# SYSTEM ANALYSIS OF MEUSE & SCHELDE DELTA'S

*BY FANTASTIC PLASTIC*

CIE4702 - Intergrated Project: Leapfrog Environmental Degradation


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# Abstract

In this research, a system analysis of the Meuse and Schelde deltas was carried out to pinpoint appropriate locations for monitoring plastics. In order to do so, a literature study was conducted on the factors that influence the distribution of plastics in a river delta. The four main natural parameters identified affecting the flow and deposition of plastics are flow velocity, wind direction and speed, salinity and tidal range. For each parameter a conceptual model and hypothesis was designed to predict the behaviour of plastics within the water. In addition to the natural parameters, the anthropogenic influences were also considered in the two deltas. A total of eight locations within the research area were chosen for monitoring plastics based on the influences of all abovementioned parameters and the availability of data. For each location, suggestions were given which hypotheses could best be tested there. These location specific suggestions are the outcome of this project and the input provided to Rijkswaterstaat for their research and monitoring programme. This research is part of a wider national programme using citizen science methodology.

The main constraint of this research was the limited availability of data in terms of locations and time. The most important conclusion, therefore, is that these eight locations are a good starting point for plastic debris monitoring, whereas additional data from other locations and more extended periods of data collection would significantly improve the reliability of the research.

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# 1. Introduction

## 1.1. Background

"Of all the waste we generate, plastic bags are perhaps the greatest symbol of our throwaway society. They are used, then forgotten, and they leave a terrible legacy" (Goldsmith, 2019).

To show the immenseness of the plastic use within our society, here are a few facts. Worldwide an amount of 500 billion plastic bags are used every year. This means that more than one million plastic bags are used every minute, and a plastic bag has an average "working life" of 15 minutes (Plastic Oceans , 2019). These numbers only represent the vast amount of plastic bags that are used. The total annual output of all plastics worldwide comes down to around 311 million tonnes. Between 4.6 and 12.7 million tonnes of these plastics enter the ocean every year (Jenna Jambeck, 2015). This is in the form of plastic bags, but also make up, cleaning products, cigarette buts and even tooth paste. The increasing number of plastic in the Oceans is often referred to as the "plastic soup", and could have devastating effects for nature and humankind itself. This is the reason why it is important that countries start monitoring rivers and deltas that carry these plastics into the oceans.

## 1.2. Motivation

Rijkswaterstaat wants to increase their understanding of the sources, transport and dispersion of plastic pollution, which travels via the Schelde and Meuse deltas to the North Sea. They would like to do this with the help of a large citizen science project. There are several non-governmental organisations that have put citizen science into use to get an idea of the presence and dispersion of plastics in the rivers, and Rijkswaterstaat wishes to evaluate how they may contribute to this. Citizen science is an ideal method for collecting data for a large scale project like this project, as it saves costs and could ensure that citizens have a better understanding of the scale of the problem. This could have a positive effect on the risk perception of plastic pollution (Kristian Syberg, 2018).

## 1.3. Goal of the research

The goal of this research is to provide a detailed system analysis of the distribution of plastic debris in the two Dutch deltas:

- The Meuse, including Nieuwe Maas, Oude Maas and Haringvliet
- Oosterschelde, including Westerschelde and Oosterschelde.

These deltas are very complex systems, but by conducting a system analysis it could be possible to find out how certain processes work which influence the locations of plastic accumulation. The goal of the system analysis is to investigate at what locations citizen science research could be done to get information about the distribution of plastics. In addition to this research, two other groups from Applied Science Universities in the Netherlands are working on the project at a larger scope as well.

## 1.4. Research questions

The following research question was established:

- *What influences the distribution of plastics in the river delta systems of the Meuse and Schelde, and how can that be used to pinpoint suitable locations for citizen science monitoring?*

For this research question the following sub questions were established:

- *What type of delta are the Meuse and Schelde?*
- *What natural and human parameters influence the distribution of plastic debris for that type of delta? And what are their effects?*
- *How do different types of plastic distribute in the vertical water column?*
- *What locations can be determined to perform citizen science monitoring of plastic accumulation?*

## 1.5. Scope of the research

The case study of the Schelde delta can be divided into the Oosterschelde and the Westerschelde (Heip C. , 1989) and the Meuse Delta is split into the Haringvliet and the Nieuwe Waterweg. The scope of the research is shown in Figure 1.

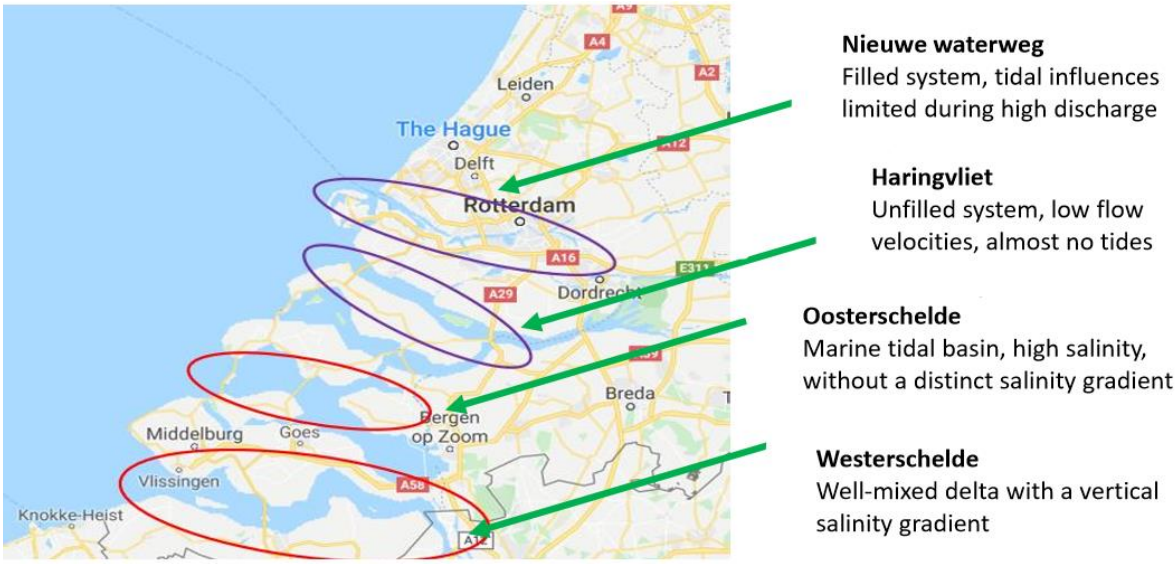


*Figure 1 Scope of the area, where in red is the Schelde delta and the purple circles indicate the Meuse delta*

## 1.6. Reading guide

This report starts off with the methodology of the conducted research. This chapter explains the approach that was taken to obtain results in five different steps. The next chapter contains the results of the research. It is divided into five subchapters, which correspond to the five different steps in the methodology. The first subchapter includes the literature research of the case studies. The second subchapter holds the data collection of the research. The third one describes the different conceptual models which were designed for this research and includes hypothesis based on these models. The fourth chapter is on the choice of possible monitoring locations and the fifth and final subchapter applies the different conceptual models and hypotheses on the test locations. A discussion on assumptions made in the system analysis and problems encountered can be read after the results chapter. Lastly, conclusions and recommendations are stated.

# 2. Methodology

This chapter describes the methodology used for the system analysis of the Meuse and Schelde deltas in the Netherlands. The methodology for the system analysis is divided into five steps that each describe the way that the data was collected and assessed.

