2002 TBBPA was the world's most common BFR with annual production of 130 thousand tonnes. There are traces of TBBPA in most common household electric equipment, such as TVs and phones. The concentration of TBBPA in the human body has increased, and with a half-life of 48 hours it can accumulate in the human body (Lyche et al., 2015). Yet not all BFRs are toxic to the environment, but there is still a risk of leaching from products (Daun, 2017). Most BFR substances bind strongly to fat, hence the marine species that have a higher fat content are more exposed to BFRs and among those species are fish that humans consume, such as salmon, herring and trout (Livsmedelsverket, 2016).

According to the Swedish National Food Agency, the average intake of PBDE for an adult is 16 ng/d and of HBCD is 11 ng/d. Prolonged exposure to PBDE will have an impact on the liver, kidneys and thyroid (Livsmedelsverket, 2016).

Phthalates are substances that makes plastics soft and elastic, used for example in the soft plastic print on clothing (Kemikalieinspektionen, 2016a) or as plasticisers in PVC (Kemikalieinspektionen, 2016b). Phthalates are leached throughout the lifespan of the plastic product since the compounds are not attached to the PVC polymer. Several phthalates are classified as teratogenic and could give rise to reproduction disorders. Phthalates such as dibutyl phthalate (DBP) are classified as hazardous to the environment and highly toxic to aquatic organisms (Kemikalieinspektionen, 2016b).

Highly fluorinated substances (PFAS) are a substance group with over 3000 different artificial chemicals that can be found, for example, in impregnation and fire foam (Norström, 2017). The degradation time for PFASs is slow to non-existent, but unlike the previously mentioned additives, PFASs do not bind to adipose tissue but to proteins, or are stored in organs due to their water repellent properties (Daun, 2017).

The dominating synthetic rubber, SBR represent 50% of the world rubber production. The combination is based on 75% of Butadiene and 25% of Styrene (Encyclopaedia Britannic, 2018). Styrene is a liquid hydrocarbon and has the task of softening rubber and plastic materials. The substance is neurotoxic if inhaled or ingested, and causes irritation in contact with eyes and skin (Encyclopaedia Britannic, 2017). The International Agency for Research on Cancer (IARC) has classified Styrene as "*probably carcinogenic to humans*" in group 2A (IARC, 2017).

2.3 Size and shape of microplastic particles

Based on information from multiple sources, the sizes of microplastic is defined to be below 5 mm, but the lowest limit is defined differently. Table 2.3 presents a summary of the properties of microplastics that are collected from different sources and shows that the definition of microplastic is not entirely unambiguous. Most of the articles referred to in this study defined microplastic as particles with size less than 5 mm, yet there are studies that draw the lower limit of microplastic at 1 µm and define smaller particles than that as nanoplastic (Svenskt Vatten, 2016), macroplastic as $>$ 5 mm and mesoplastic as $\leq$ 5 mm (Scherer et al., 2018). The size of microplastic is dependent on the degradation process since microplastics are usually created by the breakdown of larger plastic products (Eerkes-Medrano et al., 2015). The degradation process could continue for centuries (Kärrman et al., 2016).

Table 2.3 Defined size ranges of microplastics from different references.

Article title	Reference	Size ranges
Swedish sources and pathways for microplastics to the marine environment	Magnusson et al. (2016)	1 µm - 5 mm
Exposure and effects of microplastics on wildlife: A review of existing data	Kärrman et al. (2016)	1 nm - 5 mm
Mikroplast i dagvatten och spillvatten: Avskiljning i dagvatten-dammar och anlagda våtmarker; Wear and tear of tyres: A stealthy source of microplastics in the environment	Jönsson (2016); Kole et al. (2017)	$\leq$ 5mm
Mikroplaster – källor och uppströmsarbetesamt möjligheter till rening vid kommunala reningsverk; Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs; Biofouling on buoyant marine plastics: An experimental study into the effect of size on surface longevity; Sinking rates of microplastics and potential implications of their alteration by physical, biological, and chemical factors; High Quantities of Microplastic in Arctic Deep-Sea Sediments from the Hausgarten Observatory; Settling velocity of microplastic particles of regular shapes; Fate of nano- and microplastic in freshwater systems: A modelling study; Effects of biofouling on the sinking behavior of microplastics	Svenskt Vatten (2016); Eerkes-Medrano et al. (2015); Fazey and Ryan (2016); (Kowalski et al., 2016); Bergmann et al. (2017); Khatmullina and Isachenko (2017); (Besseling et al., 2017); (Kaiser et al., 2017)	<5 mm
Interactions of microplastics with freshwater biota	Scherer et al. (2018)	$>$ 1 µm - $\leq$ 1mm

Apart from the density of microplastics and the density of the surrounding environment, the shape of the particles also has a role in the settling rate. The common appearance of the microplastics found in the ocean is usually long and narrow fibre-shaped, pellet-shaped and/or irregular fragment. Table 2.4 presents the settling velocity for different types of microplastics. Particles with spherical shape settle faster than those that are angular (Khatmullina & Isachenko, 2017).

Table 2.4 The settling velocity V_s depends on properties of the particle, such as polymer type, shape, size, and the salinity in the marine environment. The polymer types presented in the table are virgin materials except for the fishing lines which are aged lines found at the coastline.

Polymer type	Shape	Size [mm]	Salinity [g/kg]	V_s[m/s]	Source
Polystyrene (PS)	Cylindrical	1.6 - 1.8	0, 15, 36	0.006 - 0.0205	Kowalski et al. (2016)
Polyamide (PA)	Nodular	1.3 - 3.6	0, 15, 36	0.012 - 0.09	
Polymethyl methacrylate (PMMA)	Angular	0.5 - 2.3	0, 15, 36	0.005 - 0.05	
Polyethylene terephthalate (PET)	Angular	0.4 - 2.6	0, 15, 36	0.01 - 0.07	
Polyoxymethylene (POM)	Angular	0.3 - 2.3	0, 15, 36	0.004 - 0.09	
polyvinyl (PVC)	Nodular	0.5 - 2.5	0, 15, 36	0.005 - 0.091	
Fishing lines cuts	Long & small cylindrical	0.15	No data	0.005 - 0.0089	Khatmullina & Isachenko (2017)
		0.22		0.006 - 0.0158	
		0.34		0.0103 - 0.0149	
		0.46		0.014 - 0.0208	
		0.6		0.0192 - 0.0259	
		0.71		0.0201 - 0.0263	
Polycaprolactone (PCL)	Spheres	0.9 - 4.9		0.0272 - 0.127	
	Cylindrical	0.59 - 5.09		0.0137 - 0.0971	

Since the most significant emission source of microplastics is road traffic, it is of interest to study the most common particle size range of microplastics in road runoff (Svenskt Vatten, 2016). Three studies of wear and tear of tires have been carried out by Kreider et al. (2010), Mathissen et al. (2011) and Kaul et al. (2009). The tests were carried out on different types of road pavement, and the results are presented in Table 2.5. The first test (Kreider et al., 2010) was performed on a concrete asphalt pavement. The result of the test showed that microplastic particles of 4 - 350 µm were generated and particles in sizes 5 µm and 25 µm were the most common. The second test (Kaul et al., 2009) was performed on concrete with sand and granite bound to cement. The collected particles had a size range between 0.3 - 20 µm with 0.3 µm and 1 µm as the dominant sizes. The last test (Mathissen et al., 2011) was carried out on a pre-existing road in a closed area, under different driving conditions such as acceleration, braking and swing. The collected particles from this test had a size range between 6 - 562 nm, mostly between 30 - 60 nm (Kole et al., 2017).

Table 2.5 Sizes of the particles from wear and tear of tires on different pavements by Kaul et al. (2009), Kreider et al. (2010) and Mathissen et al. (2011).

Study	Particle size	Dominant size
Concrete asphalt pavement	4 - 350 µm	∼5 µm , ∼25 µm
Concrete with sand and granite bound to cement	0.3- 20 µm	∼0.3 µm , ∼1 µm
Car wheel housing	6 - 562 nm	30 - 60 nm

2.4 Biofouling of microplastics

One factor influencing the sedimentation of microplastics is biofouling. After having been in the water for a while, a biofilm begins to form on the particle. This creates an opportunity for the lighter polymer to settle (faster) since the biofilm increases its density (Kärrman et al., 2016). The biofouling process is slow, an experiment in marine environment showed that to increase the chance of sedimentation by 50%, 17 - 66 days of exposure time is required (Fazey & Ryan, 2016).

The biofilm consists of organisms like bacteria, algae or mussels. One study has shown that after six weeks, the blue mussel *Mytilus edulis* begins to grow on polyethylene (PE). Biofilms do not grow continuously and can also be broken down after a certain amount of time. This means that the microplastics that have already settled at the bottom of a water-body may after some time rise again. Table 2.6 presents the result of a biofouling study showing that biofilm formed more easily on PS than on PE, which sinks after six weeks exposure to the estuary and marine water. The settling velocity increased with 170 m/d in estuary water and 264 m/d in marine water (Kaiser et al., 2017).

Table 2.6 Settling velocity (Vs) before and after biofouling (Kaiser et al., 2017). The numbers are rounded to the nearest integers for this thesis.

	Vs before biofouling [m/d]		Vs after biofouling [m/d]		
	Estuary water	Atlantic Ocean	Estuary water	Atlantic Ocean	
PS	1300	776	1470	1040	After 2 weeks incubation
PE	0	0	0	864	After 6 weeks incubation

2.5 Effect of salinity

While calculating the settling velocity of a particle, the density of the fluid is an important variable. The density of water can change with temperature and salinity. The salinity of the sea varies a lot at the surface due to the amount of freshwater added by rain and/or freshwater sources such as rivers. The standard method of determining salinity is to weigh the salt in 1 kg water and express the ratio in part per thousands (ppt). The average salinity of seawater is between 34 - 36 ppt (Science Learning Hub, n.d.). Another unit used to express the salinity is practical salinity units (PSU) and is equivalent to ppt (James, 2017). Table 2.7 presents the difference in density and salinity of different marine waters. Comparison of table 2.2 and table 2.7 shows that more than 50% of the mentioned polymers will not sink to the bottom of the sea. Yet, polymers with higher density than the surrounded medium such as PTFE, PVC, PC etc. could be found on the seabed (Munari et al., 2017).

Table 2.7 The density of different types of water

	Density [kg/m^3]	**Salinity [g/kg]**	**Reference**
Saltwater	1026.7	No data	Ballent et al. (2013)
Coastal water	1005.6	10	Kaiser et al. (2017)
Estuarine water	1005.5	9.9	Kaiser et al. (2017)
Atlantic water	1025.3	36	Kaiser et al. (2017)
Ocean water	1025	No data	Kole et al. (2017)

As previously mentioned and as the Stoke´s law (Equation 2.1) show, the greater the density of the particle, the higher the settling velocity.

$$v = \frac{gd^2(\rho_{particle} - \rho_{water})}{18\mu} \tag{2.1}$$

- $g = acceleration\ of\ gravity\ [m/s^2]$
- $d = particle\ diameter\ [m]$
- $\rho_{particle} = density\ of\ particle\ [g/m^3]$
- $\rho_{water} = density\ of\ medium\ [g/m^3]$
- $\mu = viscosity\ of\ medium\ [g/ms]$

2.6 Environmental and health impacts of microplastics

Microplastics that are in the same size range as plankton and are often unintentionally ingested by predators from a higher level in the food chain (Anderson et al., 2016). Figure 2.1 illustrates the potential predators of plankton. Based on the consumption of molluscs in Europe, the average number of microplastic particles a person ingests is estimated to between 1800 and 11000 MP/year (Anderson et al., 2016). The health effect of the intake of microplastics itself for humans is often considered as harmless but the chemicals added and/or bound to particles could result in adverse health impacts. Currently, it is not entirely possible to predict the consequences of ingesting microplastic. One possible risk could be blood clots as a result of microplastics entering the circular system since there are capillaries with only a few µm in diameter. The mentioned effects only provide an indication of potential side effects on humans of ingestion of microplastics (Daun, 2017).

