Quantification for the Flow of Microplastic Particles in Urban Environment: A Case of the Chao Phraya River, Bangkok Thailand

A Minor Field Study

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The International Relations Office at KTH the Royal Institute of Technology, Stockholm, Sweden, administers the MFS Program within engineering and applied natural sciences.

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Abstract

Plastic, including microplastic, is a common product in the society today and is starting to be more common in oceans where it can stay for a long time. Microplastic is defined usually in the size range five millimeter and smaller and together with the important Chao Phraya river in Bangkok, Thailand, the main subject of this paper is described. More clearly, the aim of this paper is to provide a first-hand quantification of microplastics flowing into the Chao Phraya River. Samples were taken at upstream, middle and downstream locations in the river with a pump-system and were then analyzed in a lab. The result showed an increasing load of microplastic entering the river from Bangkok, for example the result for size range five to one millimeter showed a six times increase of microplastic between the upstream and downstream point.

Keywords: Microplastics, Pollution, Plastic, Chao Phraya, Sustainable development
Foreword
By highlighting the importance of understanding loadings of microplastics in big cities as Bangkok, this project can maybe contribute with useful information to this quite unexplored subject, microplastics in marine environment. This project aims be a first-hand quantification of microplastic flows in the Chao Phraya River and to be a start for and support further work on this subject. Involved is Dr. Wayne Phillips, an environmental science lecturer at Mahidol University International College (MUIC) and also three hotels named The Siam Hotel, Mandarin Oriental and Anantara Riverside Bangkok Resort and one shopping mall called River City. Hopefully this project also shows the significance and the importance of further work on this subject and that more hotels and other buildings by the river want to join and be more involved as this project may be developed.

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1. Introduction

1.1 Background

1.1.1 Waste in general
The oceans of the earth are home to millions of animals and plants and have been for a very long time. Today in this anthropogenic time, the oceans are not only home to organisms, they have begun to be a common home for all kinds of human trash. Marine garbage encompasses materials such as glass, wood, metals, fabrics and plastic (Cole et al., 2014). The plastic part in marine garbage is a common product in the society today and the reasons why are a few. One of them is that plastic has a high durability. This also means it has big resistance to degradation and also, copious use of throw away plastics, for example packaging material, makes the disposing of plastic waste problematic. Some of the total plastic debris is recycled but the majority ends up in landfill, where the degradation takes centuries (Barnes et al.; Sivan, cited in Cole et al. 2011). Plastic is an internationally known pollutant which has legislation that has the aim to prevent it from entering the marine environment (Gregor; Lozano and Mouat, cited in Cole et al. 2011), but despite this it is estimated that 10 percent of plastic produced end up in the oceans (Thompson, cited in Cole et al. 2011). From expeditions in different ocean areas from year 2007 to 2013, which had the goal to estimate the total number of plastic particles and the weight of these, it was estimated that it exists a minimum of 5.25 trillion plastic pieces which are weighing over 268,940 tons (Eriksen et al., 2014).

Trash in general is an increasing factor in the world. In year 2012 the world's cities generated 1.3 billion tons of solid waste per year and this number is estimated to almost double to year 2025 due to rapid population growth and urbanization. Waste disposal looks very different depending on country. The waste in low or middle-income countries is often disposed in unregulated dumps or openly burned, which create environmental consequences and also affect safety and health for the inhabitants. To have an effective management is expensive, it is estimated that it is comprising 20 to 50 percent of municipal budgets (The World Bank, 2017).

1.1.1.1 Sources of plastic
It is human behaviors and actions, both accidental and intentional, that are the sources of the litter found in marine environments (UNEP, 2009). Marine litter mainly contains plastic items of different kinds (Larssen et al., 2015). The plastic itself in marine litter can reach the marine environment in a variety of ways, where land-based sources are the most prominent contributors to plastic in rivers, seas and oceans etcetera (Andrady, cited in Faure et al. 2012). The major land-based sources of plastic in the marine environment include waste that originate from coastal or inland areas such as beaches, piers, marinas, harbors, riverbanks etcetera (UNEP, 2009). Land-based sources also include industrial sites and outfalls, waste water systems, coastal tourism and recreational use of the coast and dump sites close to the coast or on banks of rivers (UNEP, 2009; Cole et al., cited in Faure et al. 2012). Rivers,
floodwaters and lakes, as well as other water bodies, are consequently frequent carriers of marine litter, and therefore also plastic (UNEP, 2009). In addition to this, hurricanes, tsunamis, floods and other natural storm-related events can cause large amounts of land-based material to be washed away and eventually end up in the marine environment (NOAA, cited in UNEP 2009).

Major sea-based sources of litter include all forms of shipping, for example as for public transport, as well as fishing activities and offshore mining and oil extraction (UNEP, 2009; Cole et al., cited in Faure et al. 2012). Currents, tidal cycles, wind and the structure of the seabed topography are all examples of elements that may contribute to the dispersion of litter in the marine environment (UNEP, 2009). As for today, researchers say that Asia is the biggest source of the plastic that reaches the ocean (Lee Hotz, 2015).

Once in water, the plastics in marine litter can degrade into smaller particles, eventually becoming as of microscopic size (Arthur et al., 2009). These microscopic sized particles may also arise through the two following mechanisms: direct release into different water bodies or accidental loss of industrial raw material (GESAMP, cited in Faure et al. 2012). Knowledge and understanding of the sources of litter found in the marine environment is essential as foundation for decisions regarding possible actions to prevent, reduce but also control problems that may arise because of marine litter.

1.1.2 Microplastics

Plastic is an expression often used to describe different synthetic organic polymers (Derraik, cited in Cole et al. 2011), where a number of plastics used in today’s society are produced from oil and gas (Rios et al.; Thompson et al., cited in Cole et al. 2011). The term ‘Microplastics’ where first introduced in published literature in 2004 and such particles can be described as small plastic fragments that can appear in different marine environments (Thompson et.al, cited in Dris et al. 2015). The size-range of microplastic particles is not directly established and it often varies from study to study (Cole et al., 2011). An upper bound that frequently is used is the diameter of 5 millimeters and particles smaller than this can therefore be counted as microplastics (Arthur et al. 2009; Thompson 2014), while particles above 5 millimeters count as macroplastics (Faure et al., 2012). As for the lower bound it generally varies between different studies, where sometimes no fixed lower limit is specified (Graham and Thompson; Barnes et al.; Betts; Derraik; Ryan et al.; Browne et al.; Browne et al.; Claessens et al., cited in Cole et al. 2011). However, in different field practices neuston nets with mesh size 333 microns is commonly being used to capture microplastics and 333 microns can in such studies consequently be seen as a lower bound (Arthur et al. 2009, Law 2014).

1.1.2.1 Classification of microplastics

Microplastic particles can further, based on their origin, be sorted into two different categories - primary and secondary microplastics (Dris et al. 2015). Primary microplastics can be described as microscopic sized particles that directly have entered the environment (Sundt et al., cited in Boucher and Friot 2017). They are often deliberately manufactured as of
microscopic size, either for further use in different consumer products or for direct use (Arthur et al., 2009). Microplastic particles can for example be used as abrasives (exfoliants) in personal care products, such as cosmetics and toiletries, but can also appear as pre-production plastic pellets, nurdles (Arthur et al., 2009; Dris et al., 2015; Sundt et al., cited in Boucher and Friot 2017).

Secondary microplastics on the other hand are formed when greater plastic pieces, for example different forms of marine debris, are degrading into smaller plastic pieces that is microplastic particles (Arthur et al., 2009). The breakdown of plastic happens first and foremost when plastic items reach marine environments (Sundt et al., cited in Boucher and Friot 2017). Degradation of plastic is generally due to different chemical, physical and biological processes, such as degradation by UV-radiation, biodegradation and mechanical abrasion, which reduces the structural integrity of the plastic and causes fragmentation (Browne et al., cited in Cole et al. 2011; Cole et al., cited in Dris et al. 2015). This is a continuous process, meaning that plastic particles continuously will be break down into smaller and smaller particles (Imhof et al.; Zbyszewski et al., cited in Dris et al. 2015). The rate of this process depends primarily on factors like the characteristics of the plastic and the extent of degradation in the particular environment (Arthur et al., 2009).

Flowers (2016) states that microplastics can be divided into the following five types of microplastics: foam, fragments, fibers, nurdles and microbeads. Foam can be found in food containers, coffee cups and packing material, among other things. When in water, foam can break down into smaller pieces. Like foam, smaller pieces of plastic can break off from larger pieces of plastic. This kind of microplastics is called fragments and often originate from various single-use products. Fibers come from items such as cigarette butts, diapers and fleece clothing. Nurdles are small plastic pieces that usually are melted down into different plastic products by factories and because of their size sometimes escape transportation vehicles and end up in the water. Non-biodegradable particles made of plastic and often smaller than one millimeter in diameter are called microbeads. These are usually found in personal care products, for example in facial cleaners, exfoliating soap products and in toothpaste. This kind of microplastics is often mistaken for food by fish and other aquatic species. (Flowers, 2016).

So nurdles, fibers and microbeads are manufactured as of microscopic size and can therefore be defined as primary types of microplastics. Foam and fragments, on the other hand, are formed when greater plastic pieces break down into smaller pieces of plastic and can thus be defined as secondary types of microplastics.