## 2.1. Step 1: Literature Research

First, an extensive literature research was conducted on deltas and plastics in general. From this research, different parameters of influence were determined, both anthropogenic and natural. Further literature research was conducted on the different types of plastic and their behaviour in water. Finally, reference projects were compared to determine a suitable approach for a system analysis in the deltas of the Meuse and Schelde.

## 2.2. Step 2: Data collection

The main source of data was the Rijkswaterstaat website: a collection of one week data of different areas on the deltas was used. Only one week data was used because of the lack of data availability. It was assumed that the average of one week would be a valid representative for a period in the autumn season with relatively high precipitation. The data for all parameters at different locations was statically conducted to carry out the system analysis:

- Averages for the wind speed and direction were taken.
- Maximum flow velocity and discharge were used.
- Average of the difference between the maximum and minimum values of tide height were used.
- Average salinity values at three different depths in the vertical water column were taken. Figure 2 shows the three depths that were taken into account.

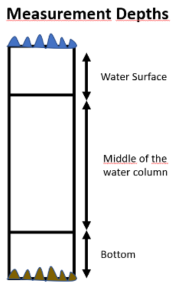


*Figure 2 Schematic overview of the three depths in the vertical water column that were used*

## 2.3. Step 3: Conceptual models

Step 3 was to identify the effect of each parameter individually by designing conceptual models according to knowledge acquired from literature. For each parameter a specific model was designed, illustrating the influence of the parameters on the transportation of plastic in the vertical and horizontal water column. An hypothesis according to the conceptual model was established, explaining the behaviour of plastics to the influencing parameters.

## 2.4. Step 4: Choosing possible monitoring locations

Conceptual models were applied to the data available of the different locations per parameter. All the allocated locations per parameter were merged and compared to conclude the locations of the high potential areas of plastic accumulation. The locations were also chosen based on their significance in terms of (industrial or recreational) activity, availability of data and accessibility for testing. In the two deltas, eight locations were determined for more in depth analysis.

## 2.5. Step 5: Applying conceptual models and hypotheses on test locations

Each location was assessed more thoroughly using the conceptual models. It depends on the location which of the specific hypotheses can be best investigated . At each location, it was also stated at which depth test samples should be taken for citizen science monitoring.

# 3. Results

In this chapter, the results are included. The chapter follows a similar structure as the methodology and the steps of the methodology correspond to the subchapters in this results chapter.

## 3.1. Literature Research and case studies

A literature research was performed on plastics and on the case studies of the two deltas.

### 3.1.1. Plastics

Since the first human settlements estuaries contain most of the World's population, because of their advantageous location. Consequently, due to human activity in these regions, these estuaries have been heavily impacted (Ivar do Sul, 2013). With plastics becoming one of the most commonly used materials in the world, humans have increased the impact we have on our environment exponentially. After entering the sewer, these plastics weather down into something so small we call "microplastics". This is the result of thermal, chemical or physical degradation. The longer the journey of the plastic, the more fragmented they become (Ivar do Sul, 2013). The weathered down plastics will eventually end up in the rivers and in the estuaries, causing great harm to the flora and fauna in these environments.

The distribution of microplastics in estuaries can be affected by several factors. The most important is density. Density determines what place the plastics have in the water column (EPA, 2006). Plastics pollution in water systems found in macro and micro size, according to (Sadri & Thompson, 2014) research micro plastics (>5mm) present more than macro plastics (<5mm). The most abundant types of plastics are polyethylene, polystyrene and polypropylene and they make up packaging that is used (Thompson, Browne, & S, Spatial Patterns of Plastic Debris along Estuarine Shorelines, 2010).

| **Substances** | **Density g/cm3** |
|---|---|
| Polyethylene | 0.9 to 0.99 |
| Polypropylene | 0.85 to 0.95 |
| Polystyrene | 1 |
| Water | 1 |
| Seawater | 1.03 |
| Polyester | 1.37 |
| Nylon | 1.15 |
| PVC | 1.1-1.45 |

| particle diameter (mm) | particle $\rho = 2{,}650\ kg/m^3$ | sedimentation time (over 30 cm) |
|---|---|---|
| 10 | gravel | 0.3 seconds |
| 1 | coarse sand | 3 seconds |
| 0.1 | fine sand | 38 seconds |
| 0.01 | silt | 33 minutes |
| 0.001 | bacteria | 35 hours |
| 0.0001 | clay | 230 days |
| 0.00001 | colloids | 63 years |

*Figure 3 Comparison of the size of sands particles to the plastics size to study the movement of the plastics*

The size and density of plastics debris are the factors that determine their vertical position within the column of water (Thompson, Browne, & S, Spatial Patterns of Plastic Debris along Estuarine Shorelines, 2010), however; plastics mostly are accumulated in the shoreline of estuaries (Sadri & Thompson, 2014). Considering the density as the influencing factor, macro plastics that are less dense will accumulate on the surface and shorelines comparing to the low dense plastics. While high density micro plastics will sediment in the bed sea.

Another big influencer for the distribution, and especially important for this research, is the mixing of fresh and saltwater. This fresh and salt water interface is present in every estuary and is a major contributor to the motion of the water present (Vermeiren & Ikejima, 2016). The intrusion of salt water prevents freshwater streams to move over the bottom, which transports materials as bedload. This could cause accumulation of microplastics on the bottom of the estuary (D.S.Mclusky, S.C.Hull, & M.Elliott, 1993). Thirdly, wind combined with the propagation of waves influences the quantity and distribution of microplastics. Windward oceanic beaches often have greater quantities of microplastics on them (Eriksson, 2013). Lastly, sandy beaches are areas of plastic marine debris. That's why, most of the time, beaches are chosen to measure plastic pollution in an estuary (Ivar do

Sul, 2013). Lower angle banks caused by higher erosion potential have greater capability to host deposits of more plastics (Vermeiren & Ikejima, 2016). This means that for the distribution of microplastics, the angle of the banks should also be taken into account.

To carry out a system analysis of different density plastic accumulation in the Meuse and Scheldt delta, explicit conceptual models were designed based on the literature research above. The influential factors can be divided in to natural and anthropogenic parameters, which can be seen in Figure 4. Four natural factors relevant to plastic distribution in delta system were determined, including wind speed and direction, flow velocity/discharge, tide and salinity. The anthropogenic factor depend on human's activities or human impact on the water surface, such as infrastructure. These anthropogenic factors are mentioned in the subchapter "Case studies".

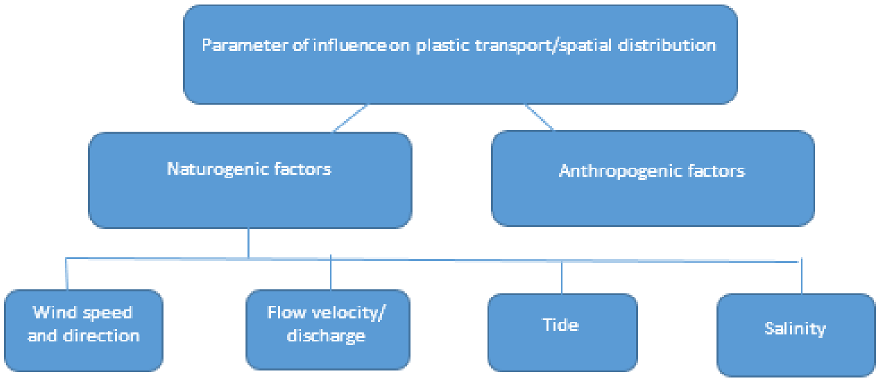


*Figure 4 Division of parameters for the conceptual model*

### 3.1.2. Case studies

The case studies as shown in Figure 1 in the chapter "Introduction", was divided into two deltas. The Meuse delta was divided again into the Haringvliet and Nieuwe Waterweg and the Schelde delta consists of the Oosterschelde and the Westerschelde. Below, these four waterways are evaluated.