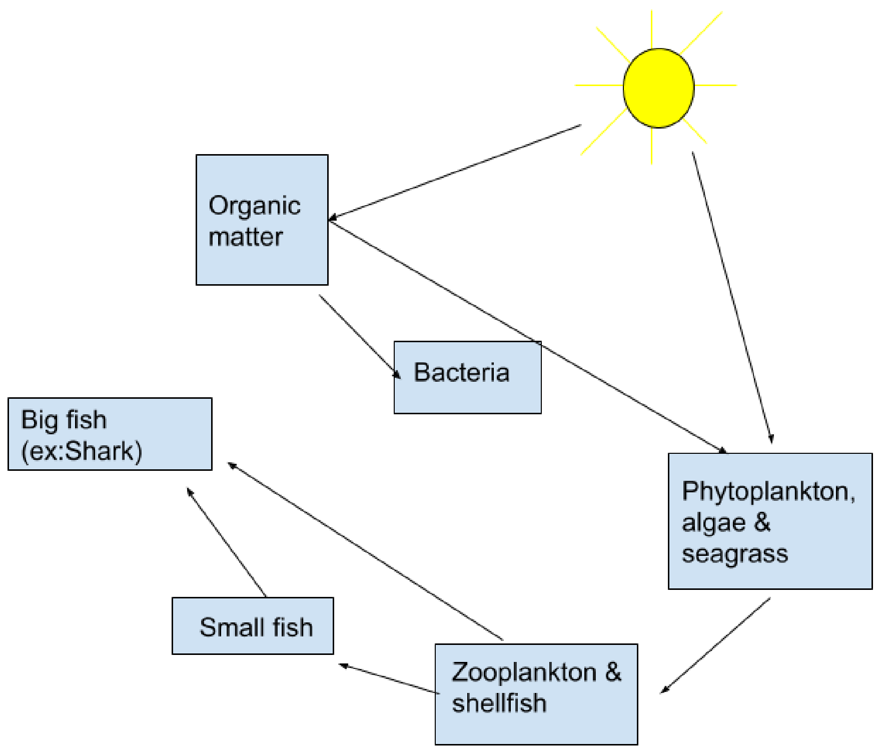


Figure 2.1: Marine food chain

The impacts of microplastics on the environment and animal health are more apparent. Algae that were exposed to PS during three days showed a reduction in growth since PS has the ability to absorb photosynthesis-generating algae such as *Chorrella* and *Scenedesmus spp.* In crustaceans, effects of PS include decreasing propagation and poorer developmental capacity in the next generation compared to the group receiving a controlled diet that did not contain PS (Anderson et al., 2016). In a similar study, effects on *Crusian carps* were both changes in behaviour and physical injuries. The group of *Crusian carps* that were fed with PS-fed *Daphnia magna* showed a definite decrease in activity level as well as heavier and more bloated brains than the control group (Mattsson et al., 2014).

2.7 Studies of microplastic transport in marina waters and rivers.

In the following sub-sections, related works within hydrodynamic modelling are presented. During this study only two works that are related by hydrodynamic modelling of microplastic and river was found.

Fate of nano- and microplastic in freshwater systems: A modeling study (Besseling et al., 2017).

In this study, land-based emission is defined as the biggest plastic emission source. The major pathway from the source to the sea is the household emission. The microplastic particles could be small particles that leaked from cosmetics products or fibres from washed synthetics material. The modelled microplastic particle sizes are from 100 nm to 10 nm with shapes of spherical and near-spherical and the biofouling process is included. The parameters that were used are literature based.

The aim of the study is to study the fate of nano- and microplastic in the Dommel River. The study is based on analysing theories and modelling with the NanoDUFLOW model. The equations included are formation processes of hetero- and homo aggregates and sedimentation equation based on Stoke´s law (Equation 2.1). Homo aggregates are performed by one type of particle and hetero aggregates are with multiple types of particles.

The results showed that the concentration of microplastic in the Dommel River reaches its steady stage within five days, and that the settling time is related to the size of the particle. The studies also showed that there are microplastic particles remained in the Dommel River. This phenomenon is believed to be depend on the particle size. Therefore, tyre dust with its size range of 60 - 80 µm, could remain in the Dommel River.

Modelled transport of benthic marine microplastic pollution in the Nazaré Canyon (Ballent et al., 2013)

Size classification of marine microplastic is in general difficult since the test needed to be performed in the deep sea. This is one of the reasons why only a few studies have been carried out on the subject. The aim of this study is to address the hydrodynamic behaviour of plastic pellets in the Nazaré Canyon. The first step was to determine the properties of the plastic pellet in the laboratory. The outcome parameters from the lab were then used as input data to the numerical model called MOHID Water Modelling System.

The results from this study showed that the transport of plastic pellets depends on the tidal forces. The plastic pellets in the model have a minor effect on the flow in the canyon. Storm activities during autumn and winter could be a possible reason for mass transportation of plastic pellets. Transportation in the canyon is irregular, the topography and the internal wave action are believed to be the reason of inhomogeneity.

3 Methods

In order to study microplastic emissions in the Göta River, three scenarios were set up with the modelling software - MIKE Powered by DHI. The input-data and assumptions for the scenarios were chosen carefully from the literature review before running the model.

3.1 Study area - a section of Göta River

Göta River has a length of 93 km and is the largest river in Sweden with a mean flow of 563 m^3/s (Water Quality Association of the Göta älv, 2016). The study area is a section of Göta River, starting at the raw water intake at Lärjeholm and to the old fort of Älvsborg (Figure 3.1). The two largest tributaries in the area are Säveån and Mölndalsån. Furthermore, there are two smaller streams connecting to the river - Fattighusån and Kvillebäcken. Figure 3.1 shows that many highways, such as the E6 and E45, are located close to the river.

Figure 3.1: Overview of the study area (Google Maps, 2018). Frihamnen is located within the red circle. Green = I (upstream), blue = II (middle) and purple = III (downstream).

In order to make it easier to understand the report, the north side of the river is from hereon called *Hisingen*, and the south side is called *City*. To facilitate the understanding of the outcomes, the river is divided into three parts (Figure 3.1): green = I (upstream), blue = II (middle) and purple = III (downstream).

3.2 Weather and simulation period

The simulated period is between 00:00 2015-07-05 and 24:00 2015-07-14. During this period, a number of rainfalls occurred as presented in Figure 3.2 (SMHI, 2018). The three most substantial rainfalls during this period occurred between the 7th and 9th of July. During the simulation period, the heaviest rainfall occurred at 2015.07.08 at 0.00 - 20.00 (Björklund et al., 2018) and the highest precipitation occurred at 16.00 during this day.

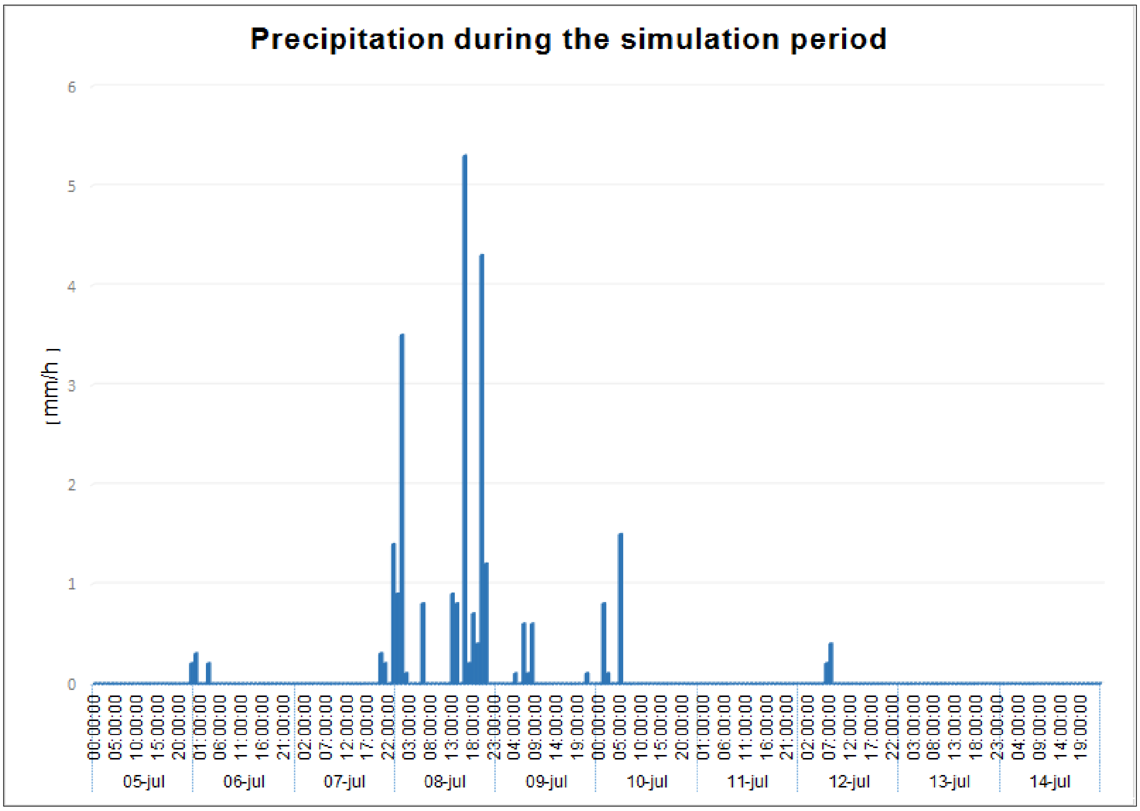


Figure 3.2: Precipitation during the simulation period

3.3 Mike 3 Flow Model FM

Mike 3 Flow Model FM (MIKE Powered by DHI) is a software that allows simulation of 3D activities in water such as flows, sedimentation and water quality processes. There are five different modules included with the software: Hydrodynamic Module, Particle tracking Module, Ecology and water quality Module (ECO lab), Sand transport Module and Mud transport Module (MIKE, 2013).

The simulation model of this thesis is based on two modules: the Hydrodynamic Module and ECO Lab Module. The Hydrodynamic Module is the basic module of MIKE 3 Flow Model FM (MIKE Powered by DHI) and can be used alone. In this study, it was used in order to simulate the water level and flows in the Göta River. The module is based on the numerical solution of Reynolds averaged Navier-Stokes equations (Ahlbom, 2011). The output parameters are computed for every time step and mesh and include information such as water depth, velocity, flow, salinity, and temperature. The ECO Lab Module is a numerical simulation software and enable simulation processes as water quality, eutrophication, heavy metals and ecology (MIKE, 2017).

3.4 Hydrodynamic model

The hydrodynamic model for this study was retrieved from earlier studies and has been validated in a previous study (Tyréns, 2016). The study area is a part of the Göta River and is 16 kilometres long, and the deepest level of the study area is around -15 meters (Figure 3.3). The depth (z-level) of the study area is divided into 18 layers with the thickness of 0.801 m/layer.