1.1.2.2 The distribution of microplastic particles in water
Depending on the density, microplastic particles either float or sink once in water. Consequently, the density of the plastic will contribute to the distribution of microplastics in a water column. Plastics, such as polypropylene, tend to have a lower density than, for example, seawater and microplastic particles of that kind therefore float at the surface but can also be found to a lower extent dispersed in the water column (Boucher and Friot, 2017; Löder and Gerdts, 2015). Microplastics such as acrylic are on the other hand usually denser than
seawater and will sink, possibly accumulate in the sediments (Woodall et al., cited in Boucher and Friot 2017).

1.1.3 Environmental impact
As plastic and microplastic waste disposal is increasing in the oceans, researchers and authorities have started to notice and studies are confirming some of the impacts this causes on the marine environment (Browne et al.; Hidalgo-Ruz and Thiel; Ng and Obbard; Claessens et al.; Van Cauwenberghe et al.; Vianello et al., cited in Löder and Gerdts 2015). Due to the small size of microplastics, they are easily ingested by marine organisms and studies have shown that microplastics travel along food-chains (Betts; Thompson, cited in Cole et al., 2011), and also long distances due to their slow natural degradation (Ebbesmeyer and Ingraham, cited in Löder and Gerdts 2015).

A range of different marine organisms as, for example, seabirds, crustaceans and fish can ingest microplastics (Blight and Burger; Turinho et al., cited in Cole 2011). In the 1960s, when global plastic production was less than 25 million annum, plastic was first found in the guts of sea birds and in year 1982 a team in the Netherlands found that 94 percent of fulmars sampled contained plastics. Similar examples exist for fish, 35% of the fish sampled, caught in the North Pacific central gyre, had microplastics in their guts (Ryan et al.; Thompson et al.; Lozano and Mouat; van Franeker; Boerger et al., cited in Cole 2011).

The small size that microplastic particles have is a key factor regarding the availability for lower trophic organisms. Many of these organisms have limited selectivity between particles and can therefore capture anything that have appropriate size. Even for higher trophic organisms this mistake is easy to make. Higher planktivores could both passively ingest microplastic during their natural feeding behavior or mistake microplastic for natural prey. For example, the fin whale Balaenoptera physalus, whom is one of the largest filter feeders in the world can devour approximately 70 000 liters at one time. This means that the risk of ingesting microplastics is big, both by direct ingesting them from the water and indirectly by plankton (Moore; Fossi et al., cited in Wright 2013). The availability of microplastics among planktonic organisms also increases by the factor that many types of microplastics are of low-density types, for example “user” plastics, and therefore buoyant, which means that possibly big amounts of microplastics can be found near the sea surface (Fendall and Sewell; Gregory, cited in Cole et al., 2011).

It is rather unclear if the non-polluted microplastics causes any severe health effects on biota, example on the mortality, reproductive success or morbidity. Some possible effects could be plastic fragments that might block feeding appendages or become a hinder for the passage of food through the intestinal tract or cause pseudo-satiation which can lead to reduced food intake (Zarf; Tourinho et al.; Derraik; Thompson, cited in Cole et al. 2011) or wounds from sharps objects (Wright et al., cited Löder and Gerdts 2015). When it comes to polluted microplastics, effects might not only occur to the single organism but also cause severe environmental impacts. POPs or Persistent Organic Pollutants can coat the plastic debris and due to its durability be transported to other far-away ecosystems and thus pollute them, or as
earlier mentioned be ingested by the marine organisms (Zarfl and Matthies; Gregory; Thompson et al., cited in Cole, 2011). This also means possible POP-transportations to human food (Engler, cited in Löder and Gerdts, 2015).

1.1.4 Bangkok and Chao Phraya
As mentioned before in 1.1.1 Sources of Plastic, countries in Asia are likely the top sources for plastic that reach the oceans. The Asian country Thailand, with Bangkok as its capital city and where the population is around 9.27 million, has many different types of industries and plastic industries is one of them (CIA, n.d.). Among the South-east Asian countries Thailand are for example one of the biggest manufacturer of polyvinyl chloride or PVC and in 2010 the domestic demand for PVC were about 450 000 tons per year. According to studies made in Bangkok year 2010, 600 000 plastic bags were used every day in the city (Lee, 2010).

The river that goes through Bangkok is the Chao Phraya river. It has a length of 365 kilometers and flows south to the Gulf of Thailand and for centuries it has been used for many purposes, especially its canals which is called khlong systems, for example drainage, recreation, fishing and as a source of water. The river is also an important transportation route for both goods and city inhabitants (The Editors of Encyclopaedia Britannica, n.d.). At the same time, it has also function as a dump for both liquid and solid wastes from all types of human activities. As the urbanization of Bangkok is growing and industrial sites increase, the pressure on water quality becomes more intense and the demand for water increases, eventually leading to water shortage. This means that pollution of the Chao Phraya river affects many different social and economic aspects for many people. These problems may occur due to, for example, lack of an efficient water management system, deforestation or discharge of untreated effluents from households and industries (Muttamara and Sales, 2008).
1.2 Aims and objectives
The aim of this project is to provide a first-hand quantification of microplastics flowing into the Chao Phraya River by performing environmental modeling from a holistic perspective coupled with field sampling of microplastics.

In order to achieve this aim, this study revolves around the two following main objectives, all connected to the Chao Phraya River:

- The first objective is to estimate Bangkok’s upstream and downstream amount of microplastic pieces per cubic meter of water.

- The second objective is to estimate and discuss the relationship of the amount of microplastics at the different locations along the river.

A further short discussion about how anthropogenic loading of microplastics in the river potentially can be reduced will also be performed.
2. Methods
The following part describes the method used in this project which is divided into different steps. A literature study was the first step for gathering background information about the subject, this was a theoretical part. Furthermore, the more practical steps of the method were the latter ones which can be described as a field study, sampling-sessions and laboration-sessions. The field study took place in Bangkok at the Chao Phraya river and was used to acknowledge and observe both surroundings and environmental aspects at and around the river. The sampling sessions took place at different locations by the river and where the data got measured. Laboration-sessions were performed to analyze the collected data from the sampling sessions. The analyze consisted of identification and counting of microplastics within different size-ranges.

2.1 Delimitations and assumptions
In this study, there are some delimitations and assumptions that were followed. Microplastics were defined in this study as plastics between the sizes 5 millimeters and 0.1 millimeters for the reason that this size interval is a common used boundary in literature. Secondly, the possible different types of plastic material were only considered for four general types, but were not further analyzed in this study, the focus is to get a first-hand relation between microplastic in general upstream and downstream in the river. Moreover, the samples were only going to be taken from the surface water due to equipment boundaries, accessibility and that many types of microplastics are floating. Also, it was assumed that the flowrate of the river was the same throughout the river and that the amount and flow of microplastics were equal at both sides of the river.

2.2 Study area
The sampling for microplastic particles in this paper was conducted in the Chao Phraya river, with focus on its passage through Bangkok. A location upstream and downstream of Bangkok was chosen as boundaries for the study area and thereby defined within which area of the Chao Phraya river the sampling was performed.

As mentioned above Chao Phraya is running through Bangkok and transportation by boat along the river is mainly offered by the Chao Phraya Express Boat company, with approximately 35,000 to 40,000 passengers each day (Chao Phraya Express Boat Co, Ltd., n.d.). With four public boat lines, the company operates between Nonthaburi and Ratburana, covering about 21 kilometers with a total of 38 piers (Chao Phraya Express Boat Co, Ltd., n.d.). While travelling along the river can, among other things, restaurants, hotel complexes, manufacturing sites, housing as well as canals be found along the river.

2.2.1 Sampling locations
Through a collaboration with a total of three hotels and one shopping mall sampling locations were made possible. River City was the shopping mall. Other public piers were owned by the Thai government and therefore could not be used as sampling locations. All sampling locations provided with a pier where the sampling took place and a standard electrical outlet.
Figure 1 shows a map over the sampling locations where The Siam Hotel was the upstream and first point, River City Bangkok and Mandarin Oriental Spa the middle points and also the second and third point respectively and Anantara Riverside Bangkok Resort the downstream and fourth point. The map over the river in Figure 1 also shows that the Chao Phraya River is a meander.

*Figure 1. The Chao Phraya River that runs through Bangkok. The black rectangles are bridges, the red dot is the pick-up-point for the hotels and the green dots with their green signs are the sampling locations.*
2.3 Sampling method

2.3.1 The pump-system
Figure 2 shows the equipment used as a pump-system to sample microplastic particles from the Chao Phraya river. The short metal-pipe marked as number 1 in Figure 2, (1), was put down in the river and water was from there pumped into the system. Consequently, this worked as an inlet for the pump-system. The equipment marked as number 2 in Figure 2, (2), worked as a coarse filter, used to prevent any larger matters from entering the system and affect the intake of the river-water. The longer metal-bar, (3), was sometimes tied together with (1) and (4), see Figure 2, and was used to get an angle out from the pier where the sampling took place.