### 3.1.3. The Oosterschelde

The Oosterschelde water is salty from the sea water (Heip C. , 1989) without a distinct salinity gradient and can be classified as a marine tidal basin or a high quality marine system (Gerringa, H.Hummel, & T.C.W.Moerdijk-Poortvliet, 1989) (Nienhuis, Smaal, & Knoester, 1994) after the construction of the storm surge barrier in the delta.

The storm surge barrier is one of the anthropogenic factors that may influence the delta (Nienhuis, Smaal, & Knoester, 1994) in terms of decrease in tides in amplitude, occurrence and speed (Nienhuis, Smaal, & Knoester, 1994). Another consequence of the storm surge barrier is a reduced water exchange, reduced saltwater inflow and a decrease om current velocities (Capelle, 2017).

Another factor could be the production of mussels in the Oosterschelde (Heip C. , 1989). Mussels are caught using two different methods: hanging culture or bottom culture (Mosselen Zo Uit Zeeland, sd). The hanging culture is used in the Oosterschelde. The nets in the water may affect the current flow at the place of the hanging nets. It could also be possible that plastics accumulate in the hanging nets (Het Nederlands Mosselbureau, sd), (Brinsley, 2002).

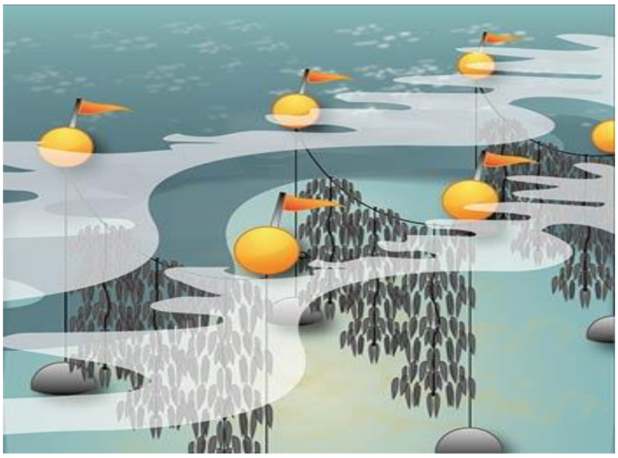

*Figure 5 Hanging nets in the water column (Capelle, 2017)*

### 3.1.4. The Westerschelde

The Westerschelde is open to the ocean and has a clear fresh-salt water interface halfway in the delta, near Terneuzen (Heip C. , 1989). It can be classified as a well-mixed delta with a vertical salinity gradient (Gerringa, H.Hummel, & T.C.W.Moerdijk-Poortvliet, 1989).

The Westerschelde is the most frequently used water way in the Netherlands (Rijkswaterstaat, sd) as ships transport goods from Vlissingen to Antwerp and back out to the ocean. The boat traffic could create turbulence on the surface of the water or the shallow depths of the water column and increase the wave amplitude. Wave generation from boating could result in a short velocity decrease, after which the velocity returns to its original value (Wikström, 2019) (Bhowmik, 1981).

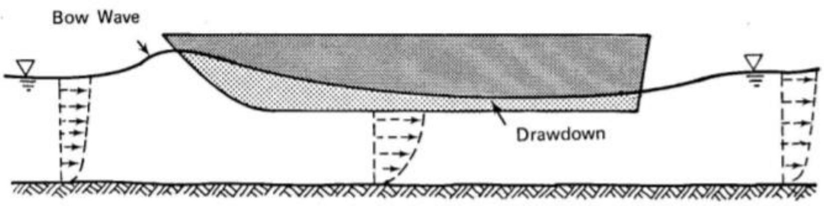


*Figure 6 Effect of shipping industry on the velocity profile of the water column (Bhowmik, 1981)*

Recreational boating occurs in the Westerschelde as well, especially between Terneuzen - Vlissingen and Terneuzen – Hansweert marked with red circles in Figure 7 (Rijkswaterstaat, sd). Tourists could throw plastics into the water. This increases macroplastics in the Westerschelde (Bhowmik, 1981).


*Figure 7 Recreational boating areas*

### 3.1.5. The Haringvliet

The Haringvliet estuary is an unfilled system as there is no or limited water flow from the sea into the estuary due to the presence of sluices (Martinius & Berg, 2011). The sluices of the Haringvliet determine the water discharge of the delta (Rijkswaterstaat, sd). The flow is low in this system as high velocities do not coincide with closed sluices (M.J. Baptist, 2207). Since 2018, the sluices are open three quarters of the year to make it possible for fish to swim back further upstream. This opening of the sluices is small, such that the tides have no or small influence on the water level (De Ingenieur, 2018). The establishment of the sluices causes a decrease in discharge and velocity and increases sedimentation. During high water levels, the sluices open and this scenario results in changes in the tidal flow and causes salt water to enter the delta (P. Paalvast, 1998).

### 3.1.6. The Nieuwe Waterweg

The Nieuwe Waterweg and Brielse Maas are filled estuaries (Martinius & Berg, 2011) means that water from the sea can flow into the Nieuwe Waterweg. This is possible because the storm surge barrier called the Maeslantkering is nearly always open. In a filled system, tidal influences are limited during high discharge, but do affect the flow during low discharges (Martinius & Berg, 2011).

The harbour of Rotterdam is located in the middle of the delta of the Nieuwe Waterweg. Traffic and industry in the harbour increases the production of plastic waste in the Nieuwe Waterweg. Plastic accumulation in the harbour of Rotterdam stimulated the establishment of plastic removal initiatives. At this moment, industries and boats can dispose their plastic waste for free in the harbour (Port of Rotterdam, 2015), to reduce its accumulation in the water. The Port Waste Catch, for example, strives to significantly reduce the amount of plastic soup in the harbour by 2020 (Port of Rotterdam, 2015). A third initiative collects floating plastics in the harbour which are afterwards recycled (Speksnijder, 2017). These are only three of many innovations to reduce plastic waste in the Nieuwe Waterweg.

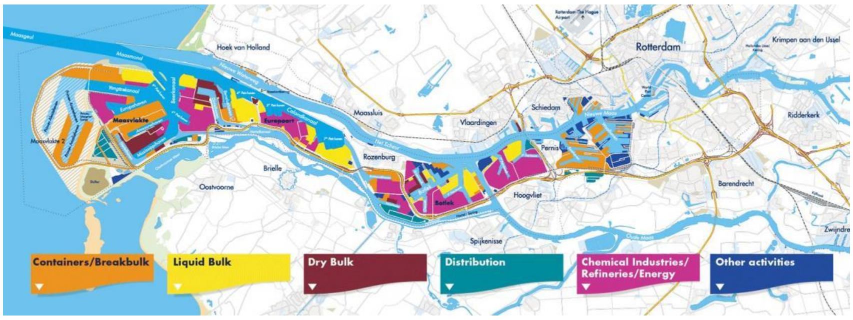

*Figure 8 Harbour of Rotterdam (Port of Rotterdam, sd)*

## 3.2. Data Collection

The data used in this research was measured every ten minutes over the course of one week (8th to 14th October 2019). The average of the data was calculated for all locations at which data was available. This procedure was followed for the following three parameters: wind speed, tide and salinity. For the velocity and discharge parameters, the average of the maximum values only was calculated. The minimum values were negative as they correspond to water flowing inland, away from the coast. Therefore they are irrelevant when analysing the distribution of plastic debris in the deltas because only the plastics that are carried by the rivers towards the sea need to be monitored. All the calculations were carried out with excel and the results of each parameter at each location can be found in Appendix A.