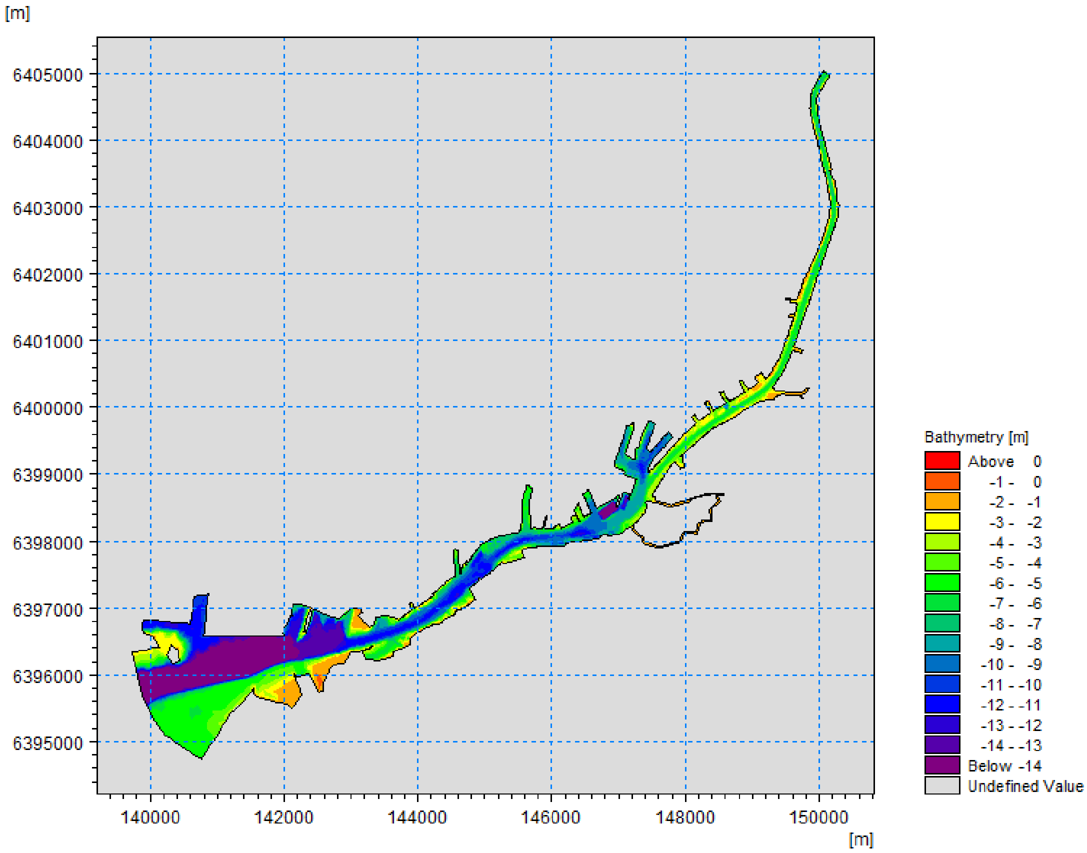


Figure 3.3: Bathymetry of the study area. The deepest areas are at -15 m and located at the mouth of the river. The dark purple square at the middle is a part of the old harbour activities.

Part III of the river and the region close to Lindholmen contains the deepest parts -15 meters (Figure 3.3). Its areas consist of coarser mesh, and therefore, no investigation will be carried out in that area. The mesh consists of both triangle and quadrangle boxes (Figure 3.4).

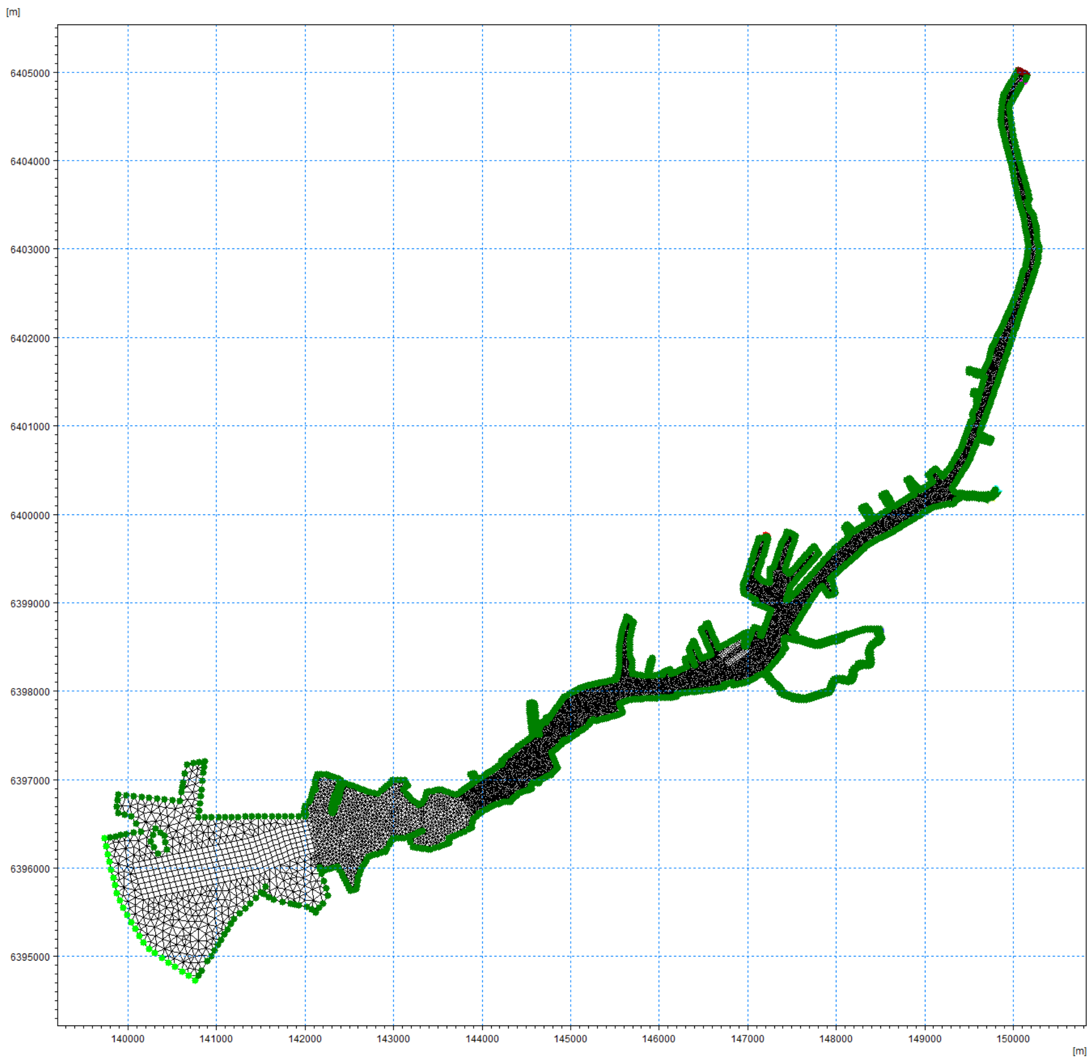
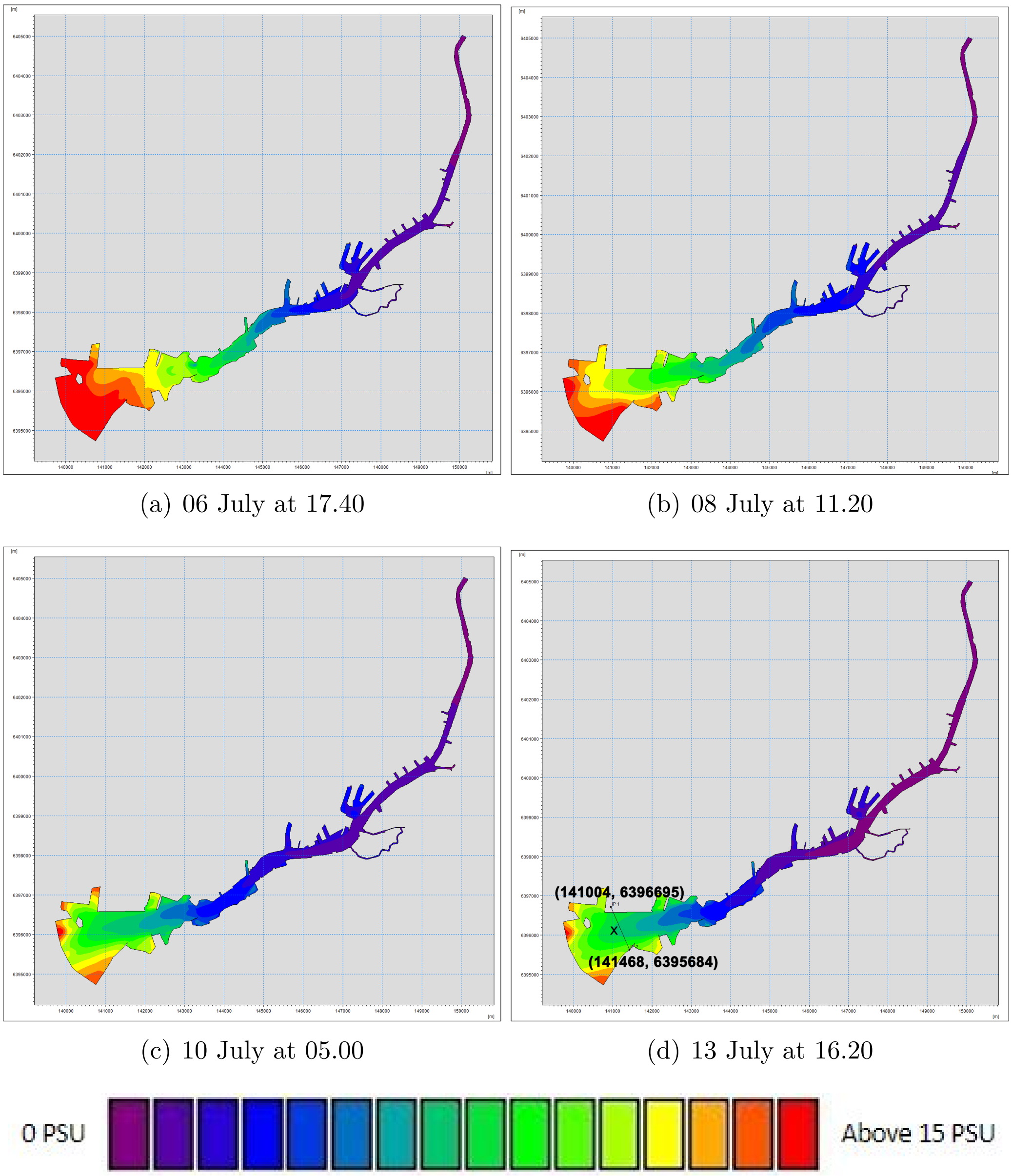


Figure 3.4: Description of the mesh of the study area. The denser the areas, the finer the mesh.

The Göta River is connected to the sea Kattegatt, hence the water in the river is not 100% freshwater, due to saltwater intrusion. In order to recreate a study area in MIKE 3 Flow Module FM that mimics reality, various salinity levels are added to the software. The highest salinity on the water surface is around 15 PSU in the downstream and 0 PSU in the upstream section of the river.