Thus, water from the river was pumped through the metal-pipe, (1) and then through the pipe marked as (4) in Figure 2 further to a yellow container, shown as number 5 in Figure 2 and more closely in Figure 3. This yellow container had a valve at its inlet as well as at its outlet, see (10) and (11) respectively in Figure 3. As seen in Figure 2 above, a third valve was connected to a garden hose, (6). At the end of the hose coupling was attached. When the valve was open, water could flood into the container from the hose through this attached part. With the help of the hose coupling, the hose could still be on once the valve was closed.

Connected to the outlet-pipe, (7), was a construction with, apart from one of the valves, a filter with the size of 50 microns, see Figure 3. The filter was used to prevent any particles bigger than 50 microns to be pumped back into the river and by that microplastic particles, among other things, were trapped inside the yellow container. This construction with the filter was partly placed inside the yellow container at its outlet, leaving the valve outside. When water was pumped out of the yellow container it went through the filter and further through the outlet-pipe connected to a pump, (7) (Figure 3). From the pump, (8), the water was pumped back into the river through the tube shown as number 9 in Figure 2. Consequently, (9) shows the outlet of the pump-system.
Figure 2. The equipment used in the pump-system.
2.3.2 The filters
A total of 4 filters with different mesh-sizes was used to filter the microplastic particles trapped in the yellow container. Figure 4 shows the filters more closely. The filters had the mesh-sizes of 5 millimeters, 1 millimeter, 0.3 millimeters and 0.1 millimeters and were stacked on each other with a decreasing mesh-size downwards. This gave rise to a distribution of the microplastic particles in different fractions depending on size. The filters used were further made of aluminum, in order to avoid plastic contamination. Between every two filters stacked on each other was a rubber band used to hold them together, see Figure A in Appendix A.
2.3.3 Before the pumping-session
To get the pump working a standard electrical outlet was used at the sampling locations and it was a necessity for making the pump-system work throughout all sampling locations. In this method, it was assumed that an electrical outlet did exist at the sampling locations. Before the start of the pumping-sessions, the golden screws on the pipes were first greased with a bit of vaseline and then they were connected as shown in Figure 2. They were not tightened too much; the hardness was in the scale in which the pipes were not turning. It was important that the system was sealed as much as possible. After this, still before the session started, some parts of the pump-system had to be filled up with water or to the same potential, meaning the yellow container and the two pipes attached to the pump. This could be done either by hand or by a hose, where the hose in that case was connected to the third valve marked as 6 in Figure 2. This needed to be done since the pump could not pump air. The pipe that was only connected to the yellow container did not need to be filled up with water.

2.3.4 During the pumping-sessions
When the pump started both the valves marked as 4 and 7 in Figure 2 were opened at the same time. If the hose case was used, the hose could be on until remaining air was let out and then when this was done the hose valve was closed. If the pump-system sometime changed a bit in how its water flowed out from the outlet, if it wasn’t flowing as much as it should or if it

Figure 4. The filters, presented with which size they are.
did not have a smooth and constant flow, it mainly was due to macro-plastic clogging the inlet or that the system was not sealed enough. It was important that the system was sealed and watched sometimes during the sessions. One pump-session was for about two hours, a clock watch was used to measure the time and was stopped if the flow rate changed and the pump was shut off, at each sampling location and this equals approximately of 11 cubic meters of water flowing through the yellow containers’ filter.

2.3.5 After the pumping sessions
When the pumping session was done the valves were closed, the pipes removed and the yellow container was moved away from the water to the filters and at the same time minimizing the risk of contamination of the collected water. After doing this, the collected sample was run through the filters. The rubber that were holding the sieves together was rolled down under the filter edge. Possible particles on the five-millimeter filter was not included in the method, but for each of the other filter sizes the particles were gently squirted with distilled water from underneath the filter into a glass jar. Under the squirting process aluminum foil was used under the jars to minimizing the risk of contamination of both the sample in total and of plastic which may missed the glass jar and therefore had to be picked up. One filter had one glass jar and that was counted as one sample. These steps were repeated at every sampling location. During transportation, the samples or the sieves were covered with aluminum foil to minimize the contamination risk.

2.4 Measurement of the pump flow
The flow rate of the pump was stated as 90 liters per minute. However, in order to get an estimation of the flow rate in practice, a number of measurements of the flow were made at one of the sampling locations. A bucket with a known volume, in this case 10 liters, was places at the outlet of the pump-system. When water was pumped through the system, the time to fill up the bucket was measured. This approach was repeated a total of 8 times and the time given for each test run was written down. The 8 different times measured were later on added and a mean value was calculated. By then dividing the volume of the bucket with the calculated mean value measured in seconds, an approximate value for the pump flow was obtained, see equation (2.1).

\[ p_{\text{pump flow}} = \frac{\text{volume of the bucket}}{\text{measured mean value}} \]  

(2.1)

The pump flow was now given in the unit liters per second. However, the stated flow rate of the pump was 90 liters per minute. Therefore, the calculated pump flow was converted to the unit liters per minute in order to compare the given pump flow to the rate measured in practice. Furthermore, this measured flow rate was assumed to be the same at every sampling location throughout the report.

By using the flow of the pump and the pumped time for which the sampling took place, the total sampling volume was now calculated for each sampling location. With the help of the
volume and the total amount of microplastic particles collected from this volume, the amount of microplastics per volume unit was calculated.

2.5 Lab-method

2.5.1 Laboratory equipment
Following equipment was used in the laboratory method and were available in the lab at Mahidol University, Thailand.

- Vacuum filter
- Tweezers
- 50 microns filter membranes
- Dissecting microscope
- Vacuum motor
- Camera
- Squirt bottle containing distilled water
- Watch glass

In the laboratory method, a vacuum filter construction was used, shown in Figure 5. Between the funnel and base were a S.S. support screen and a filter membrane with the size 50 microns placed. A clamp held the construction together. A No. 8 stopper was connected to the base to be between it and the collecting liquid bottle, making it more sealed. During the filtering, a vacuum motor was in interval connected to the construction with a pipe.
2.5.2 Laboratory method
In the following part a description of the practical laboratory method that was used is described and it is divided into the different microplastic sizes due to different approaches for the different microplastic sizes. All of the samples were placed in glass jars which were filled with distilled water and were transported to a lab.

2.5.2.1 Lab-method size range 5-1 millimeter
This size was the biggest size and also enough big to easily see the different, both colorful and transparent, microplastics. Moreover, meaning most of the plastic could, with a help of a tweezer, be picked up by hand from the water which they were held in and transported with and was moved to a watch glass were the microplastics were divided into four general plastic types and counted for each type. The general plastic types were hard plastic, soft plastic, foam
and nurdles. All of these types had clear differences in their appearance which made it easier to divide them. If there were uncertainties about if some pieces were of the organic nature or what type it was, a dissecting microscope was used to investigate. Also, all of the plastic pieces found in the water were picked up by hand and counted for this size range, 5-1 millimeter, even if they were part of another size range.

When macroplastics were found, the same method as described above was used.

2.5.2.2 Lab-method size range 1-0.3 millimeter
Size 1-0.3 millimeter were performed partially in the same way as section 2.6.2.1. One difference was due to the small size and therefore risking missing floating pieces, the samples went through a vacuum filter construction instead shown in Figure 5 before they were moved, in a similar way as for the bigger sizes, to a watch glass by hand. They were then counted and divided into the same types as above. Also, the dissecting microscope was used to analyze if there was any plastic stuck in the organic material. Moreover, as mentioned above, all of the plastic pieces found on the vacuum filter membrane were picked up by hand and counted for this size range, 1-0.3 millimeter, even if they were part another size range.

2.5.2.3 Lab-method size range 0.3 to 0.1 millimeter
Size 0.3-0.1 millimeter was the smallest size and could not be treated with the same method as the other sizes. Though, a similar step that was applied for section 2.6.2.2 was the vacuum filter step. The vacuum filter construction is shown in Figure 5. To get rid of all of the water and make the sample drier and still, without risking losing or contaminating the samples, vacuum filtration was necessary. Also, due to the very small size, it was not possible to count and divide the microplastics into types on a watch glass. Instead, both visual observations and visual comparisons with the dissecting microscope were performed. A camera was used for taking pictures through a dissecting microscope for the comparisons in the result. In the pictures that were taken through the dissecting microscope is also the organic material shown together with the microplastic pieces.

2.6 Calculation of results
In order to make a comparison between the different sampling locations, the amount of microplastic pieces per cubic meter of water was calculated and presented in tables and graphs. This calculation was necessary because pumped time and therefore also pumped volume differed between the sampling occasions, which led to different pump conditions. This further means that the values that correspond to the different numbers of microplastic pieces found at each sampling location was divided by their respective volume of water pumped at the location in question, see equation (2.2).

\[
pieces of microplastic pieces = \frac{\text{number of microplastic pieces}}{\text{pumped volume}} \tag{2.2}
\]
The calculated quotient has further, if necessary, been rounded to the nearest integer. If the quotient was a number between 0 or 1 it was also rounded to the nearest integer. However, it made a big difference to round to either 0 or 1 when a quotient was a value between those numbers. It could have been interpreted incorrectly to in some cases only state that there were 0 pieces of microplastic per cubic meter of water when some actually had been found in the samples at the locations in question. Therefore, the initial quotient is also presented in the tables, within brackets, to show that some pieces had been found after all.