## 3.3. Conceptual models

The next step was to identify the effect of each parameter individually by designing conceptual models according to knowledge acquired from the literature. The models are illustrated per parameter below and after every paragraph of the conceptual model a hypothesis is given on that parameter.

### 3.3.1. Flow and velocity

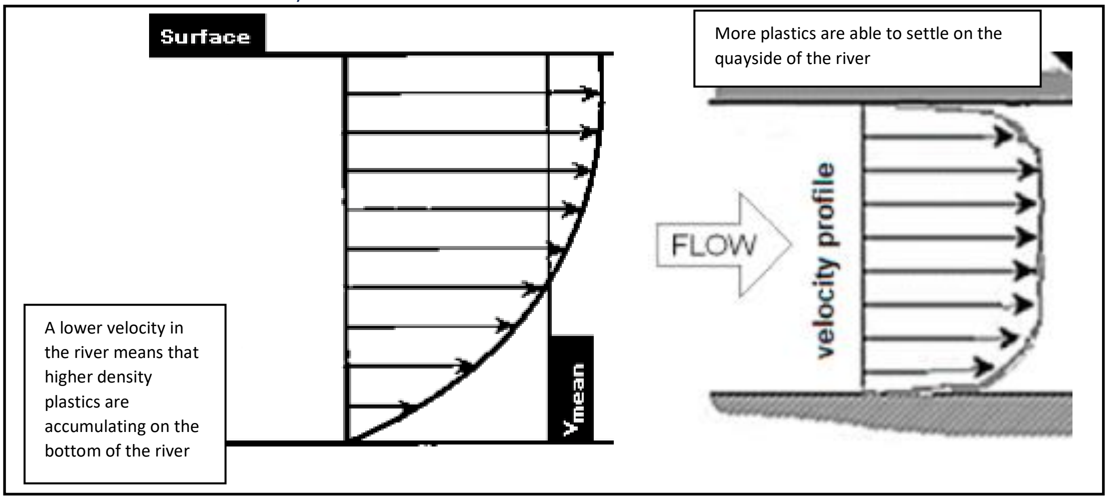


*Figure 9 Conceptual model of velocity parameter*

Water velocity is one of the main driving forces behind sedimentation of macro plastics. In a conducted research on plastics in the Rhine an unexpected drop in the amount of macro plastics near the Rhine-Meuse Delta towards Rotterdam was observed. This is likely because the river has its lowest slope near Rotterdam, slowing flow velocity, whereby sedimentation rates increase for particles with a specific density similar to water (Mani, 2015). Figure 9 shows the velocity profile over the whole river and of the river depth. Velocities near the bottom of the river are almost equal to zero due to shear. This makes it easier for plastics to settle on low velocity river beds. Also Figure 9 show that velocity near the river quaysides are lower due to shear. This makes it easier for plastics to settle near the quaysides of the river. Concentrations of plastics along the river could also differ due to turbulences. A “rougher” riverside, due to an uneven river border, will create disturbances in the flow pattern of the river water, so called eddies. Plastics with a high buoyancy can get trapped inside areas where these eddies are created in the quayside.

- <u>Hypothesis one</u>: *In areas with low flow velocity, higher density macro plastics will settle on the riverbed.*

### 3.3.2. Tidal influence

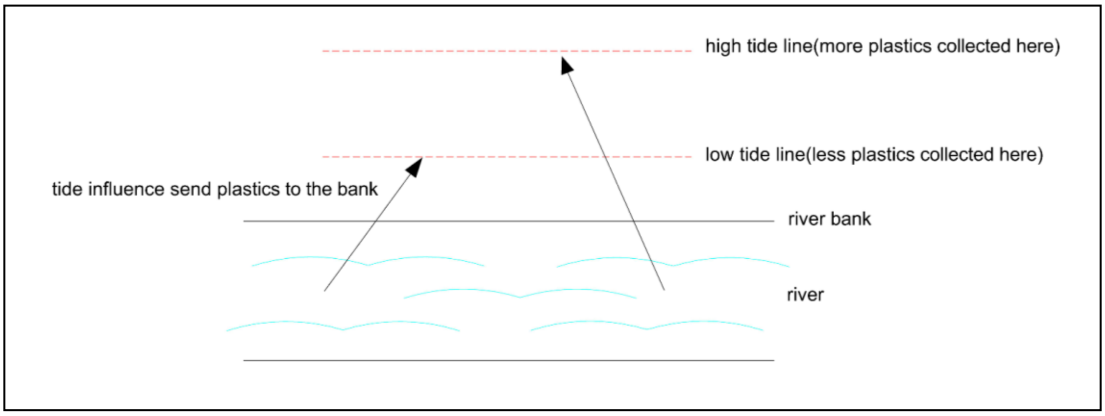


*Figure 10 Conceptual model of Tidal influences parameter*

The tidal range represents the magnitude of the tidal influence. The higher the difference between low tide and high tide, the more plastics will be accumulated on the river bank. However, on the river bank is still a big difference between the high tide line and low tide line. The place where the high tide reaches each time the tide comes in could have much more plastics than the line to which the low tide reaches. Therefore the high tide line on the river bank would be the best place to take measurements (Kurniawan & Imron, 2019).

- <u>Hypotheses two</u>***:*** *Macro plastics of lower density will accumulate on the surface water, and on sandy depositions where tidal fluctuations play a part.*

### 3.3.3. Wind influence

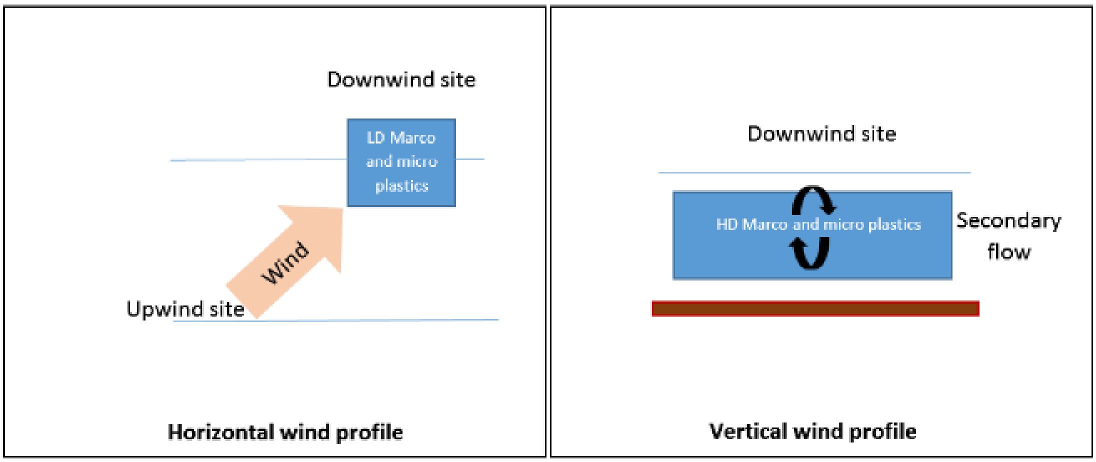


*Figure 11 Conceptual model of the wind parameter*

The wind force and direction have an important role in the spatial distribution of floating plastics. The downwind site is a potential location of plastics debris accumulation. Plastics with a lower density are highly influenced by wind direction due to the buoyancy effect. In contrast, denser plastics are distributed constantly, irrespective of wind direction (Thompson, Browne, & S, Spatial Patterns of Plastic Debris along Estuarine Shorelines, 2010). Macro plastics are more effected by windspeed and direction than microplastics, because microplastics experience more friction with the water. Microplastics have a higher surface area to volume ratio than macro plastics, therefore macro plastics have a high potential to be accumulated on downwind shorelines (Pet16).