(a) 06 July at 17.40

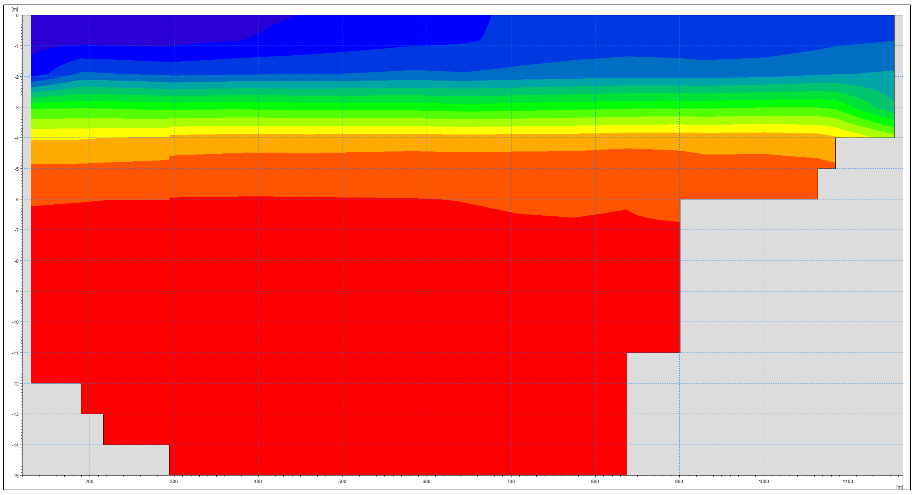
(b) 08 July at 11.20

(c) 10 July at 05.00

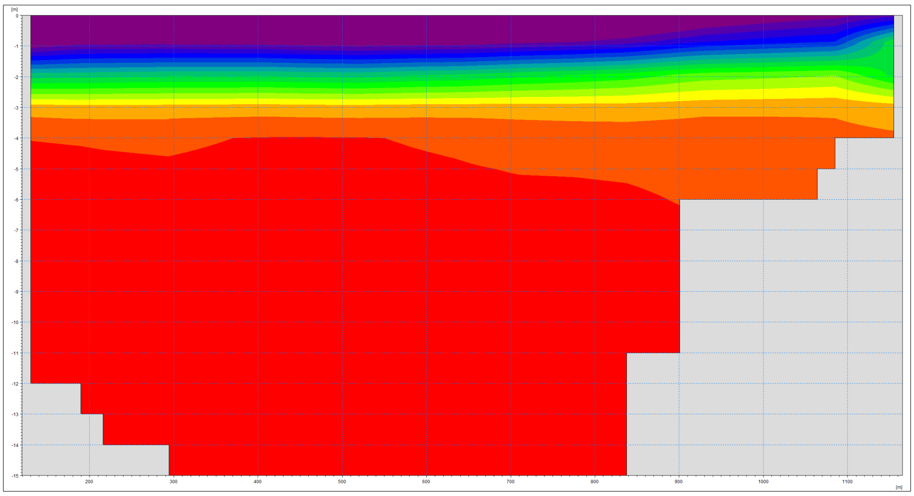
(d) 13 July at 16.20

Figure 3.5: Variation of salinity of the Göta River on the water surface.

In addition to the distance to the sea, the salinity also depends on the depth. Figure 3.6 illustrates an example of the salinity from a cross section at position X (Figure 3.5 d). The highest salinity at this location is above 22.4 PSU. Figures 3.5 and 3.6 are snapshots from 2015-07-13 at 16:20.



(a) 06 July at 17.40



(b) 13 July at 16.20

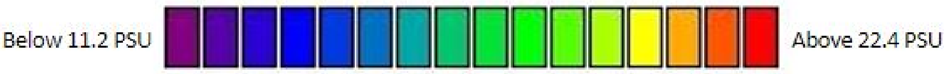
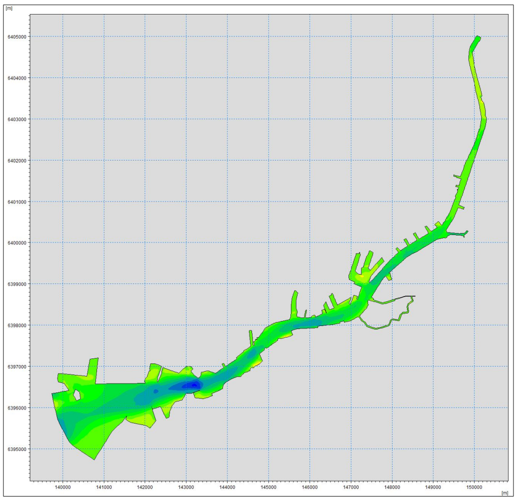


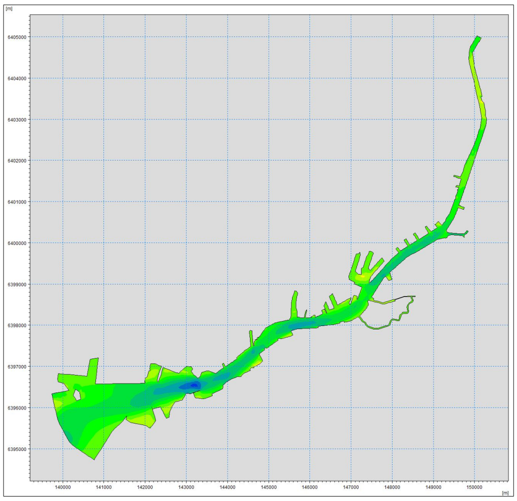
Figure 3.6: Salinity of the study area at the cross section at position X at 17.40, 2015-07-06 and at 16:20, 2015-07-13.

3.4.1 Flow and velocity pattern

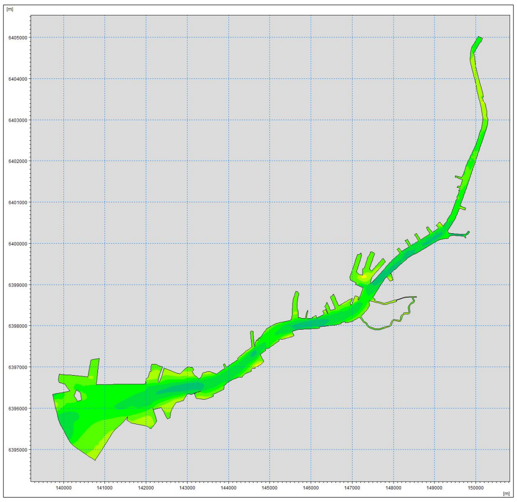
Figure 3.7 presentes the velocity pattern in the Göta River at the surface. The water velocity varies over time in the Göta River. The variation is due to the inflows of different surrounding streams and the sluices that control the flow of the Göta River. Rain and water that discharge from different pipe systems also has an effect on the river's flow pattern. Due to the geometry of the river and the high flow, the flow has a smaller effect on the edges of the river, such as at the moat and the ports.



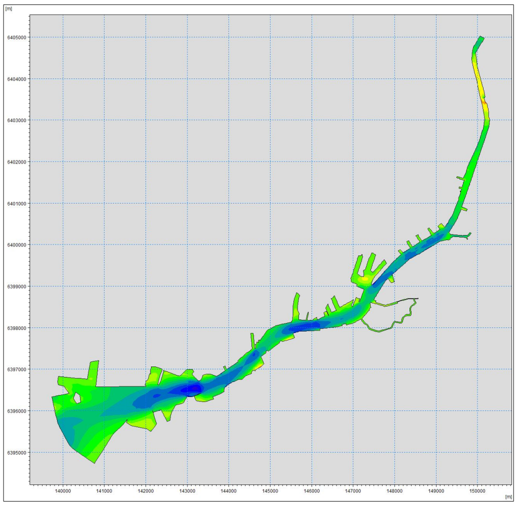
(a) 06 July at 05.10



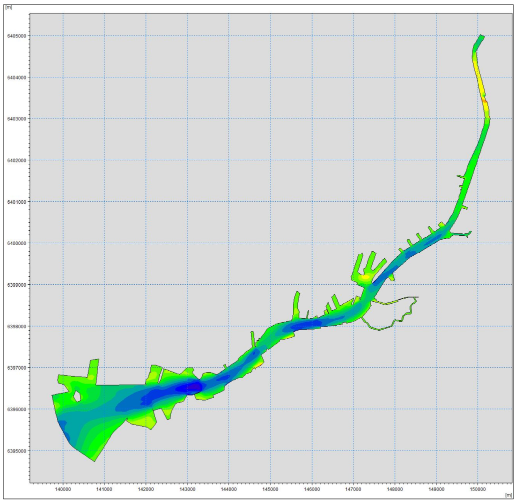
(b) 08 July at 07.10



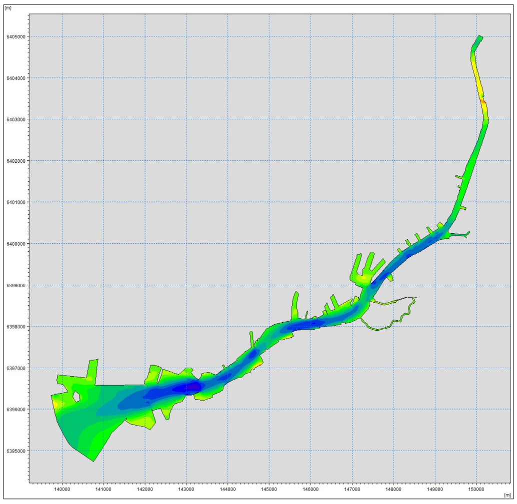
(c) 08 July at 11.20



(d) 08 July at 19.40



(e) 09 July at 04.00



(f) 09 July at 12.20

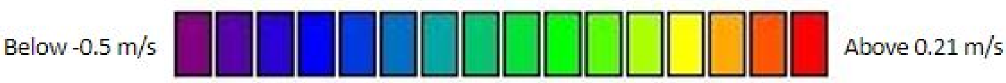


Figure 3.7: The velocity and flow pattern of the Göta River at the surface.

3.5 ECO Lab module

The ECO Lab module was used in this study in order to simulate the settling of microplastic particles. The module allows simulation of settling and sediment process (MIKE, 2017). For this study, one equation has been added to the ECO lab module to enable the settling process (Equation 3.1), where the settling velocity v_s is a constant, and the concentration c is defined as a state variable.

$$\frac{dc}{dt} = -\frac{v_s}{z}c \tag{3.1}$$

- $c = concentration\ of\ microplastic$
- $v_s = settling\ velocity$
- $z = vertical\ grid\ size$
- $t = time$

3.6 Emission sources

A total of 22 discharge points of stormwater were included for this study (Figure 3.8). The discharge points are located at the water surface in the model, but in reality, stormwater is usually released under the water surface. Since the released water has a lower density than salt water, the released water will rise to the water surface (Björklund et al., 2018).