3. Results

3.1 The flow rate of the pump-system
Presented in Table 1 below is the time measured in seconds when a 10-liter bucket was filled with water by the pump-system. The time it took to fill the bucket up was measured a total of 8 times, where each of the measured times are presented separately in the table. Also displayed is the total time of the measured test-runs and the then calculated mean value.

Table 1. Measured time presented in seconds.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Total time</th>
<th>Mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.24</td>
<td>7.73</td>
<td>8.04</td>
<td>8.05</td>
<td>8.40</td>
<td>8.17</td>
<td>8.41</td>
<td>8.71</td>
<td>(65.75)</td>
<td>(8.21875)</td>
</tr>
</tbody>
</table>

The mean value and the volume of the bucket give an approximate value of the pump flow as \(1.23\) liters per second, when equation (2.1) was used. Converted to the unit liters per minute, the measured pump flow is approximately \(73.81\) liters per minute. As mentioned earlier in the report, the given flow rate of the pump alone is \(90\) liters per minute. Based on the result above, however, the pump flow seems to be lower for the pump-system in practice, than the theoretical value given as the flow rate for the pump. Therefore, what is later used in the calculations in this report is the flow rate \(73.81\) liters per minute because it is the measured mean value of the pump rate when the system as a whole was used and not only the pump itself.

3.2 Field samples
The results obtained during the practical investigation of microplastic particles in Chao Phraya are presented in the form of written observations, tables, graphs and pictures and are presented in order from upstream to downstream. The written observations account for important information regarding the surroundings of the sampling location and the performed sampling itself. Furthermore, the pumped volume and time as well as the pump flow are specified for each sampling performed.

All collected plastic is shown in pictures. A picture for each of the following size-ranges are presented for every location where sampling was performed: 5-1 millimeters and 1-0.3 millimeters. Macroplastics that were found are also shown in pictures presented along with
the other size-ranges. The pictures for the size-range 0.3-0.1 millimeters are presented together for all the sampling locations in section 3.2.5.

The quantification of the plastic pieces is presented in tables. This applies to all of the size-ranges, even macroplastics, except for the size-range 0.3-0.1 millimeters. The microplastic particles of this size are only presented in pictures for every location where the sampling was performed. The pieces of microplastics that are accounted for in the tables apply to the pumped volume specified for the regarding sampling location and are not, at least not in section 3.2, presented as pieces of microplastics per unit volume.

Important assumptions made regarding the results presented below are that the pump flow remained the same during the pumping sessions and that the pump flow was the same at all of the sampling locations.

3.2.1 The Siam Hotel

3.2.1.1 Observations and surroundings
At the Siam Hotel location, which was the upstream and first point and before the inner city of Bangkok, the boat traffic was calm and it was not many other piers around the hotel, for example not many express boat piers which usually bring a lot of traffic with tourists. Observations of the river water showed no sign or very little amount of plastic floating around on the surface. At this part of the river it was not many other hotels located by or near the river like The Siam Hotel and similar, not many temples either. Some industries could be seen as surroundings and also The Siam Hotel was not located in a significant meander curve. The filter in the yellow container did not clog often at all during the two-hour pump-session, but was cleaned once after one hour even though it really was not needed.

The days before the sampling day were very sunny and clear. Another observation that was made was that it was a lack of trash cans at the current location.

3.2.1.2 Collected data
Presented right below is the pump flow of the pump-system and the total sampling time at The Siam Hotel. The volume that passed through the pump-system during the sampling was calculated from the pump flow and the time and is also presented below.

Pump flow: 73.81 liters per minute
Time: 120 minutes
Pumped volume: 8857.2 liters = 8.8572 cubic meters

The pictures in Figure 6 show the microplastics collected at The Siam Hotel from the sampling there. The left picture in Figure 6 shows the microplastic pieces found within the size-range 5-1 millimeters and the right picture shows pieces found within the size-range 1-0.3 millimeters. The microplastic pieces are divided on the watch glass according to what type of plastic it is and are presented clockwise around the glass, starting in the left upper “corner”,

18
in the following order: hard plastic, soft plastic, nurdles and foam. From this it becomes clear that the type of plastic that dominates in these samples is the soft plastic. For the size-range 5-1 millimeters, this was the only type of plastic that was found. As for the size-range 1-0.3, it is apparent that the amount of soft plastic pieces is more than the amount of hard plastic pieces, barely visible in Figure 6. In this sample, there are further some thin and translucent plastic “threads” that are hard to see.

The quantification of the pieces of plastic shown in Figure 6 are presented in Table 2.

![Figure 6. Pieces of microplastics within the size-ranges 5-1 millimeters and 1-0.3 millimeters collected at The Siam Hotel.](image)

Table 2 shows the amount of microplastic particles collected at the Siam Hotel, the upstream point, divided into different size-ranges and different types of microplastics. No particles bigger than 5 millimeters were found and only a total of 2 pieces of plastic were found within the size-range 5-1 millimeters. More soft plastic particles were found compared to the other types of microplastics.

Table 2. Pieces of microplastics found for every size-range and type of microplastic at the Siam Hotel.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Size-range [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 - 1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1 - 0.3</td>
<td>5</td>
<td>25</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
River City was the second point and one of the middle points, assumed to be at the river’s inner-city part. River City differ from the rest of the sampling locations because it is not a hotel but a shopping mall with many incoming and departing boats. At this part of the river the boat traffic was big with a lot of express boats, hotel boats and other types of small ferries going back and forth and across which means it was also a lot of piers around this building. Observations of the river water showed big amounts of plastic garbage floating and coming in relatively short intervals on the surface. The plastics consisted of a wide range of sizes, for example plastic bottles and plastic bags. Also, a lot of organic material could be noted in the surface water which led to a frequently clogged filter in the yellow container and cleaning of this filter every fifth minute, therefore the pump-session only lasted for one hour. River city is located in an outer meander curve.

At this part of the river many hotel complexes and shopping malls could be noted as well as other in-the-making constructions of new hotels and shopping malls. Before River City are many temples and popular places, as The Grand Palace, located along the river.

The day before the sampling day was rainy, with massive and intense rainfalls the whole day. Another observation that was made was that it was a lack of trash cans at the current location.

### 3.2.2.2 Collected data

Presented right below is the pump flow of the pump-system and the total sampling time at River City Bangkok. The volume that passed through the pump-system during the sampling was calculated from the pump flow and the time and is also presented below.

- **Pump flow:** 73.81 liters per minute
- **Time:** 60 minutes
- **Pumped volume:** 4428.6 liters = 4.4286 cubic meters

This sampling location differs from the others, since the total pumped time here was only one hour compared to two hours at the other sampling locations.

Figure 7 and Figure 8 show the microplastics collected at River City Bangkok from the sampling. Figure 7 shows the microplastic pieces found within the size-range 5-1 millimeters and the two pictures in Figure 8 show the pieces found within the size-range 1-0.3 millimeters. The microplastic pieces are divided on the watch glass according to what type of plastic it is and are presented clockwise around the glass, starting in the left upper “corner”, in the following order: hard plastic, soft plastic, nurdles and foam. However, the right picture in Figure 8 only shows soft plastic pieces. It becomes evident that soft plastic is the type of plastic that dominates in these samples, particularly in Figure 8 where the amount of soft plastic greatly outnumbers the other types of plastic. The second most common type is hard plastic and thereafter foam, while nurdles only were found within the size-range 5-1 millimeters.

The quantification of the pieces of plastic shown in Figure 7 and Figure 8 are presented in Table 3.
Figure 7. Pieces of microplastics within the size-range 5-1 millimeters collected at River City.

Figure 8. Pieces of microplastics within the size-range 1-0.3 millimeters collected at River City.

Table 3 shows the amount of microplastic particles collected at River City Bangkok, the second point, divided into different size-ranges and different types of microplastic. No particles bigger than 5 millimeters were found. A large amount of soft plastic particles was found compared to the other types of microplastics.
Table 3. Pieces of microplastics found for every size-range and type of microplastic at River City Bangkok.

<table>
<thead>
<tr>
<th>Type of Microplastic [pieces]</th>
<th>Hard plastic</th>
<th>Soft Plastic</th>
<th>Foam</th>
<th>Nurdles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size-range [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 - 1</td>
<td>5</td>
<td>47</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1 - 0.3</td>
<td>8</td>
<td>220</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

3.2.3 Mandarin Oriental Bangkok

3.2.3.1 Observations and surroundings
Mandarin Oriental Spa was the third and the other middle point, also assumed to be at the river’s inner-city part where, the boat traffic is very busy on a daily basis. River city and Mandarin Oriental Spa were located relatively close to each other, but on opposite sides of the river. Furthermore, this means that Mandarin Oriental Spa has similar surroundings as River City has, but is instead located at the inner meander curve. There were visible plastics floating on the surface of the water, but compared to River City it was not much. Clogging of the filter in the yellow container did not happen that often either, every half hour the filter needed to be cleaned during the two-hour pump-session.

Similar to The Siam Hotel, the days before the sampling days were really sunny and clear. Another observation that was made was that it was a lack of trash cans at the current location.

3.2.3.2 Collected data
Presented right below is the pump flow of the pump-system and the total sampling time at Mandarin Oriental. The volume that passed through the pump-system during the sampling was calculated from the pump flow and the time is also presented below.