- <u>Hypotheses three:</u> *There will be a higher accumulation of plastic debris in downwind areas*

### 3.3.4. Anthropogenic activity

In a conducted research on microplastics in an estuary in France, higher quantities of microplastics were observed in areas characterized by intense anthropogenic activity (L. Frere, 2017). Anthropogenic influences which are found in the Meuse delta's are the sluices and recreational activities. In the Schelde delta this includes the production of mussels, the storm surge barrier and the port of Rotterdam. Concentrations in macro plastics along the river also differ due to entries of effluents of industries, like a waste water treatment plant that is connected to the riverside (Mani, 2015), which may occur in the port of Rotterdam. Macro plastics may accumulate in stagnant water close to sluices or the storm surge barrier or in the nets for mussel productions. Highly populated or recreational areas may also be of importance as humans produce plastic waste and this could easily end up in the river delta (Bhowmik, 1981). It is therefore important to take into account the anthropogenic influences within a delta for the distribution of macro plastics.

- <u>Hypothesis four</u>: *There will be a higher macro plastics concentrations near densely populated areas or areas with high anthropogenic activity.*

### 3.3.5. Salinity gradient

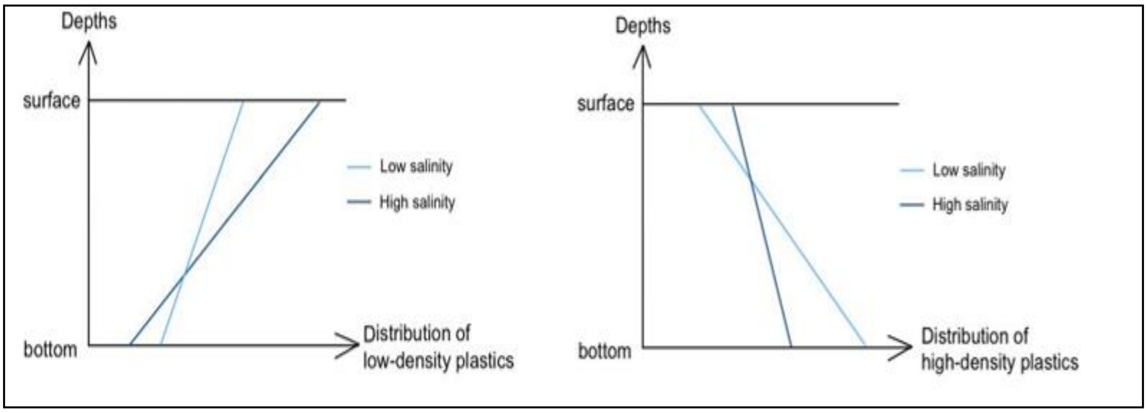


*Figure 12 Conceptual model of salinity parameter*

The salinity gradient can influence the distribution patterns of plastics in estuaries where fresh water and salt water flows and mix together. There will be more buoyancy in salt water than fresh water due to the high density of salty water. When the salinity is high, more plastics can be considered as low-density plastics and float on the surface instead of settling down to the riverbed where the salinity is high (Gerringa, H.Hummel, & T.C.W.Moerdijk-Poortvliet, 1989).

For microplastics, a net negative charge could lead to flocculation near the mouth of deltas. However, distribution of microplastics is largely unknown (Vermeiren & Ikejima, 2016) since complicated physical and chemical reaction processes occur across the estuaries. In well mixed estuaries, such as the Westerschelde, there is a high flushing rate of plastics (D.S.Mclusky, S.C.Hull, & M.Elliott, 1993). This implies that the measurements in well mixed estuaries could indicate the outflow of plastics to the marine environment.

The presupposition of the schematic diagram is that the total amount of plastics is the same. When the salinity is low, more plastics can be considered as high dense plastics, while more plastics can be considered as low dense plastics when the salinity is high. In this diagram it is assumed that the salinity is the same in different levels of depths, however for the research itself, three depths were taken into account. High dense plastics are more likely to settle down while low dense plastics are more likely to float.

- <u>Hypothesis five:</u> *In areas with high salinity, more plastics will be accumulated on the surface of the water.*

## 3.4. Choosing possible monitoring locations

In this chapter the results are given of the conducted research. There are a total of eight locations that are of interest for citizen science research. These locations are indicated in Figure 13 with a red triangle, numbered one to eight. The locations were determined based on the following natural parameters:

- The effect of wind speed and direction
- Salinity gradient
- Tidal features
- Flow velocity and discharge
- Anthropogenic parameters such as nearby cities, nearby sluices and shipping industry.

The following paragraphs explain the reasoning behind choosing the specific eight locations. Each paragraph contains a close up image of the locations, a small table with the data of the most important parameters and answers to the questions stated in the methodology:

- Why was this location chosen?
- Which parameters are of significant importance at that location?
- Assessment of different hypothesis on the area of influence
- How will the plastics be distributed over the area (water column and land), and where do measurements need to be done


Figure 13 The final eight locations best suited for citizen science measurements

| Number | Location |
|---|---|
| 1 | Hoek van Holland |
| 2 | Rozenburg |
| 3 | Vlaardingen |
| 4 | Haringvlietweg |
| 5 | Willemstad |
| 6 | Westenschouwen |
| 7 | Bath |
| 8 | Terneuzen |

## 3.5. Applying conceptual models and hypotheses on test locations

The following tables include the values of each parameter per location, based on the numbering in Figure 13. In green the parameters of influence per location are indicated. This data was collected from the site of Rijkswaterstaat. The complete data collection is shown in Appendix A

*Table 1 Values of different parameters for the eight different locations, showing the parameters of influence in green.*

| # | Average wind speed (m/s) | Average Wind direction (Degree) | Tides (difference low – high tide) (cm) | Max flow (m/s) | Max discharge ($m^3/s$) | Anthropogenic influences |
|---|---|---|---|---|---|---|
| 1 | 7.92 | 200 | 180.14 | 0.9 | 7000 | Cities, Shipping Industry |
| 2 | N/A | N/A | 184.00 | 1.2 | 6300 | Industry, Cities |
| 3 | 5.26 | 192 | 169.86 | 1.0 | 6200 | Industry |
| 4 | 6.33 | 197 | 229.86 | 0.5 | 100 | Sluices |
| 5 | N/A | N/A | 32.43 | 0.17 | 2500 | N/A |
| 6 | 7.70 | 201 | 259.00 | 0.5 | 150 | Storm surge barrier |
| 7 | 1.82 @ 6th/11 | N/A | 504.00 | N/A | N/A | N/A |
| 8 | 3.83 | 181 | 435.14 | N/A | N/A | Boating & Recreation |

*Table 2 Values for salinity in the water column for the eight different locations*

| # | Salinity(mg/L) | | |
|---|---|---|---|
| | Surface | Middle | Bottom |
| 1 | 5321 | N/A | N/A |
| 2 | 3500 | N/A | N/A |
| 3 | 467 | 530 | 583 |
| 4 | 128 | 133 | 178 |
| 5 | 57 | N/A | 70 |
| 6 | N/A | N/A | N/A |
| 7 | 11645 | N/A | 11902 |
| 8 | 14408 | N/A | 15697 |

In the following three subchapters, three locations will be discussed elaborately. Location one was chosen as this location is located close to the mouth of the delta and includes a downwind area, a high discharge and is close to industry. Location six was chosen as it is close to the storm surge barrier, which is of big influence for plastic distribution as it influences velocity and discharge as well. The downwind site of the location was chosen. Lastly, location seven is included as this is the location with the highest tidal influence. All other locations can be found in the Appendix B, where each location is assessed similarly to the locations in these subchapters.