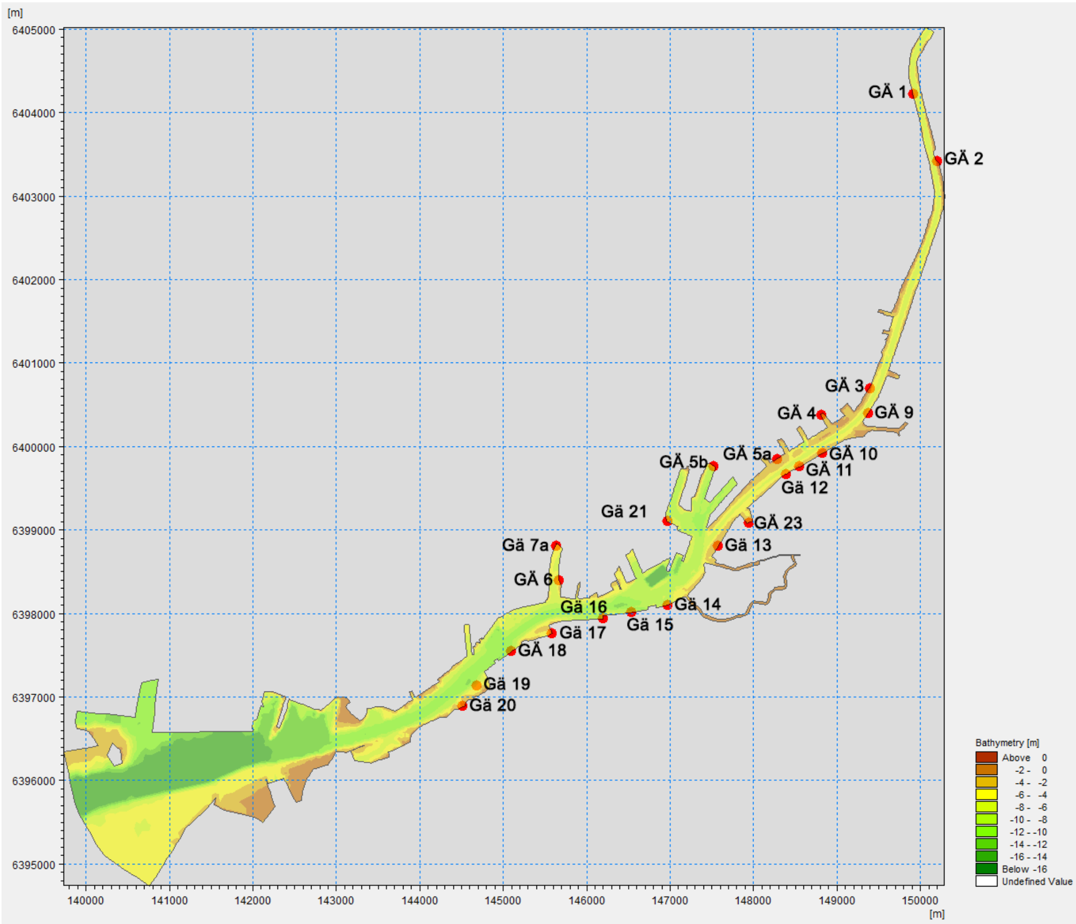


Figure 3.8: Position of microplastic emission sources and points of stormwater discharge.

Since this study focuses on the emissions from road traffic, it is important to determine the concentration of microplastic in road runoff from each of the discharge points. Since no data about the concentration of microplastic from the discharge points were found, the assumption of concentrations has been made based on a study by Jannö (2016). The concentration of 1050 MP/L is a result from a trafficked road in Gothenburg (Jannö, 2016), this number is also used as the highest concentration of microplastic for this study at discharge point GÄ10 in Figure 3.8. For the other discharge points, the concentrations were calculated in relation to the annual number of vehicles in comparison with GÄ10 (Table 3.1).

Table 3.1 Estimated traffic count and related microplastic concentration in stormwater from 22 different discharge points (Göteborgs Stad, 2018).

Emission point	Year when traffic data were collected	Total veh./day	Traffic count compared with GÄ10	MP/L
GÄ1	2015	49130	0.8	840
GÄ2	2015	1950	0.03	33.3
GÄ3	2015	15500	0.25	264.6
GÄ4	2015	33600	0.55	573.7
GÄ5a	2015	4700	0.08	80.2
GÄ5b	2017	2100	0.03	35.9
GÄ6	2016	1400	0.02	23.9
GÄ7a	2016	1400	0.02	23.9
GÄ9	2017	18000	0.29	307.3
GÄ10	2018	61500	1.00	1050
GÄ11	2018	57500	0.93	981.7
GÄ12	2018	57500	0.93	981.7
GÄ13	2017	2300	0.04	39.3
GÄ14	2017	45000	0.73	768.3
GÄ15	2014	49940	0.81	852.6
GÄ16	2014	51410	0.84	877.7
GÄ17	2014	48110	0.78	821.4
GÄ18	2014	45750	0.74	781.1
GÄ19	2014	46510	0.76	794.1
GÄ20	2015	15600	0.25	266.3
GÄ21	2015	9080	0.15	155
GÄ23	2017	2300	0.04	39.3

3.7 Simulated scenarios

This section presents different simulation scenarios tested in this thesis, summarised in Table 3.2. A comparison of these three scenarios gave an indication about the relationship between the spreading and the settling rate of microplastics.

The data to calculate the settling velocities used in scenario 3 are retrieved from Table 2.2 and Table 2.5. A small particle diameter is chosen since the density is high. Compared with Equation 2.1 (Stoke´s law) kinematic viscosity (ν) is used instead of viscosity (µ), retrieved from Häggström (2009) (Equation 3.2). The following particle data were used for the model:

- $d = 20\ \mu m$
- $\rho_{particle} = 1700\ kg/m$
- $\rho_{water} = 999.1\ kg/m^3$
- $\nu_{15°C} = 1.141 * 10^{-6}\ m^2/s$

The temperature is assumed to be 15°C. The settling velocity v_p is calculated using Equation 3.2.

$$v_p = \frac{gd^2(\rho_{particle} - \rho_{water})}{18\nu\rho_{water}} \tag{3.2}$$

- $g = acceleration\ of\ gravity\ [m/s^2]$
- $d = particle\ diameter\ [m]$
- $\rho_{particle} = density\ of\ particle\ [g/m^3]$
- $\rho_{water} = density\ of\ medium\ [g/m^3]$
- $\nu = kinematic\ viscosity\ of\ the\ medium\ [m^2/s]$

Table 3.2 The description of scenarios. The location of discharge points are presented in Figure 3.8

Scenario	1	2	3
Date & time	2015.07.05, 00:00 - 2015.07.14, 00:00	2015.07.05, 00:00 - 2015.07.14, 00:00	2015.07.05, 00:00 - 2015.07.14, 00:00
Discharge points	GÄ10	All 22 discharge points	All 22 discharge points
Settling rate [m/s]	0	0	0.00013
Concentration [MP/L]	1050	See Table 3.1	See Table 3.1

The results of this study are presented at points and horizontal and vertical sections. The volume-output shows the spreading of microplastic on the surface and at different depths, while the output in points presents the variation of microplastics concentration at a specific location.

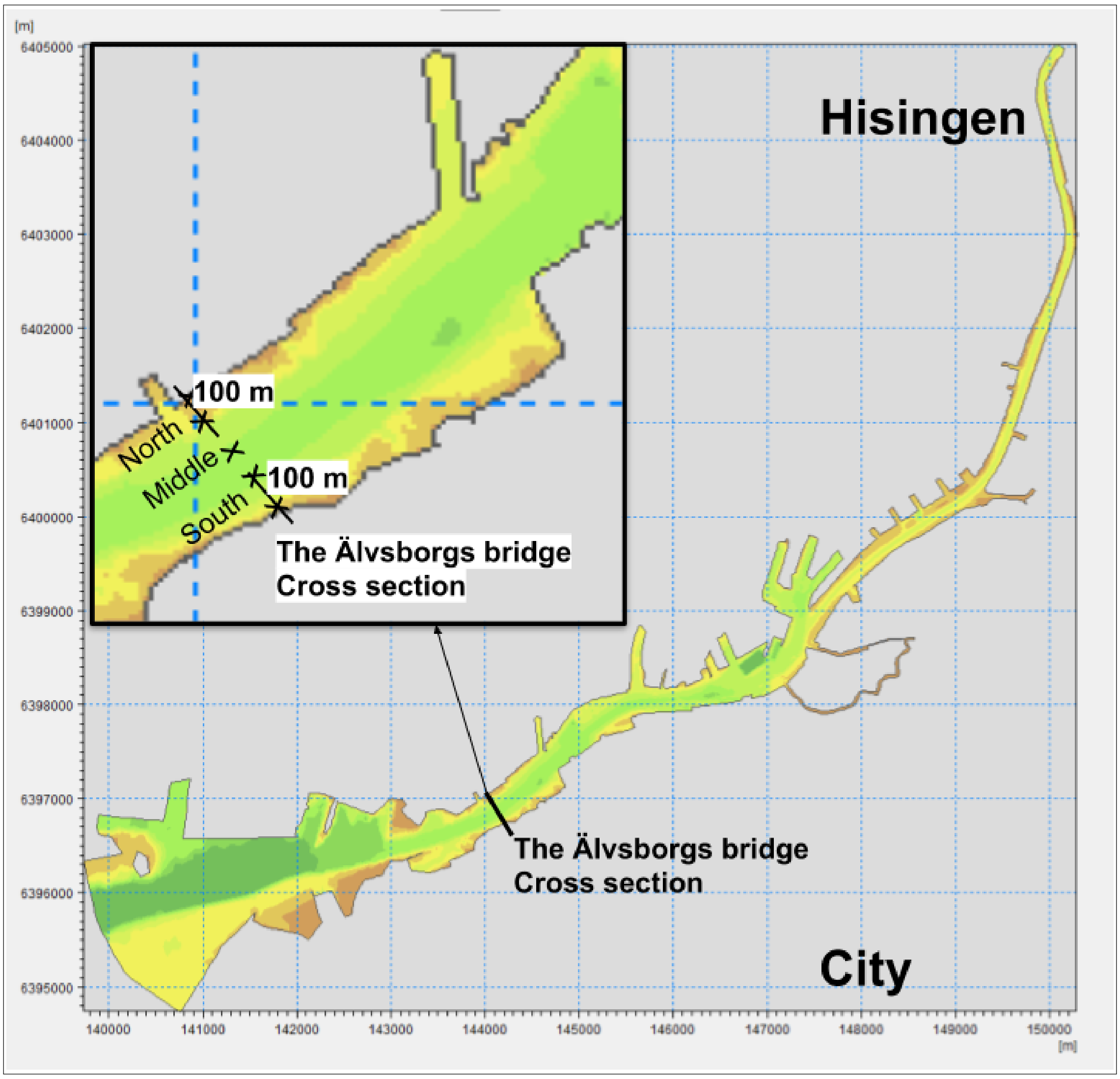


Figure 3.9: Cross section locations

One cross section (Figure 3.9) was chosen to analyse the sedimentation of microplastic in each scenario and is located under the Älvsborgs bridge. In order to analyse the sedimentation at the depths, three points along the cross section were selected: One at the middle of the cross section and two other points are placed 100 m from the shores of the river.

4 Results

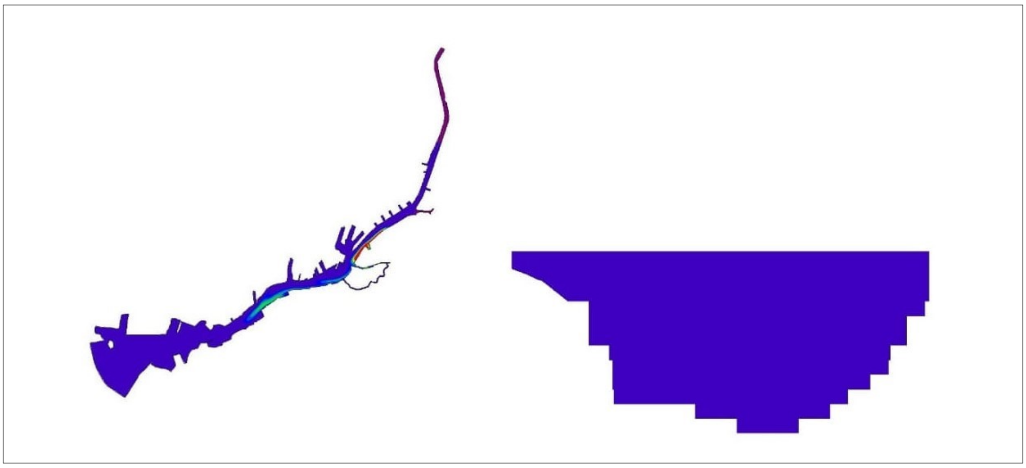
The results of each scenario are presented in the following subsections.