**Pump flow:** 73.81 liters per minute  
**Time:** 120 minutes  
**Pumped volume:** 8857.2 liters = 8.8572 cubic meters

Figure 9 show the microplastics collected at Mandarin Oriental from the sampling. The left picture in Figure 9 shows the microplastic pieces found within the size-range 5-1 millimeters and the right picture shows pieces found within the size-range 1-0.3 millimeters. The microplastic pieces are divided on the watch glass according to what type of plastic it is and are presented clockwise around the glass, starting in the left upper “corner”, in the
following order: hard plastic, soft plastic, nurdles and foam. This means that no nurdles or foam pieces were found. The amount of hard plastic pieces is far less than the amount of soft plastic pieces.

The quantification of the pieces of plastic shown in Figure 9 are presented in Table 4.

![Figure 9. Pieces of microplastics within the size-ranges 5-1 millimeters and 1-0.3 millimeters collected at Mandarin Oriental Bangkok.](image)

Table 4 shows the amount of microplastic pieces collected at Mandarin Oriental Bangkok, the third point, divided into different size-ranges and different types of microplastic. No particles bigger than 5 millimeters were found. There are big differences in how many soft plastic particles that were found compared to the other types of microplastics.

<table>
<thead>
<tr>
<th>Type of Microplastic [pieces]</th>
<th>Hard plastic</th>
<th>Soft Plastic</th>
<th>Foam</th>
<th>Nurdles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size-range [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 - 1</td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1 - 0.3</td>
<td>7</td>
<td>80</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
3.2.4 Anantara Riverside Bangkok Resort

3.2.4.1 Observations and surroundings
Anantara was the downstream and the fourth point and assumed to be after the inner-city of Bangkok. At this sampling location, it was relatively busy boat traffic, but compared to the two sampling locations in the inner-city part of the river, River City and Mandarin Oriental, it was less public piers in the area and calmer. Moreover, there were still a lot of hotels located by the river in this location area which means a bunch of shuttle boats going there. Also, many condos and in-making constructions of new condos were located by the river. Observations of the surface water showed a lot of plastic floating around. Compared to River City’s flow of plastic in the water, Anantara had a more constant flow of incoming plastic. The filter in the yellow container had to be cleaned every quarter during the two-hour pump-session due to clogging of the filter in the yellow container. Anantara is located in an outer meander curve.

The days before sampling day at Anantara were sunny and clear. Another observation that was made was that it was a lack of trash cans at the current location.

3.2.4.2 Collected data
Presented right below is the pump flow of the pump-system and the total sampling time at Anantara Riverside Bangkok Resort. The volume that passed through the pump-system during the sampling was calculated from the pump flow and the time and is also presented below.

Pump flow: 73.81 liters per minute
Time: 120 minutes
Pumped volume: 8857.2 liters = 8.8572 cubic meters

The pictures in Figure 10 and Figure 11 show the microplastics collected at Anantara Riverside Bangkok Resort from the sampling there. Here, also pieces of macroplastics were found, which are shown in the left picture in Figure 10. The right picture in Figure 10 shows the amount of microplastics that was found within the size-range 5-1 millimeters and in Figure 11 are the pieces within the size-range 1-0.3 millimeters shown. The microplastic pieces are divided on the watch glass according to what type of plastic it is and are presented clockwise around the glass, starting in the left upper “corner”, in the following order: hard plastic, soft plastic, nurdles and foam. Hard plastic and soft plastic pieces were found in all of the samples, while nurdles only were found in the 5-1-millimeter sample. Foam pieces were found within both the size-ranges 5-1 millimeters and 1-0.3 millimeters. It seems that the amount of soft plastic is greater than the amount of the rest of the plastic types.

The quantification of the pieces of plastic shown in Figure 10 and Figure 11 are presented in Table 5.
Figure 10. Pieces of microplastics within the size-range bigger than 5 millimeters and 5-1 millimeters collected at Anantara Riverside Bangkok Resort.

Figure 11. Pieces of microplastics within the size-range 1-0.3 millimeters collected at Anantara Riverside Bangkok Resort.

Table 5 shows the amount of microplastic particles collected at Anantara Riverside Bangkok Resort, the downstream point. The total number of pieces are in the table divided into different size-ranges and different types of microplastic. Particles bigger than 5 millimeters were found, i.e. macroplastics. The ratio of soft plastic particles to the other types of microplastics is high, in other words: there is a large amount of soft plastic particles compared to the other types of microplastics.

Table 5. Pieces of microplastics found for every size-range and type of microplastic at Anantara Riverside Bangkok Resort.

<table>
<thead>
<tr>
<th>Type of Microplastic [pieces]</th>
<th>Hard plastic</th>
<th>Soft Plastic</th>
<th>Foam</th>
<th>Nurdles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size-range [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2.5 Microplastics within the size-range 0.3-0.1 millimeters

The microplastics that were found at each of the sampling locations within the size-range 0.3-0.1 millimeters were photographed through a dissecting microscope and are shown in Figure 12 to 15. These pictures show all kinds of material that was found in the samples, both organics and microplastics included. However, not everything that was found are shown in the pictures, since these pictures were taken through a dissecting microscope and therefore show only a magnified part of the sample. Despite this, the figures are assumed to provide an approximate measurement of the amount of microplastics found at each of the locations. Though, it is hard to see some of the plastic pieces among the organic material, since there are particles that are transparent and blend in. For an even more magnified part of each of the samples see Figure B, Figure D, Figure E and Figure F in Appendix A.

The sample from The Siam Hotel is presented in Figure 12, where the microplastic pieces are hard to see and not particularly visible. The large amount of material in the sample from River City Bangkok is shown in Figure 13, but also in Figure C and Figure D in Appendix A. Not even the white membrane is visible underneath the thick layer of material from the river, despite that the total sampling time was only 60 minutes, which was half the time compared to the other samples. However, some really visible plastic pieces can be seen among the organic material, especially visible are the blue pieces but some red and white ones can also be seen. In addition to what can be seen in the picture, it is certainly more hidden in the thick layer of material as well. Figure 14 show the sample from Mandarin Oriental. In this sample, some transparent thin threads can be seen as well as some blue and white plastic pieces, among others (Figure E in Appendix A). Figure F in Appendix A and Figure 15 both show the sample from Anantara Riverside Bangkok Resort. Here a lot of white microplastic pieces can be seen, but also red and blue. When looking at the two magnified parts of the sample in Figure F and Figure G in Appendix A, it becomes apparent that there is a lot of transparent thin fibers among the organic material that are difficult to see in Figure 15.
Figure 12. Pieces of microplastics within the size-range 0.3-0.1 millimeters collected at The Siam Hotel.

Figure 13. Pieces of microplastics within the size-range 0.3-0.1 millimeters collected at River City Bangkok.
Figure 14. Pieces of microplastics within the size-range 0.3-0.1 millimeters collected at Mandarin Hotel.

Figure 15. Pieces of microplastics within the size-range 0.3-0.1 millimeters collected at Anantara Riverside Bangkok Resort.
3.3 Summarized data

A summary of the values accounted for in Table 2 to 5 are presented in tables and graphs below. The difference, however, is that the collected data now is presented as pieces of microplastic per cubic meter, by using equation (2.2). The presented values have been rounded to the nearest integer. For some of the samples, the calculated quotient was a value between 0 and 1. In those cases, the initial quotient is also shown in the tables in addition to the rounded value (0 or 1), but in that case within brackets.

3.3.1 Pieces of microplastic per cubic meter within the size-range 5-1 millimeters.

Table 6 shows rounded values of how many pieces of microplastic particles that were found per cubic meter within the size-range 5-1 millimeters at the different locations where sampling was performed. As shown in the table there are some samples in which there were neither 0 or 1 pieces of microplastic per cubic meter of water, but a value between those numbers; see the numbers within the brackets. An interpretation that can be made from these results is that a piece of microplastic can be found in every third (0.34), every fifth, (0.22) and every other, (0.45) and (0.56), cubic meter of water (see Table 6).

Table 6. The amount of microplastic pieces per cubic meter within the size-range 5-1 millimeters divided into different types of microplastic and where the sample was collected.

<table>
<thead>
<tr>
<th>Sampling Location</th>
<th>Hard Plastic</th>
<th>Soft Plastic</th>
<th>Foam</th>
<th>Nurdles</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Siam Hotel</td>
<td>0</td>
<td>0 (0.22)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>River City Bangkok</td>
<td>1</td>
<td>11</td>
<td>1 (0.45)</td>
<td>1 (0.45)</td>
</tr>
<tr>
<td>Mandarin Oriental</td>
<td>0 (0.34)</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Anantara Riverside Bangkok Resort</td>
<td>1 (0.56)</td>
<td>4</td>
<td>1</td>
<td>1 (0.45)</td>
</tr>
</tbody>
</table>

Table 6 is shown as a bar graph in Figure 16, which for each type of microplastic more clearly shows the distribution of microplastic pieces between the different sampling locations. Among the different types of microplastic, soft plastic was the form that was found most in the samples for this particular size-range and therefore the dominant one (see Figure 16). The amount of soft plastics that was found per cubic meter at River City differs to a great extent from the amount found at the other sampling locations.
In terms of the hard plastic, foam and nurdles, about the same amount per cubic meter seem to have been found at River City, Mandarin Oriental as well as at Anantara Riverside Bangkok Resort. However, as seen in Table 6 and as interpreted above it is rather clear that for some of the samples microplastics were found in every other cubic meter of water and not in each as shown in Figure 16. The values shown in the figure below are rounded to the nearest integer and therefore gives an approximate value of the number of pieces found per cubic meter. Further, almost no pieces of microplastic within the size-range 5-1 millimeters were found at the Siam Hotel. Only in about every fifth cubic meter of water was a soft plastic found within this size-range (see Table 6).