### 3.5.1. Location 1 Hoek van Holland


*Figure 14 Area of interest for location 1, upper channel is called the Nieuwe Waterweg and the lower channel Challand channel*

**Location description:**
Hoek van Holland was chosen as it is close to the mouth of the delta with a high discharge. There is an interface between delta and ocean and the salinity level is high. The southwestern wind there is of high velocity. Traffic and industry in the harbour increases the production of plastic waste in this area.

**Parameters of influence:**
*<u>Flow and discharge</u>:* This is the location with the most discharge passing by, as it forms the mouth of the delta. The Nieuwe Waterweg can reach a discharge level of 7000 $m^3/s$ and has an average velocity of 0.9 m/s. With such a high discharge, there is a big chance that a lot of microplastics will pass by this location. The maximum discharge of the Caland channel reaches values of 1500 $m^3/s$, which is considerably smaller than the discharge in the upper channel. The same goes for the flow velocity, which is 0.13 m/s.
*<u>Wind</u>:* Hoek van Holland is also the location with the highest wind speeds, averaging out on 7.92 m/s. The average wind direction is 200 degrees. This means that the water is influenced by a heavy downwind, driving the upper part of the water column towards the northern quayside.
*<u>Salinity</u>:* The average value of salinity gradient is 5300 mg/L. This salinity value is high since the location is really close to the sea and is dependent on tidal features.
*<u>Anthropogenic influences</u>:* This location is close to Hoek van Holland, a small township with around 10,000 inhabitants. Situated a little bit more upstream is wastewater treatment plant “Nieuwe Waterweg”. The Caland channel is used for the shipping industry.

**Hypothesis Assessment**
Firstly, due to the heavy winds coming from the southwest, plastic debris on surface water will be blown towards the northern quayside of the channel. That is why hypothesis can be 3 assessed here. Also, hypothesis 4 can be analysed, as there is a wastewater treatment plant upstream. This can bring a lot of plastics in the water stream. Comparing this location with a location more upstream could give more insights in whether hypothesis 4 is true. Lastly, because of the high salinity in the water, hypothesis 5 could have an effect in the channels. More macro plastics of low density could accumulate in the surface water.

**Plastic distrubution and measurements**
Due to the high salinity gradient, less dense macro plastics will float around the surface level of the water. The wind gradient coming from the southwest makes it plausible that plastics trapped in the upper part of the water column accumulate on the northern quayside of the channel. There is a small groove visible in the quay with a small sand deposition in it. This could be an interesting area for citizen science measurements. Plastics will accumulate on this deposition due to tidal features and easy,

frequent measurements can be taken there. Also, measurements should be taken from the bottom of the channel for the denser plastics that precipitated. Finally, it is advised to take regular measurements from the water in the surface layer to obtain measurements of the lower density plastics floating on the surface.

### 3.5.2. Location 6: Westenschouwen

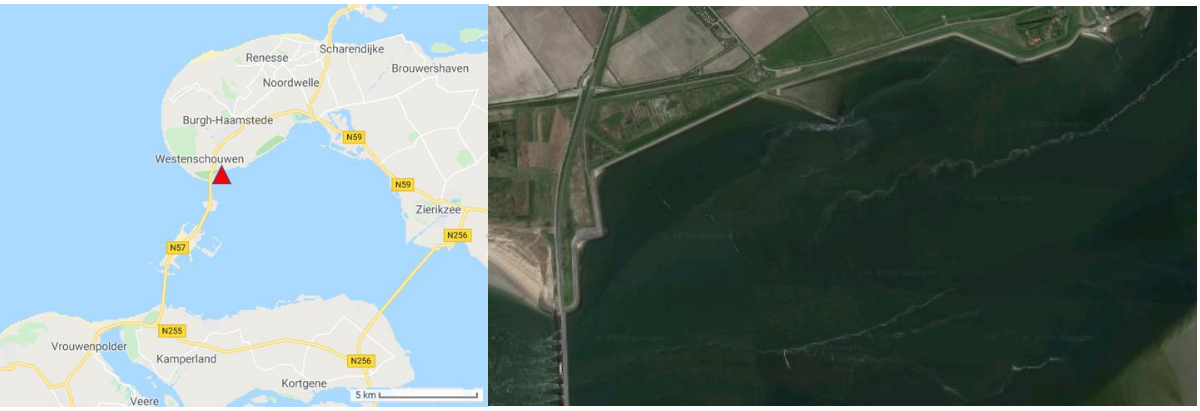


*Figure 15 Area of interest for location 6*

**Location description:**
This location is chosen as the storm surge barrier is located close to the location and it is a downwind area.

**Parameters of influence:**
*<u>Wind</u>:* The wind direction of Westenschouwen is South-West and there is a downwind site. The average wind speed is about 7.70 m/s, which can be considered as a high wind speed.
*<u>Flow velocity, discharge and tide</u>:* This location is close to the storm surge barrier hence the status of the storm surge barrier will determine the characteristics of the flow greatly. The status of the storm surge barrier changes weekly. When the storm surge barrier is closed, the water is almost stagnant. The velocity and discharge are nearly zero and the tidal difference is small. When the storm surge barrier is open, the tidal difference is 259 cm on average, which is a medium level compared to other locations.
*<u>Salinity influence</u>:* When the storm surge barrier is closed, the barrier separates fresh water with seawater. When the storm surge barrier is open, the salinity is relatively high since there will be an interface of freshwater and salt water.

**Hypothesis Assessment**
Hypothesis 1 can be tested here. It is assumed that there is more high-density plastics in bottom water in stagnant water than that in running water. The measurements can be taken at different levels of depths using the diving method. Hypothesis 2 can be assessed here and the distribution of low-density plastics in water column can be concluded after measurements, which can be taken at different levels of depths using the net method. Hypothesis 3 can be tested on the northern riverside. Since the northern shore is the downwind area and can hold plastic debris.

**Plastic distribution and measurements**
Due to the wind direction and the high wind speed, it can be assumed that plastics could accumulate on the northern riverside. Sampling does not have to be performed frequently.

It is assumed that low dense plastic accumulation occurs in the surface water while high dense plastic accumulates in the bottom water. When the storm surge barrier is closed, more high dense plastics will settle down and accumulate as bedload due to stagnant water and low salinity. When the storm surge barrier is open, more plastics will be transported to the sea instead of settling down compared with the closed status. The density of plastics in the surface in running water will be larger than that in stagnant water. Low density macro plastics can deposit in higher places of the shoreline because of the tide. Measurements should be taken weekly in three levels of depths using diving and net methods. Sampling should be done in the middle of the water both when the barrier is open and closed, and barrier status should be recorded with the measurement data.