4.1 Scenario 1

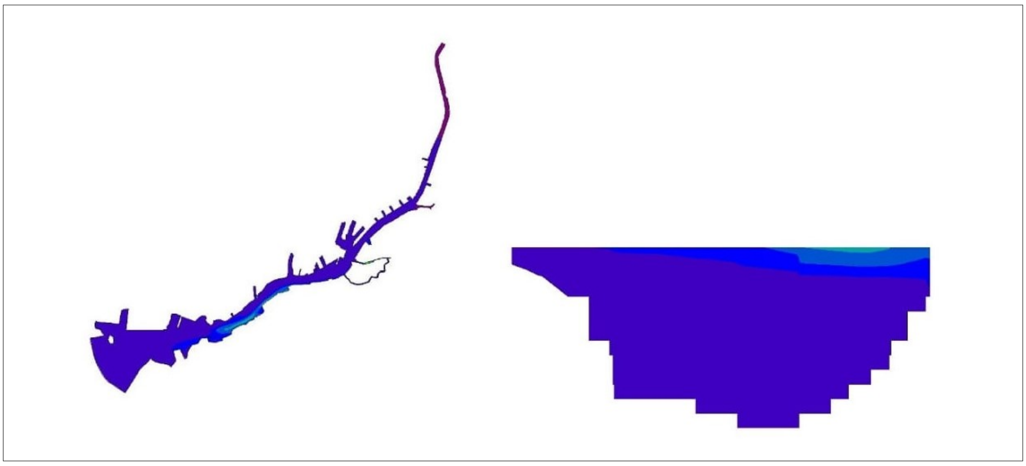
The first release of microplastics from discharge point GÄ10 occurred on 06 July at 00:51 and left the study area around 23 h later. Several releases follow thereafter, Figure 3.2. Figure 4.1 shows the spread of microplastic during the simulation period. Most of the microplastics follow the main stream of the river and are transported out to the sea. At the end of the simulation period, the only location with remaining microplastics is the moat. Figure 4.1 also shows that with GÄ10 as the only emission source, the concentration of microplastics will mainly spread along the city-side of the river. Since discharge point GÄ10 is located at the upstream end of part II of the simulated river, part I will not be affected by the emissions from this point.

Figure 4.1 shows that microplastics will not remain entirely at the water surface, even though the discharge is at the water surface and the settling velocity for this scenario is 0 m/s. This behaviour is due to the mixing of water in the river, which brings the microplastic particles to a deeper level. The deepest level where microplastics are found is around -2.5 m (Figure 4.1b).

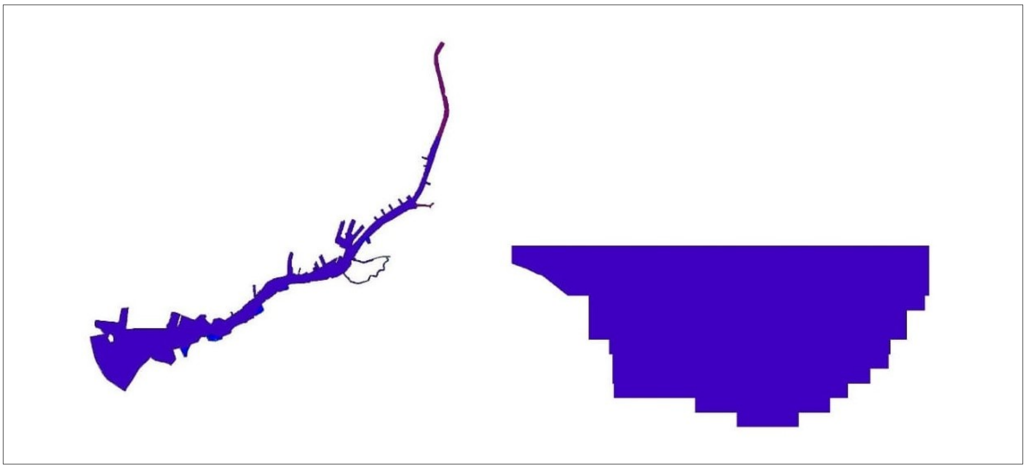
The concentration of microplastics increases from North, middle to South for the surface layer (Figure 4.2). For the deeper layers the trend is not as visible. The concentration at the surface layers is much higher than at the deeper layers. The discharge follows the rain event and highest concentrations are seen between 8 - 10th of July (Figure 4.2).



(a) 08 July at 23.00



(b) 09 July at 04.00



(c) 09 July at 09.00

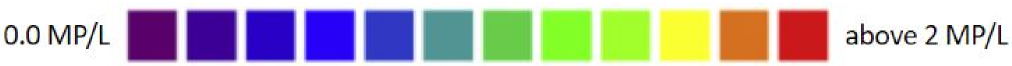


Figure 4.1: Scenario 1: Simulated microplastic concentrations in Göta River at the water surface (left) and at the cross sections (right).

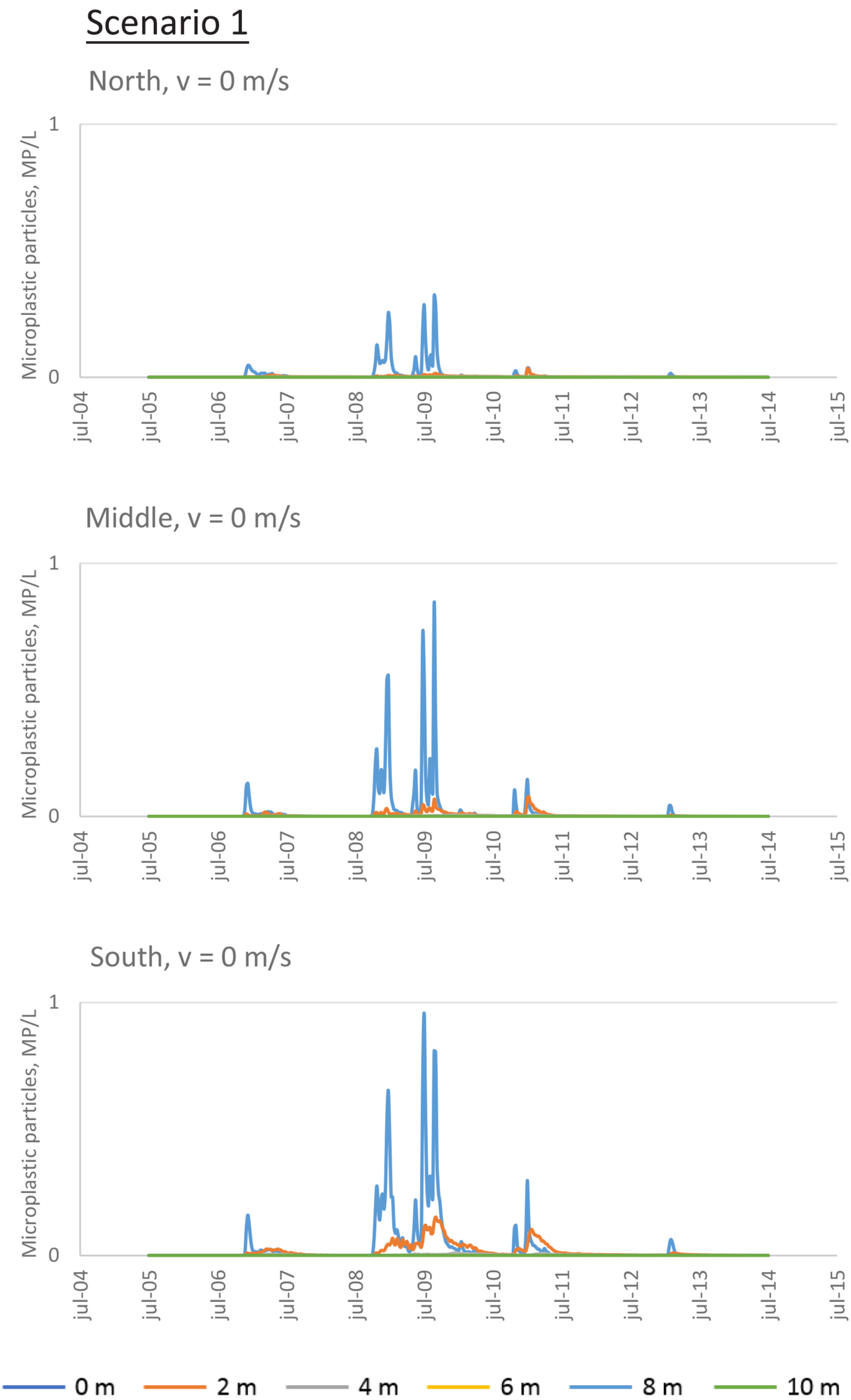


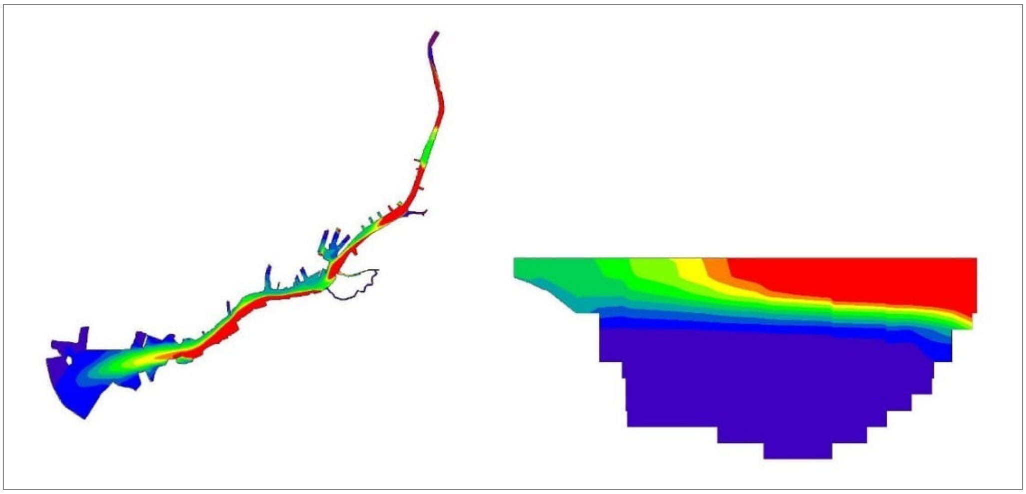
Figure 4.2: Concentration of microplastic particles at the cross section Älvsborg bridge at different depths using a settling velocity of 0 m/s. The description of the output positions can be found in Figure 3.9.