For all the locations where the sampling was performed, River City and Anantara Riverside Bangkok Resort are the most prominent based on where the largest total amounts of plastic pieces were found per cubic meter.

Figure 16. The distribution of the microplastic pieces between the different sampling locations for each type of microplastic.

3.3.2 Pieces of microplastic per cubic meter within the size-range 1-0.3 millimeters

Table 7 shows rounded values of how many pieces of microplastic particles that were found per cubic meter within the size-range 1-0.3 millimeters at the different locations where sampling was performed. As shown in the table there is one sample where there were neither 0 or 1 pieces of microplastic per cubic meter of water, but a value between those numbers. An interpretation that can be made of this result is that a hard piece of plastic can be found in about every other, (0.57), cubic meter of water at The Siam Hotel (see Table 7).
Table 7. The amount of microplastic pieces per cubic meter within the size-range 1-0.3 millimeters divided into different types of microplastic and where the sample was collected.

<table>
<thead>
<tr>
<th>Sampling Location</th>
<th>Hard Plastic [pieces/m³]</th>
<th>Soft Plastic</th>
<th>Foam</th>
<th>Nurdles</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Siam Hotel</td>
<td>1 (0.57)</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>River City Bangkok</td>
<td>2</td>
<td>50</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Mandarin Oriental</td>
<td>1</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Anantara Riverside Bangkok Resort</td>
<td>7</td>
<td>12</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 7 is shown as a bar graph in Figure 17. This more clearly shows the distribution of microplastic pieces between the different sampling locations for each type of microplastic. As can be seen in Figure 17, soft plastic is the most prominent type of microplastic and therefore the form that dominates for this size-range and in these samples. The second most dominant form of plastic is hard plastic, where only a few foam pieces and no nurdles were found. The amount of soft plastics that were found per cubic meter at River City differs to a great extent from the amount found at the other sampling locations. When it comes to the hard plastic, a larger amount was found at Anantara Riverside Bangkok Resort, which also differs greatly from the other locations. For all the locations where the sampling was performed, River City and Anantara Riverside Bangkok Resort are the most prominent based on where the largest amounts of plastic pieces were found.
3.3.3 The variation and relationships of microplastic pieces per cubic meter along Chao Phraya

Regardless of the type of plastic, Table 8 shows the amount of microplastic pieces per cubic meter for the size-ranges 5-1 millimeters and 1-0.3 millimeters and for the locations where the sampling was performed. The values presented in the table are rounded values and therefore give an approximate measure of the amounts of microplastics per cubic meter in the water at the different locations. An interpretation of the value 0.22, shown in brackets, for The Siam Hotel and the size-range 5-1 millimeters, is that at this location approximately one piece of microplastic was found in every fifth cubic meter of water.

Table 8. The total amount of microplastic pieces per cubic meter at each sampling location for the size-ranges 5-1 millimeters and 1-0.3 millimeters.

<table>
<thead>
<tr>
<th>Sampling-location [pieces/m³]</th>
<th>The Siam Hotel</th>
<th>River City Bangkok</th>
<th>Mandarin Oriental</th>
<th>Anantara Riverside Bangkok Resort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size-range [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 1</td>
<td>0 (0.22)</td>
<td>13</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>1 - 0.3</td>
<td>3</td>
<td>52</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

From the values in Table 8, the following approximate relationships for the amount of microplastic pieces per cubic meter at the sampling locations can be written as:
The relationship for the 5-1-millimeter samples: 0:13:1:6
The relationship for the 1-0.3-millimeter samples: 1:17:3:7
The values in Table 8 are shown as graphs in Figure 18 below, one graph for each of the two size-ranges. In this way, it is more clearly shown how the amount varies between the different sampling locations, but also how it changes as the river flows downstream. By looking at the two graphs, there is a clear deviation at the second point from the rest of the result. This corresponds to the amount of microplastics found per cubic meter at River City. From the remaining sampling locations, there is a gradual increase in microplastics from the upstream point to the downstream point. In Figure 18 it also become clearer that a larger amount of microplastics within the size-range 1-0.3 millimeters was found per cubic meter at all of the locations. Consequently, smaller particles dominated the collected samples.

![Figure 18. The variation of microplastic pieces per cubic meter, from upstream to downstream, for the size-ranges 5-1 millimeters and 1-0.3 millimeters.](image)
4. Discussion

Measuring and studying microplastic flows in marine environments is a quite unexplored field and subject in the society today and there exists a lack of information about microplastics in marine environments. Therefore, studying and achieving knowledge about what microplastic loadings cities contribute with, how microplastic behaves and what impact microplastic eventually causes is essential. The unexploration and lack of information of this subject and believe in a sustainable development are important reasons to why this project was made. A sustainable development means creating a development that meet today’s needs but at the same time do not risk future and coming generations possibilities to meet their needs. Sustainable development can be related to the project both from a holistic and an individual perspective based upon water quality. Water quality from a holistic perspective is important both in ecosystems and for species conservation and from an individual perspective for the reason that water is an essential part for organisms’ fundamental needs. Thus, to create a sustainable development that follows this approach, for marine environment and water quality, it is of importance to focus on the reducing of microplastic in the world’s oceans.

4.1 Upstream and downstream

As shown in section 3.3.3, in the tables and the diagrams, the upstream point, The Siam hotel location, had nearly no pieces at all within the 5-1-millimeter size-range, only 0.22 pieces per cubic meter, and for 1-0.3 millimeter the value was three pieces per cubic meter. The downstream point, Anantara Riverside Bangkok Resort, has six pieces per cubic meter and 20 pieces per cubic meter respectively. A comparison with these locations shows approximately a six times and seven times increase in microplastic pieces for 5-1 millimeter and 1-0.3 millimeter between the upstream and downstream point. Thus, an interpretation is that there is a load coming into the river from Bangkok’s inner city.

The amounts that are presented in the result, for example 20 pieces per cubic meter, may sound small but what is of importance to perceive is that the pumping-sessions only lasted, at its longest, for two hours and secondly, it shouldn’t be any microplastic pieces at all floating around in the river. Moreover, as one delimitation were to only sample from the surface water there are possibly also more plastics in the bed sediment which is not shown in these results.

From the visual observations and comparisons on the 0.3-0.1-millimeter size for the upstream and downstream point, presented in pictures in 3.3.3, also shows an increasing amount of microplastics. Both the upstream and the downstream samples are dominated by fiber plastic, but the amount of the fiber is much more at the downstream point. Another important note from the pictures is that, it is much more organic material at the downstream point compared to the upstream point. A further look, with a dissecting microscope, into this organic material mass shows even more hidden microplastics, presumably making it even easier for marine animals and other organisms to passively ingest these microplastics.

4.2 The ratio of the amount of microplastics at the various sampling locations

In the matter of whether the city of Bangkok contributes to an increase in the amount of microplastics in the river, a naturally made assumption was that the total content of plastics in
In general, the amount of microplastics per cubic meter of water is increasing as the river runs through the city. However, the relationships between the different sampling locations regarding the amount of microplastics per cubic meter of water contradict this assumption. These were given as 0:13:16 for microplastics within the size-range 5-1 millimeters and as 1:17:37 for the size-range 1-0.3 millimeters. As also shown in Figure 18, it is particularly clear that the largest amount of plastic per cubic meter was found at River City, the second sampling location, which applies to both of the specified size-ranges. If one cubic meter of water is considered, more than twice the amount of microplastics per cubic meter was found at River City compared to the downstream point, i.e. Anantara Riverside Bangkok Resort. Thus, based on the assumption that the amount of microplastics should have been increasing as the river was running through the city, Figure 18 and the relationships discussed show that this was not the case as the samples collected at River City very much contradicts this.

By looking at the relationships, the amount of microplastics seem to decrease between the second and the third sampling location, i.e. between River City and Mandarin Oriental. The distance between these point is about a kilometer and there is nothing that clearly can explain such a big decrease. However, a natural explanation for this and perhaps also to why the samples collected at River City in general differ to a great extent from the remaining samples are previous intense rainfalls that occurred the day before the sampling, as accounted for in section 3.2.2.1. These rainfalls may very well have resulted in that a large amount of material, including both organic matter and plastics, was washed into the water from nearby land areas. Rain is a common contributing factor in how litter often end up in different marine environments, rivers included. If this now is a big part of the explanation for the large amount of microplastics that was found at River City, this shows how much that really can end up in the water just because of for example rain, compared to the smaller amount that probably would have been found otherwise.