### 3.5.3 Location 7: Bath

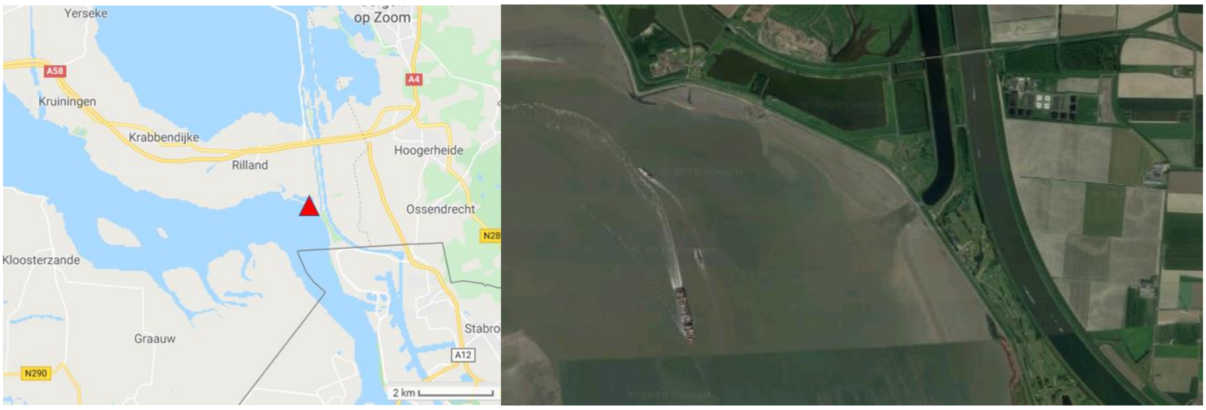


*Figure 16 Area of interest for location 7*

**Location description**

This location was chosen as it shows the highest tidal difference in both deltas. According to hypothesis 2, this suggests that macro plastics will accumulate on the sandy shoreline during low tide. Also, Bath is located close to the shoreline. Thus location 7 is recommended to investigate using citizen science.

**Parameters of influence**

*Flow velocity influence*: Bath is located on the outer side of a bend in the Scheldt river. This is an area where water flow velocity is higher than on the inner side of the bend. (Elina Kasvi, 2017). The inner banks are therefore an area of deposition.

*Wind Influence*: According to the average wind direction in the Netherlands, Bath is considered to be the downwind site of this area. This will enhance plastic accumulation at the outer bend of the river.

*Tidal influence*: In comparison to the other chosen locations, Bath has the highest differences of high and low tide. This difference is 504 cm (the minimal difference is 32 cm). This is therefore an important parameter that influences plastic accumulation. The large tidal difference has two consequences. Firstly, at high tides, there is higher plastic accumulation than during low tides. Secondly, lower density plastic is more likely to float and expected to deposit more than higher density plastic.

**Hypothesis Assessment**

Due to the low velocity at the shoreline, it is advised to test for hypothesis 1. Furthermore, the large tidal difference is ideal for testing of hypothesis 2. This location can also be used for testing of hypothesis 3 because it is downwind.

**Plastic distribution and measurements**

It is advised to do two types of sampling. In case, the river banks are dry during low tide, it would be useful to take a sand sample to check the amount of macro plastics that have been deposited. In addition, it would be useful to take water samples monthly during high tide at three different depths: surface, middle and river bed. This would give an indication of the amount of plastics that have accumulated throughout the water column.

### 3.5.9. Summary

This subsection includes two tables on the final findings of the research. Table 3 states the hypotheses which can be assessed at the eight monitoring sites and Table 4 clearly shows where measurements should be taken and how frequently. Some of the eight locations are suitable to make sandy deposition measurements and plastic debris measurements on the riverbank.

*Table 3 Hypotheses which can be assessed at the eight different locations*

| | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **1** | | | √ | √ | √ |
| **2** | √ | √ | | | √ |
| **3** | √ | | √ | √ | |
| **4** | √ | | √ | √ | |
| **5** | | √ | √ | | |
| **6** | √ | √ | √ | | |
| **7** | √ | √ | √ | | |
| **8** | | | √ | √ | √ |

*Table 4 Measurement methods which can be made in eight different locations*

| | **Frequency of measurements in water column** | **Sandy deposition measurements (yearly)** | **Plastic debris measurements (monthly)** |
|---|---|---|---|
| **1** | monthly | | |
| **2** | monthly | √ | |
| **3** | monthly | | √ |
| **4** | weekly | | √ |
| **5** | monthly | | √ |
| **6** | weekly | | √ |
| **7** | monthly | √ | |
| **8** | monthly | | |

# 4. Discussion

Eight locations within the research area have been chosen for citizen science testing. The main limiting factor in this decision making was the spatial availability of data. Therefore only locations with available data of at least some of the parameters were chosen. These locations are therefore better for citizen science measurements because there is data available that is important for plastic distribution. By interpolation, each parameter could also be characterized at locations with no data availability. Especially for the wind parameter, this was assumed to be a reasonable method as the wind direction is on a yearly average directed North East (Windfinder, 2019). This correlated to the weekly averages of nearby locations. The data used in this research was published by Rijkswaterstaat for the week of 8$^{th}$ to 14$^{th}$ of October. Due to the lack of availability of yearly data and a too long processing time for monthly data, it was decided to work with this particular week for all parameters. This data gives an early indication of possible areas for citizen science monitoring. The averages of the weekly data were taken as they are the most accurate representative of average conditions in the autumn season. It would be more accurate to further investigate the influence of these parameters during other seasons, over the year or over many years if data is available.

For this research it was assumed that the main natural parameters that influences plastic distribution in the water are water flow, wind direction and speed, tidal range and salinity. However, plastic distribution may also be influenced by other factors that are yet unknown. For the scope of this research, the data of these parameters were useful to predict areas of plastic accumulation and are assumed to be a good representative as these parameters have a big influence on the movement of plastic in water. However, it would be more reliable to perform a system analysis again when more research is done and available on the behaviour of plastics in water.

For each parameters a conceptual model was designed to visualize the impact of the parameter. This model was assumed to be applicable to all locations in the two delta's, meaning that each parameter affects plastic distribution in the same way at all locations. This could be a reasonable assumption if the physics in the delta area works the same at all locations despite small geographical differences. The eight locations assigned in this research were chosen because they experienced the highest consequences of most, if not all, parameters. Monitoring measurements will allow measuring these effects. The conceptual models were simplified by making various assumptions. It was assumed that at the downwind site plastics accumulate. This is reasonable, because even if there had been buildings or trees in between, the river delta is wide enough such that these obstacles will not influence wind speed. Plastics are also assumed to flow towards the sea. Therefore only the average of the maximum flow velocity was considered for this research and the negative minimum flow velocity values were neglected (as these account for flow inwards). Since plastics enter the river mostly through anthropogenic sources this is logical. This was furthermore confirmed by the types of plastic, such as cans and lids, found during the fieldtrip to the opposite side of the river at location 3. It is also assumed that the salinity is an important parameter in terms of where plastics can be found in the vertical water column. This parameter takes into account the different densities of plastics without considering the size of the plastic particles distribution. It would be recommended to also measure the size of plastic debris in citizen science monitoring. This allows more insight into the effect of salinity on the distribution of different sized plastics.

Regarding the final decisions on measurements by citizen science, it was assumed that the water column consisted out of three layers (the surface of the water, the middle and the bed of the water vertical column). The techniques and the frequency of the measurements are beyond the scope of this research. However, suggestions were made according to the knowledge at hand.

# 5. Conclusion and recommendations

In this chapter, the final conclusions and recommendations concerning the distribution patterns of plastics in the Schelde and Meuse deltas of the Netherlands are stated.

## 5.1. Conclusion

Despite the limited data that was available, the research has produced results showing which hypotheses to test at each location. Based on specific characteristics of each location, certain hypotheses can be tested much more effectively than others. A clear example is the testing of hypothesis 2 at location 7 because it has the highest tidal range in the research area.