4.2 Scenario 2

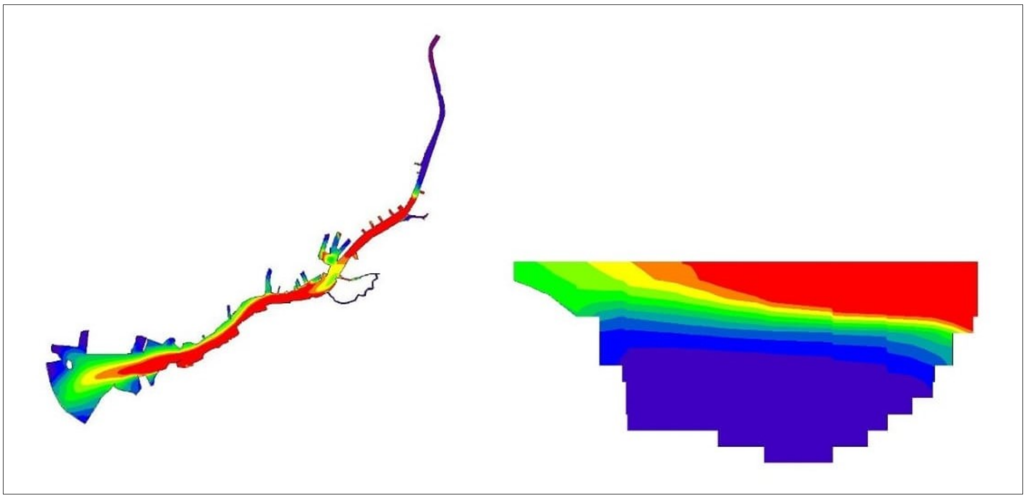
Scenario 2 is mostly the same as scenario 1 except that this time all emission sources are included. Consequently, part I of the Göta River is now exposed to microplastic particles. The first discharges of microplastics occurred on 06 July, 00:51 at GÄ1, 3, 4, 10, 11, 14, 16, 17 and 18. 54 h after the first discharges, microplastics covers most of part I of the river (Figure 4.3). In part II, the highest microplastic concentrations appear on the city side of the river. This is due to 14 of 22 emission sources being located on the city side (Figure 3.8) and these are also more polluted, Table 3.1. When all emission points are accounted for microplastics are also found in part 1 and the ports, such as Frihamnen and Sannegårdshamnen. When the emission points are located within the ports, the microplastic concentration are high since the water renewal rate is slow. The emission at the moat continue but with higher microplastic concentration than in scenario 1.

The spread of microplastic particles matches the flow pattern of the river. The results also show that despite the settling rate of 0 m/s, microplastic particles will, with the flow of Göta River, reach the deeper layers due to the mixing in the river (Figure 4.3).

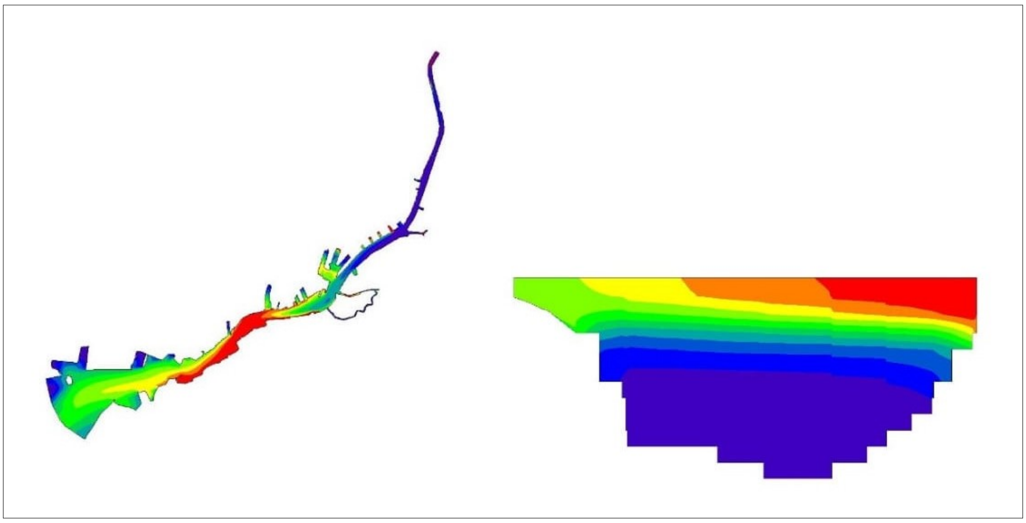
Same as in the scenario 1 the concentration increases from North, middle to South for the surface layers (Figure 4.4). Large concentration differences are seen between the surface layers and -2 m, but at layers at -4 m and deeper, the differences are small (Figure 4.4). The pattern is as previous scenario not clear at the layers deeper than -4 m (Figure 4.4). The results from both scenarios present the same variation in concentration as the precipitation during the simulation period (Figure 3.2).



(a) 08 July at 23.00



(b) 09 July at 04.00



(c) 09 July at 09.00

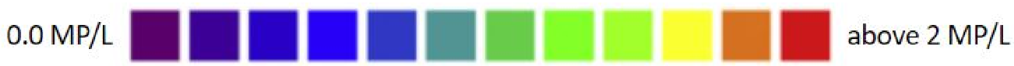


Figure 4.3: Scenario 2: Simulated microplastic concentrations in Göta River at the water surface (left) and at the cross sections (right).

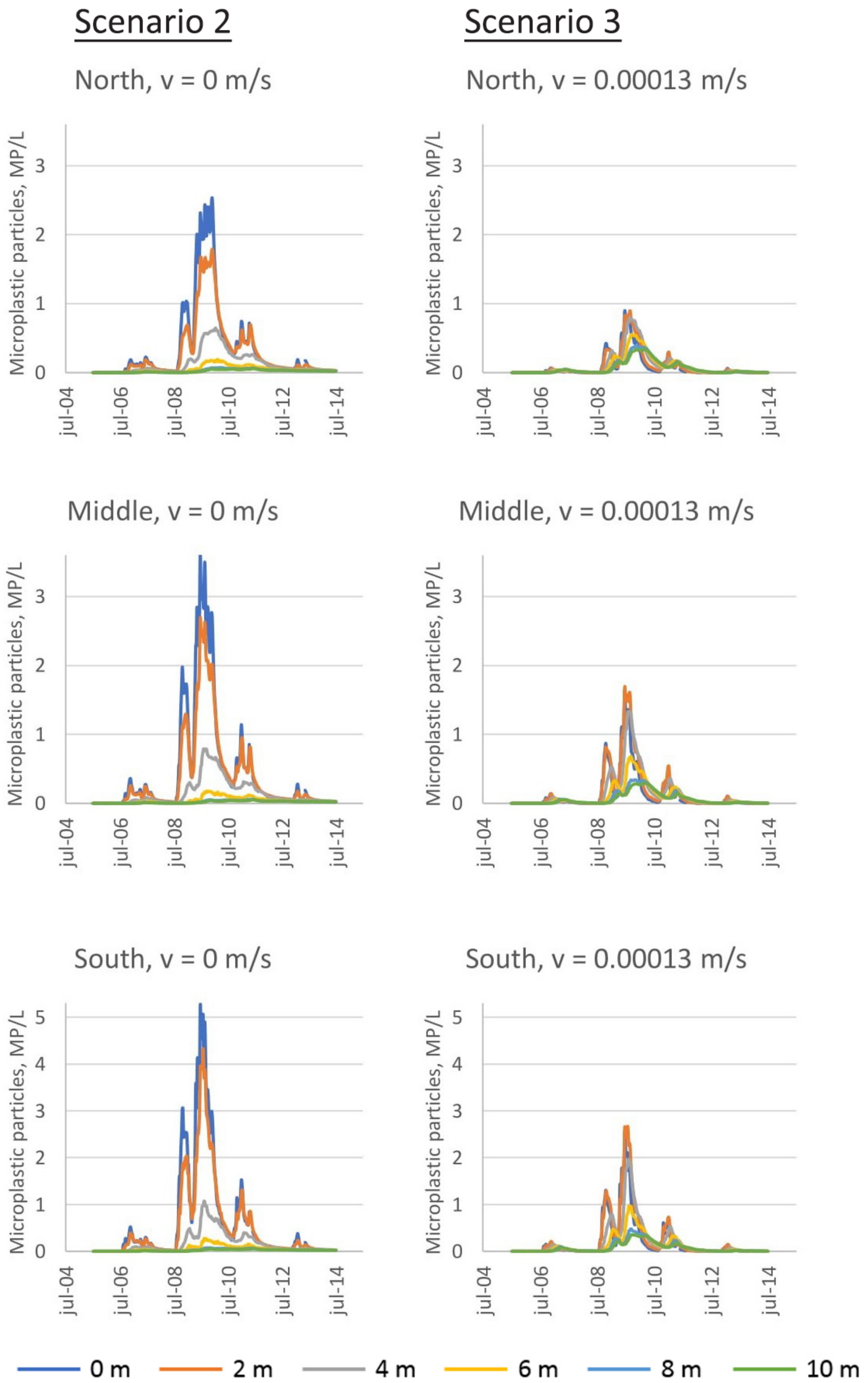


Figure 4.4: Concentration of microplastic particles at the cross section Älvsborg bridge at different depths using different settling velocities. The description of the output positions can be found in Figure 3.9.

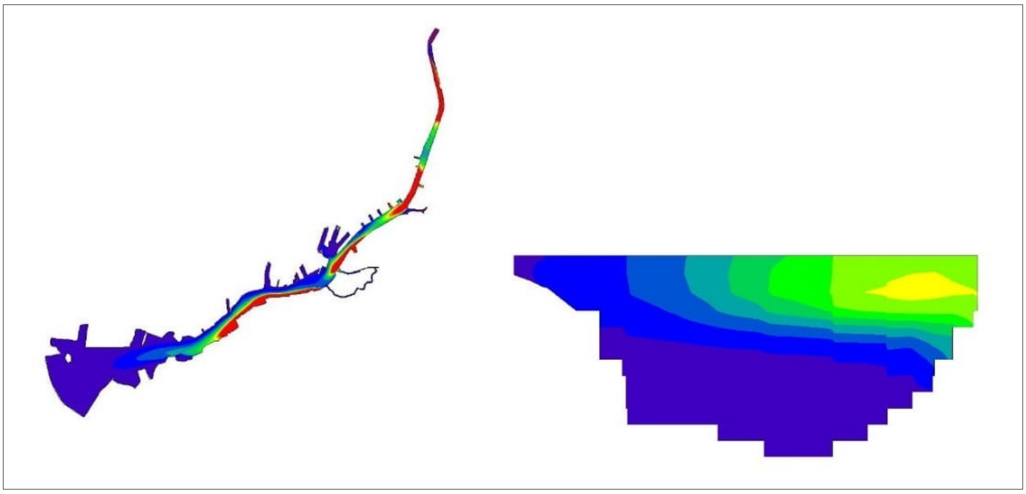
4.3 Scenario 3

In this scenario a settling rate of 0.00013 m/s is applied and as in scenario 2, all emission points are included. The result of applying a settling rate is presented clearly in Figure 4.5. The microplastic concentration on the surface layers decreased to below 1 MP/L as seen in Figure 4.5c when during the same period in scenario 2 the surface of Göta River is covered in red.

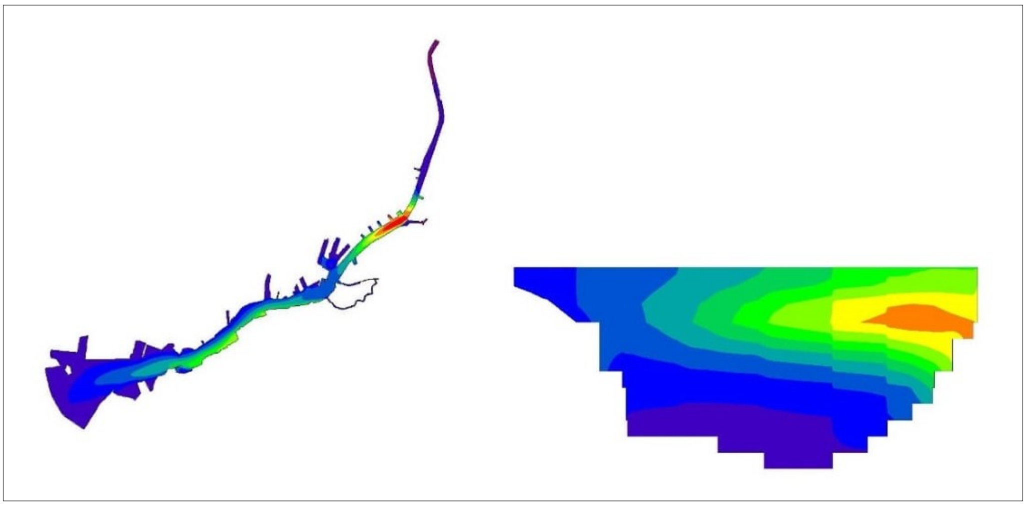
As the cross section figures presented, the increased settling rate let the microplastic particles reach the bed of the Göta River (Figure 4.5c). These figures also proved the decrease of microplastic concentration. The microplastic particles have settled along the Göta River, therefore, only a smaller concentration reached the output points (Figure 4.5).