Another explanation to the large amount of microplastics found at River City can for example be that this location possesses a public pier, as opposed the other hotels whose piers only are for the hotel guests. Therefore, there are a lot of incoming and departing boats there. However, because the amount of microplastics found at the next sampling location was not particularly large this means that the amount at River City should not have been much higher than at Mandarin Oriental, since the locations are close to each other. The results otherwise show a large decrease of microplastics in the river between the two sampling locations. This further makes the rain-theory, as discussed above, more credible. On the other hand, the sampling at the two locations in question was performed on different sides of the river. (see Figure 1). Because of the proximity to each other, this could have affected the results. The amount of plastic that perhaps came from River City may not have been evenly distributed across the river as it arrived at Mandarin Oriental, which may explain the “decrease”. But due to the fact that such a large number of particles, both plastic and organic, was found especially within the smaller size-ranges a conclusion is that the rain is the greater explanation for the large amount of microplastics found at River City compared to the other sampling locations.
When ignoring River City’s contribution to the relationships, i.e. the second point in them, can the assumption of a gradually increasing amount of microplastics along the river be assumed to be correct. This because the relationships will in that case show an increase in microplastics as the river flows through the city of Bangkok, as assumed. As mentioned earlier, the relationships show that the amount of microplastic pieces found at Anantara Riverside Bangkok Resort was about 12 times more than the amount found at the Siam Hotel when the two size-ranges were combined. This difference can further be interpreted as the load from the city, which is a considerable amount compared to what was originally found per cubic meter in the river at the upstream location.

The total amount of plastic was generally very small at the Siam Hotel, the upstream point, which further was the sampling location before the city of Bangkok. The increase between the Siam Hotel and Mandarin Oriental was not significantly large, as the amount of microplastics increased with one piece per cubic meter for the size-range 5-1 millimeters. However, the amount was 3 times higher at Mandarin Oriental compared to the Siam Hotel for microplastics within the size-range 1-0.3 millimeters. By now looking at the two relationships between the third and fourth location and compare that to the relationships between the first and the third location, it becomes clear that the biggest increase presumably was made between Mandarin Oriental and Anantara Riverside Bangkok Resort. An interpretation that consequently can be made from this is that the city’s largest contribution to the total increase of microplastics in the river took place on the distance between those two locations.

Figure 1 shows that the distance between the Siam Hotel and Mandarin Oriental is much longer than the distance between Mandarin Oriental and Anantara Riverside Bangkok Resort. This indicates that the larger proportion of the microplastic load from the city was supplied to the water at a short distance. This could partly be explained by the fact that a short distance downstream from Mandarin Oriental is the Sathorn pier located (see Figure 1). Since this is the main pier for the Chao Phraya express boats and furthermore the only pier where commuters can transfer between the Chao Phraya express boat service and the Bangkok BTS Skytrain rail service, there are a lot of incoming and departing boats there as well as many people coming and going in this area. This can of course have an impact on the amount of plastic that in general eventually ends up in the river, originating from this area. However, this is hard to say for sure since Sathorn pier and Anantara Riverside Bangkok Resort are located on different sides of the river. But assuming that the microplastics had had time to get evenly distributed across the river before the downstream point, then it may very well have been one source for the microplastics found at Anantara Riverside Bangkok Resort and thus also a reason for the microplastic load from the city of Bangkok.

By looking at the pictures in section 3.2.5 for the size-range 0.3-0.1 millimeters, there seems to be a gradual increase of microplastics from Figure 12, to Figure 13 and on to Figure 15. Like the other size-ranges discussed above, River City differs a lot from the remaining samples and this sample for the size-range 0.3-0.1 millimeters is therefore no exception. River City now differs both in, as it appears, the amount of microplastics and the amount of organic material in the sample. The reasons why the relationship between the pictures is like this have
already been discussed earlier in this section, as the same may also apply to the samples for the size-range 0.3-0.1 millimeters.

A factor that may have affected the relationships is that the river can be assumed to be a meander. Because the water velocity in the river is greater in an outer curve than in an inner curve, this may have contributed to an uneven distribution of the microplastic pieces in the surface water of Chao Phraya. Since the samples were collected at only one of the sides of the river at each of the sampling locations, the overall impact of the meandering on the distribution cannot be accurately stated. Why the relationships may have been affected by the river being a meander is because the sampling locations vary between lying at inner curves and outer curves, which depending on the impact of the meandering may have affected the results (see Figure 1). The largest amounts of microplastics per cubic meter were found at River City and Anantara Riverside Bangkok Resort. However, the larger amount of microplastics can be assumed to be found at an inner curve, where, due to the low speed, more pieces may accumulate. Because Mandarin Oriental is located at an inner curve and River City and Anantara Bangkok Resort are located at outer curves, this could mean that the relationships would look different if the sampling would have been performed only at inner curves or outer curves of the river.

4.3 The types of microplastics
First when the type of plastic has been established it can help to find the source of emissions and thus find a solution to reduce these emissions. That is why the pieces found in the samples were divided into foam, nurdles, soft plastic and hard plastic. Soft plastic was the type of microplastics that dominated in all of the samples for the size-ranges 5-1 millimeters and 1-0.3 millimeters. These pieces can be assumed to originate from larger pieces of plastic that one way or another ended up in the river and began to break down into smaller pieces of plastic. So, an explanation to this large amount of soft plastic pieces can be because a lot of products made of soft plastic, such as plastic bags and other single-use products, possibly are thrown into the river or in different ways are transported to the river by for example water or wind. The second most common type of plastic in the samples was hard plastic that also presumably originate from different larger plastic products, for example plastic cutlery and plastic corks. The differences in amount between the two types of microplastics may be because soft plastic generally more easily is spread in different ways to the water.

The remaining types of microplastic as given account for in this report, i.e. foam and nurdles, were only found at River City and Anantara Riverside Bangkok Resort. This may be due to the fact that River City is a big shopping mall and a lot of boats stop at the piers there, so many plastic products can end up in the water in different ways. It also had been heavily raining the day before the sampling at River City, which may have contributed to foam and nurdles, among other things, to be washed into the water. The foam and nurdles that were found at Anantara Riverside Bangkok Resort may be due to that this location is the downstream point but also because the hotel is located downstream of the main pier for the Chao Phraya express boats, Sathorn. Therefore, there are a lot of people who visit this pier
every day, which may mean that a lot of plastic derive from this area and can explain that foam and nurdles were found there.

There is research that suggest that urban rivers may serve as important sources of microplastics found in oceans, lakes and at the coasts (McCormick et al., 2014). However, there is lack of data to confirm this and that is why it is important that studies about the load of plastic in urban rivers and canals are performed and about the potential impact these may have on marine environments further downstream. (McCormick et al. 2014; Fok and Cheung 2015; Wagner et al. 2014; Lechner et al. 2014). McCormick et al. (2014) looked at the amount of microplastics upstream and downstream of a wastewater treatment plant (WWTP), often pointed out as point sources of microplastics, in the North Shore Channel in Chicago, Illinois, USA, that joins the North Branch of the Chicago River. The total amount of microplastic pieces within the size-range 5-0.333 millimeters was divided into the following four types: fibers, fragments, styrofoam and pellets, and like this study in Chao Phraya, the amount of foam and pellets (nurdles) was relatively low compared to the combined amount that was found of fragments and fibers. The amount of nurdles and foam found per cubic meter further fits well with the amounts found upstream and downstream in this research for those two types of microplastics. The pieces were only found at the downstream location in both of the studies. (McCormick et al., 2014).

When it comes to the total increase of microplastics between the upstream and downstream point, it was bigger in the Chao Phraya river than in the North Shore Channel (McCormick et al., 2014). In Chao Phraya, the amount increased from 3 pieces per cubic meter at the upstream location to 26 pieces per cubic meter at the downstream location, compared to an increase from 1.94 to 17.93 pieces per cubic meter in the North Shore Channel (McCormick et al., 2014). Consequently, the load from the city of Bangkok was greater than the increase of microplastics in the channel.

In a study from 2000 made at the outlet of the San Gabriel River in the coastal ocean near Long Beach, California, USA, the mean value of the amount of microplastic pieces found per cubic meter of water within the size-range 5-0.333 millimeters was 7.25 (Moore et al., 2002; Moore et al., cited in Gewert et al. 2017). The amount found downstream of Bangkok in Chao Phraya was thus greater than the mean value of the amount of microplastics found in the San Gabriel river, although mostly being an urban waterway. An interpretation that can be made from this and from the case of the North Shore Channel, discussed above, is that the impact from Bangkok on the amount of microplastics in the river can be assumed to be high or at least above average. The concentration (pieces per cubic meter) of microplastics collected in this study downstream of Bangkok was further higher than mean concentrations from several other studies, among other studies performed in the North Pacific Gyre, on the Southern Californian shore and in Stockholm Archipelago and the Baltic Sea (Moore et al., cited in Gewert et al. 2017; Lattin et al., cited in Gewert et al. 2017; Gewert et al., 2017). The mean plastic concentration of the samples collected in the urban area of Stockholm, considered a highly impacted area, was higher than the concentration found more remote in the Baltic Sea, but it was still lower than the concentration (pieces per cubic meter) found downstream in
Chao Phraya. However, the lower amounts of microplastic pieces per cubic meter further offshore and in open oceans can generally be explained by dilution in a greater volume of water.