Figure 4.4 presented results of scenario 2 and 3. In scenario 2 no microplastic particle could reach to the depth of 10 m but the situation changed in scenario 3. The difference between layers is smaller in scenario 3 and the trend of concentration increases from North, middle to South in the deeper layers is now clearer. For the case with no settling, the highest concentration is seen at the surface layer z = 0. For the case with settling the highest concentrations are at the depth z = 0 and z = 2 m.

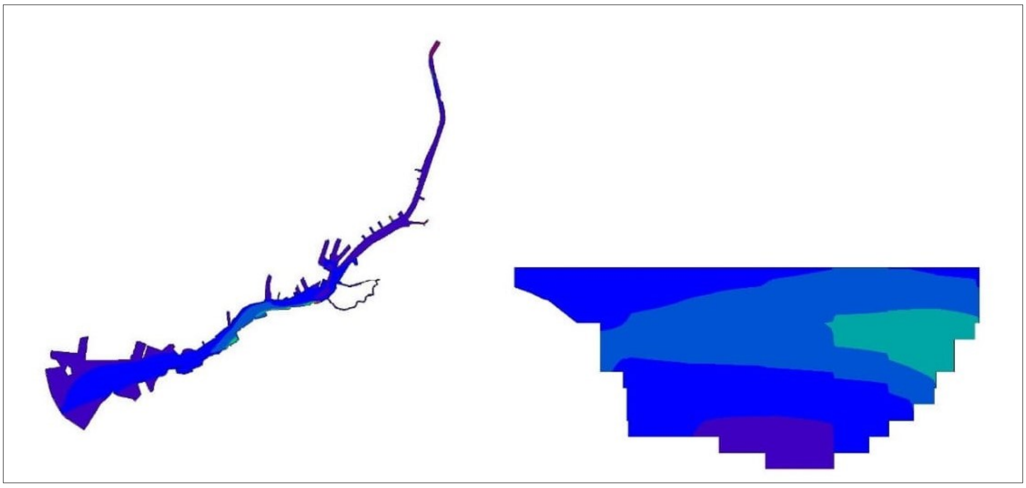
When settling is included in the model, a higher load of MP will remain in the river. This may suggest that MP are present in the sediments of the river and that a lower load of MP reaches the sea.



(a) 08 July at 23.00



(b) 09 July at 04.00



(c) 09 July at 09.00

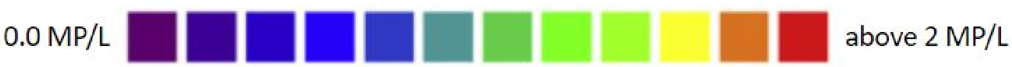


Figure 4.5: Scenario 3: Simulated microplastic concentrations in Göta River at the water surface (left) and at the cross sections (right).

5 Discussion

The model includes settling of microplastic particles. However, the model does not account for resuspension nor the accumulation of settled particles at the bottom of the river. In a real-life scenario, the settled particles can rise again with the flow and because of defouling, which decreases density (Kaiser et al., 2017). Therefore, the final sedimentation is difficult to determine accurately. To simulate the final sedimentation, the module Mud transport in MIKE 3 Flow Model FM or other similar software could be used instead of, or as a supplement for ECO Lab.

The mesh size varies in the simulation area. Parts of the moat, the ports and the area downstream of the river before it enters the sea have a lower resolution. Hence, the results at these locations are not as accurate as at locations simulated with a finer mesh, but the results are assumed to be reasonable.

Generally, the spread of microplastic particles matches the flow pattern of the river in all scenarios. The comparison between scenarios 1 and 2 shows that the source of emission affects which side of the river the microplastic particles will end up in. In scenario 1, GÄ10 is the only emission source, and this scenario indicate that the microplastics remain on the same side of the river as the source (the city side). For scenario 2 where all emission sources are included, the highest microplastic concentrations appear on the city side of the river. This is due to that the highest emission sources are located on the city side and the concentration does not spread to the other side of the river.

In this study, scenario 3 was simulated with settling velocity in order to investigate the effect of settling while scenario 2 was simulated without settling. The particles included in the model have a high density and will to some extent settle in the river. It may be reasoned that if the particles are transported a longer distance in the sewer system they could have settled here and thus not entered the river at all.

Since the simulated particles are small, they are considered to not have an effect on the flow of the Göta River.

When comparing scenario 2 and 3, it can be observed that the highest concentration of microplastic particles is seen at the surface layer $z = 0$ and $z = 2$ m. When settling is included in the model, a higher load of microplastic particles will remain in the river. This may suggest that microplastic particle are present in the sediments of the river and that a lower load of microplastic reaches the sea. In scenario 3, it can also be seen that the further away the discharge location is from the main flow, the higher the chances are for settling of particles. Therefore if microplastics enter areas like the port or the moat, there is a higher chance of sedimentation. Frihamnen is a good example; apart from the discharge from the stormwater pipe, the area is also exposed to boat traffic every day. As the literature review presented, boat paint can contain polymer and is therefore a possible source of microplastic emission. If there is a chance to take a sample, Frihamnen or Sannegårdshamnen would be one of areas of interest.

The literature review showed that biofouling has an effect on the settling rate (Table 2.6) but this effect is small, since the biofouling process is slow (Fazey & Ryan, 2016). Studies on biofouling effects on microplastic have increased during the last few years, yet further studies need to be conducted to answer questions regarding the reaction of different types of plastics with different environments, causes of the different reactivities, how the water environment has an effect on biofouling, and how different contents of organisms, particles and densities affect the biofouling process.

The microplastic concentrations used in Table 3.1 may not be true, because in this study only discharge from separated stormwater system was simulated rather than a combined sewer system which is usually the real-life scenario. In addition, the concentrations of microplastic are based on assumptions and reviewed literature, the result may not correspond to the reality of the Göta River. The traffic volume data presented in Table 3.1 suggest that the traffic volume has the most effect on the microplastic concentrations in the river. The number of vehicles is based on the latest available traffic data published (Göteborgs Stad, 2018). However, the traffic measurement points are not all collected from the same location as the discharge point. In 2010, traffic data for the catchment area around point GÄ10 show in total 61 370 veh./day and the number increased to 61 500 veh./day in 2017 (Göteborgs Stad, 2018). The reason for the small increase could be the congestion charge that was applied in 2013. The municipality of Gothenburg presented that from 2013 the trend of travel have become more sustainable, meaning that the use of public transport has increased (Göteborgs Stad, n.d.-a).

More vehicles result in higher concentrations of microplastic particles being discharged into the river. Car transport is an important means of conveyance in today's society, which makes microplastics from tires and road wear unavoidable. The need for transportation increases with the population growth, and to reduce the microplastic emissions use of rubber needs to decrease. Moreover, stormwater should be filtered and treated before discharging into the river.

Several methods for general stormwater treatment have been applied in Gothenburg, for example, retention basin, local-infiltration and rain garden (Göteborgs Stad, n.d.-b). However, none of these methods are specific for microplastics. Since the size of microplastic could be 1 µm, or even smaller, the soil filtration may not be effective to keep microplastics away from entering the groundwater. No detection of microplastic in groundwater has yet been found in the reviewed literature of this study. Clay is the dominant soil type in Gothenburg and has particle size < 0.002 mm (SGI, 2018), which means that as long as the microplastic is > 0.002 mm the groundwater is secured.

In addition to stormwater treatment, a large portion of household microplastic can be filtered away in the wastewater treatment plant, and a finer filter can prevent the release of the remaining microplastic from the treatment plant to the sea (Svenskt Vatten, 2016). The last step of water treatment process at the wastewater treatment plant in Gothenburg- Ryaverket is filtration through a disc filter. The disc filter has the capacity to block particles with size > 15 µm (Gryaab, n.d.). Even though it is possible to remove 40 - 98.5% of the microplastic particle with size > 20 µm with disc filters (Talvitie, 2017), microplastic particles having a size 1 µm or smaller can still be discharged into the sea (Table 2.3). This means that these microplastic particles have entered the sea, where most of the fish and seafood we consume is harvested (Mora et al., 2011).

Due to the increasing knowledge of microplastic and its effect on the environment, many European countries have together declared a ban on microplastics in personal care products (Anderson et al., 2016). Sweden decided at the beginning of 2018 to prohibit microplastics in certain cosmetic products such as toothpaste, scrub, shampoo etc. From 1 July 2018, products with microplastic content should be replaced with a natural polymer, such as rice corn and coconut shell. Products containing microplastic purchased before 1 July 2018 may be sold until January 1, 2019 (Björnfors, 2018). Even though the first article of microplastic was published many years ago and the Swedish Environmental Protection Agency already in 2016 presented a report about microplastic and its effect on the environment, the ban of microplastic cosmetic products did not come until two years after. With the result from this study, the amount of microplastic concentration that has been released during this time to the Göta River has already reached the sea or settled in the river.

It is important to mention that most of the published studies does not mention or include rubber as microplastic. The definition of size is also defined differently between studies (Table 2.3). The determination of microplastic properties needs to be more explicit to facilitate future studies and treatment/removal.

6 Conclusion

The size of microplastics is defined as less than or equal to 5 mm. The literature study shows that particle sizes of 60 nm - 1 µm are common in road traffic and originate from the wear of tires and roads.

One of the certain conditions for sedimentation of microplastics in water is that the particle density has to be higher than the density of the surrounding water. Freshwater density is usually defined as 1000 kg/m^3 while saltwater density is dependent on salinity and higher than freshwater density. Microplastics will sink if the particle's density is higher than its environment. The density of microplastics that has been found in the literature is between 855 - 2200 kg/m^3, most microplastics have densities around 1000 kg/m^3. One cause of increased density of particles is biofouling.

The results from the modelled scenarios show that a large portion of microplastics from stormwater discharges will settle on the bottom of the river. The shallow part of the Göta River, the port and the moat are exposed to a higher risk of microplastic settling. The flow in the river brings the plastic particles to different depths: the deeper the layer, the lower the concentration of microplastics.

The transportation time of a microplastic particle is dependent on the water flow pattern and velocity. Low exchange flows, as for example, in Frihamnen, allow the particles to remain in one place longer and may provide opportunities for settling.

7 Further investigation and recommendation

A limitation of this study is that it does not include a field study of the Göta River. Emission concentrations are based on assumptions and a literature study. To make the results more realistic, a field study should be performed to collect real-time data. Data from the different discharge points can be used for further investigation to perform a validation study to evaluate the effectiveness of the model.

The ECO lab module used in this study cannot illustrate the settling of the microplastics at the bottom of the river, thus another module, for example Mud transport, should be utilised to study the possible thickness of the sedimentation layers.

For water, there is a method called water footprint which can be used to check and trace the water consumption of one person or bigger scales such as company and nation (Aldaya et al., 2012). The same concept could be applied for the use of plastic and rubber, with the goal of increasing awareness of plastic and rubber consumption.

In the end, the use of polymer-based products should be reduced and replaced with environmentally friendly materials.

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