4.4 Potential reduction of anthropogenic loading of microplastics

According to the result shown above and discussed, there is an incoming load of microplastics entering the river. Bangkok is a big city with many inhabitants and also many tourists coming every year and Chao Phraya, which is running through this city and is busy, has its outlet in the ocean, which means to establish a good environmental infrastructure and an efficient water management in Bangkok is needed. One step to reduce this incoming plastic to the river is to first confirm what kind of plastic material that is flowing in the river, because then it is easier to do something about it. Otherwise it will be hard to know what it exactly is that have to be reduced.

Also, as shown in the River City sampling case, when it had been a long and an intense rain the day before the sampling day, more plastic was noted on the water’s surface, probably washed down to the water from the city’s land. On land, it was a lack of trash cans. With a lack of trash cans and many piers located by the river, different types of plastics are often dumped into the river or on land close to the river. This shows the importance of having a functioning and an efficient garbage management, especially in a big city as Bangkok. Thus, to make Bangkok’s garbage management more efficient is a way of reducing incoming plastic and microplastic to the river. This also applies to industries by the river who has its outlet to the river.

Other similar studies which have investigated and compared microplastic concentrations between urban areas and open water areas discuss similar sources of microplastic loading as Bangkok have which have derived from anthropogenic activities, but also point out other possible sources of potential anthropogenic microplastic loading, and thus also sources that can be reduced or developed in Bangkok. For example, in the study from 2017 that took place in Stockholm Archipelago and the Baltic Sea and that also looked closer to the compositions of the microplastics, showed highest microplastic concentrations in Stockholm’s urban areas (Gewert et al., 2017). A conclusion which were made was that land sources are likely predominate microplastic loading in the marine environment and thus correlate to the discussion in this study in Bangkok.

Moreover, another important source of anthropogenic microplastic load that can be applied to this study’s results from Gewert et. al.’s study (2017) originate from the boat traffic which were busy on certain sample locations. According to the Stockholm study, or a hypothesis that was made and discussed, many plastic pieces that were collected were of a certain type that may derived from ropes used on boats (Gewert et al., 2017). Ropes used on boats are often made of plastic material (PlasticsEurope, cited in Gewart et al. 2017). Moreover, as Chao Phraya also have a busy boat traffic, this could also be a contributing factor to the results in this study. Thus, a check-up on boat ropes or developed boat ropes could be one way to reduce anthropogenic loading of microplastics in the Chao Phraya river.
Another important factor related to the reducing of incoming plastic to the river is consumption behavior. It seems to be very common to use a lot of single use products, as plastic bottles and plastic bags in Bangkok. Also, Gewert et. al. (2017) found out and discussed that single used products such as packaging material could be a reason for the high amount of plastic that were found in the Stockholm area (Gewert et al., 2017). In general, especially in urban cities with a lot of inhabitants and tourism, to establish a behavior that promote recycling and multi-use products would therefore benefit a changed and developed garbage management.

4.5 Reliability of the results

4.5.1 The sampling
The collected data was naturally affected by the conditions present when the sampling was performed. Because the sampling was divided between several days and different locations, this meant that the conditions differed between the sampling occasions. The most prominent change in conditions arises because of the continuous flow of Chao Phraya, which among other things contributes to a constant redistribution of the amount of microplastics in the river. The weather conditions for 3 out of the 4 sampling locations were practically the same. Regarding the fourth location, it had been heavily raining the day before the sampling which, as discussed in section 4.2, most likely affected the results due to the assumption that a large amount of microplastics then was washed into the water. Consequently, a conclusion that can be made based on this information is that the sampling very much was weather sensitive.

The amounts of microplastics per cubic meter presented in the results are representative of the amount of microplastics in the surface water of Chao Phraya, as the samples were collected from this part of the river. Microplastic pieces further down in a water column have thus not been taken into consideration, nor microplastics in the bed sediments.

4.5.2 The laboratory part
When the microplastic pieces were hand-picked from the different size-fractions to watch-glasses, some plastic pieces could have been missed. The microplastic pieces that were hidden in some of the organic matter, as well as the transparent ones, were sometimes hard to detect. But with the help of a dissecting microscope, most of the microplastics were detected. All of the plastic pieces that were found within a size-range were counted as findings of microplastics for that specific size-range, even the pieces that might have ended up in the wrong size-fraction. Consequently, all plastics have, one way or another been accounted for in the results.

4.5.3 Calculation of the results
The pump was said to be pumping 90 liters per minute, but when tested, the result showed that the pump flow varied slightly during sampling. The average of the pump flow that then was calculated from the test results was used as a constant value for the pump flow in the calculations. This assumption of a constant pump flow affected the size of the calculated
values of the amount of microplastics per cubic meter, since the pump flow as proved in reality was varying during sampling. However, this variation of the pump flow can be assumed to be very small (see Table 1). By using the calculated mean value of the pump flow in the calculations and not the pump flow 90 liters per minute, this gave a maximum value of the amount of microplastics per cubic meter. A larger pump flow instead yields a larger pumped volume and thus a larger denominator in the division when calculating the amount of microplastics per cubic meter.

4.6 Method improvements and further project proceedings
There are some improvements that can be made which mostly are related to the laboratory method. In the used laboratory method, possible sediments or organic material were not separated from the samples, meaning some plastic pieces could be hidden in the organic and therefore not counted. This was applied primarily to the sample locations which were more downstream in the river, these samples had much more organic material compared with the upstream location. To get rid of especially the organic material another step in the laboratory method could therefore be added, namely a density separator step.

Another improvement that could be made for this method are related to the pumping-sessions. As mentioned above in 4.5.1, the sampling was very weather sensitive, meaning the sampling result could differ depending if it had been an intense rainfall before or not. An improvement could therefore be to do the sampling of all the locations on the same day. Also, at every sampling location sampling was only performed at one side of the river and due to that the Chao Phraya is a meander, it is rather unclear if the flow of microplastics fluctuate in the different sides. Therefore, to ensure the result more an improvement for this could be, if possible, to sample at both sides of the river and even across the river. Furthermore, more sampling locations is also desirable for the same reason.

A naturally question is maybe why all of these improvement to this method was not made from the start, but the reasons why is simply practical difficulties. Nearly every public pier was government own and needed therefore approval for using them for this project, which was not made. Instead these three hotels and shopping mall, which wanted to be a part of this project, supplied with piers on a specific side of the river.

There are also other interesting further proceedings or developments for this method or project that can be made. For example, the type of plastic material is not considered in the project’s issues for now, but by looking into what material the plastic actually is made of, it is easier to localize its origin and thus make it easier how to better prevent the plastic from enter the river and also how to handle the already existing in the river. Moreover, in this way it will show which companies that have to take a bigger environmental responsibility in their activity and a more direct approach can be made. This means that not only environmental aspects will be affected, but also political and economic aspects.
5. Conclusions
By comparing the samples for the upstream and downstream locations, an interpretation and a conclusion that can be made is that there is a load coming into the Chao Phraya river from Bangkok’s inner city. Between the upstream and downstream locations were a six times increase in microplastic loading for the quantified size 5-1 millimeter and a seven times increase in microplastic loading for the other quantified size 1-0.3 millimeter.

The largest amount of microplastic pieces was found at River City, the second sampling location, which consequently contradicts the assumption of a gradual increase of microplastic pieces as the river runs through the city of Bangkok. However, the reason why the samples from River City differ from the rest of the samples may be because of the heavy raining the day before the sampling, which might have caused a lot of material to be washed into the water. From the three other sampling locations in the relationships, there is a gradual increase of microplastics in the river as it runs through the city. Consequently, this means there is a load that most certainly derive from the city and the people there. The greatest increase in microplastics occurred between Mandarin Oriental and Anantara Riverside Bangkok Resort, where the big main pier Sathorn between the two locations may have been one reason to this increase.

Also, an important conclusion, which is related to potential reductions of microplastics, is that having an efficient garbage management in Bangkok is of importance where the River City sample is example of this. Massive and intense rainfalls are contributing to wash down garbage from the land which means trash on land has to be managed in a more efficient way. At last, many potential reduction ways are related to single use plastic and simply behavior. Single use plastic is a common used product, but as long as the attitude against it stays the same a change is harder to achieve. Thus, if the attitude about recycling and multi-use products change in Bangkok, the possibilities to a more environmental infrastructure in the city is infinite.
6. Acknowledgements
First and foremost, the authors of this project want to acknowledge all the help and support from head supervisor Daniel Franzén, a Researcher at the Department of Sustainable development, Environmental science and Engineering (SEED) at the Royal Institute of Technology (KTH) in Stockholm. Further, special thanks are offered to assisting supervisor Joseph Santhi Pechsiri, a PhD Student at the same apartment at KTH who participated in shaping the project during its early stages.

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7. References

Books, journals and scientific articles


Electronic references


Appendices

Appendix A - Photos

Figure A. The filters with rubber bands.
Figure B. A magnified part of The Siam Hotel sample, size-range 0.3-0.1 millimeters.

Figure C. A part of the River City sample, size-range 0.3-0.1 millimeters.
Figure D. A magnified part of the River City sample, size-range 0.3-0.1 millimeters.

Figure E. A magnified part of the Mandarin Oriental sample, size-range 0.3-0.1 millimeters.
Figure F. A magnified part of the Anantara Riverside Bangkok Resort, size-range 0.3-0.1 millimeters.

Figure G. A part of the Anantara Riverside Bangkok Resort sample, size-range 0.3-0.1 millimeters.