The system analysis performed for the Meuse and Schelde river deltas was based on conceptual models of four natural parameters and anthropogenic influences. The conceptual models give a first understanding of the possible distribution patterns of plastic in the two deltas. Eight specific locations were determined. These locations are a starting point to test the hypotheses on plastic distribution. Location three was visited and it was concluded that more sampling should be done at a deeper depth and not only at the surface of the water. It may also be concluded that assessing these parameters alone is not enough to determine possible locations of accumulations of plastics. They are dependent on each other and on many more parameters which were not included in this system analysis.

## 5.2. Recommendations

Future research and plastic monitoring programs involving citizen science should consider the following recommendations to improve the reliability of the results:

- To improve the reliability of this research, it is recommended to look at yearly or seasonal averages for all parameters if available. This is because the parameter values might vary across the year. Also, even though interpolation gives a good estimate, it would also be recommended to collect measurements at the exact location of interest.
- Due to time limitations, only location three could be visited. It is important to verify the hypotheses that had been established and it is therefore recommended to make a fieldtrip to all locations, analyse the data at the locations and determine whether the location is suitable for monitoring.
- It is recommended to perform citizen science at all levels of the water column to be more precise and not only at certain depths. Although this would take more time, it would be more accurate.
- Find more reliable and replicable information on the parameters within the system. Other parameters should be taken into consideration when assessing plastic accumulation in a delta. If more data is known, also on other parameters, other locations could be considered as well.

In short, it can be concluded that the eight determined location can be visited and recorded and plastic accumulation can be assessed by citizen science. Yet it is possible that more locations may be evaluated if more data is known on the two deltas.

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# Appendices

## A. Data per parameter per location

*Wind speed and direction in Meuse and Schelde*

| Wind | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Delta | Location | Speed(m/s) | | | | Direction | | | |
| | | Max | Min | Median | Average | Max | Min | Median | Average |
| Meuse | Rotterdam Geulhaven | 10.97 | 0.30 | 5.21 | 5.26 | 359.20 | 93.80 | 189.40 | 192.27 |
| Meuse | Geulhaven Radarpost 10 | 0.11 | 0.00 | 0.05 | 0.05 | 35.90 | 9.40 | 18.90 | 19.23 |
| Meuse | Maeslantkering guide tower | 11.02 | 0.58 | 6.13 | 5.83 | 296.90 | 69.60 | 183.40 | 190.82 |
| Meuse | Hoek van Holland | 14.80 | 0.43 | 8.08 | 7.92 | 313.90 | 78.00 | 191.00 | 200.54 |
| Meuse | Low Light | 12.94 | 0.60 | 6.90 | 6.77 | 304.30 | 83.20 | 190.60 | 201.02 |
| Meuse | Haringvliet locks sch 1 | 14.50 | 0.30 | 6.30 | 6.33 | 311.00 | 90.00 | 197.00 | 197.41 |
| Schelde | Marollegat | 11.98 | 0.56 | 6.76 | 6.53 | 349.90 | 11.70 | 193.70 | 181.57 |
| Schelde | Bergsediepsluis wind | 11.15 | 0.69 | 6.49 | 6.25 | 358.70 | 18.10 | 191.45 | 178.80 |
| Schelde | Stavenisse | 11.58 | 1.12 | 5.62 | 5.56 | 309.40 | 28.20 | 198.00 | 184.62 |
| Schelde | Wilhelminadorp | 9.38 | 0.57 | 4.57 | 4.45 | 293.30 | 24.30 | 196.80 | 184.84 |
| Schelde | Zeeland bridge wind | 13.08 | 0.19 | 7.18 | 6.94 | 312.10 | 45.20 | 196.10 | 184.75 |
| Schelde | Oosterschelde 4 | 14.05 | 0.48 | 7.73 | 7.70 | 303.30 | 64.50 | 199.25 | 201.61 |

Source: Rijkswaterstaat,2019

*Flow and discharge in Meuse and Schelde*

| Flow and discharge | | | | | | | |
|---|---|---|---|---|---|---|---|
| Delta | Location | Flow velocity(m/s) | | | | | |
| | | Max | Min | Average | Max | Min | Average |
| Meuse | Rotterdam Geulhaven | 111 | -72 | 20 | 3327 | -2508 | 500 |
| Meuse | Geulhaven Radarpost 10 | 68 | -86 | -20 | 4092 | -5700 | -1000 |
| Meuse | Maeslantkering guide tower | 16 | -24 | -5 | 1576 | -2490 | -500 |
| Meuse | Hoek van Holland | 100 | -77 | 10 | 7554 | -6964 | 0 |
| Meuse | Low Light | 38 | -63 | -10 | 5300 | -9000 | -2500 |
| Meuse | Haringvliet locks sch 1 | 1 | -0.5 | 0.15 | 260 | -90 | 110 |

Source: Rijkswaterstaat,2019

*Salinity in different depth in Meuse and Schelde*

| Salinity | | | | | | |
|---|---|---|---|---|---|---|
| Delta | Location number | Depth(m) | Max(mg/L) | Min(mg/L) | Median(mg/L) | Average(mg/L) |
| Meuse | Cl_CONCTTE_HVL02 | 2.00 | 157.00 | 115.00 | 131.00 | 132.33 |
| Meuse | Cl_CONCTTE_HVL08 | 8.00 | 160.00 | 118.00 | 135.00 | 136.67 |
| Meuse | Cl_CONCTTE_HVL13 | 13.00 | 10916.00 | 10832.00 | 10896.00 | 10886.81 |
| Meuse | Cl_CONCTTE_KR1b | 2.00 | 157.00 | 109.00 | 130.00 | 129.82 |
| Meuse | Cl_CONCTTE_KR1m | 7.00 | 172.00 | 112.00 | 128.00 | 128.91 |
| Meuse | Cl_CONCTTE_KR1o | 15.00 | 9739.00 | 9671.00 | 9710.00 | 9709.01 |
| Meuse | Cl_CONCTTE_KR3b | 10.00 | 9322.00 | 143.00 | 8575.00 | 7722.35 |
| Meuse | Cl_CONCTTE_KR3m | 11 | 10557.00 | 8965.00 | 9647.00 | 9688.72 |
| Meuse | Cl_CONCTTE_KR3o | 12 | 10901.00 | 10134.00 | 10846.00 | 10826.61 |
| Meuse | Cl_CONCTTE_KR4b | 2 | 150.00 | 118.00 | 134.00 | 132.87 |
| Meuse | Cl_CONCTTE_KR4m | 7 | 152.00 | 119.00 | 135.00 | 134.20 |
| Meuse | Cl_CONCTTE_KR4o | 23 | 9630.00 | 9580.00 | 9615.00 | 9613.09 |
| Meuse | Cl_CONCTTE_MH020 | 2 | 147.00 | 92.00 | 100.00 | 101.64 |
| Meuse | Cl_CONCTTE_MH080 | 8 | 150.00 | 94.00 | 102.00 | 103.24 |
| Meuse | Cl_CONCTTE_MH150 | 15 | 157.00 | 92.00 | 103.00 | 105.89 |
| Meuse | Cl_CONCTTE_SPU10 | 1 | 88.00 | 73.00 | 77.00 | 77.68 |
| Meuse | Cl_CONCTTE_SPU50 | 5 | 93.00 | 78.00 | 81.00 | 82.02 |
| Meuse | Cl_CONCTTE_STB02 | 2 | 149.00 | 112.00 | 127.00 | 128.22 |
| Meuse | Cl_CONCTTE_STB06 | 6 | 164.00 | 115.00 | 130.00 | 133.07 |
| Meuse | Cl_CONCTTE_STB11 | 11 | 295.00 | 107.00 | 168.00 | 177.78 |
| Meuse | Cl_CONCTTE_STBUb | b | 16882.00 | 13886.00 | 15591.00 | 15517.84 |
| Meuse | Cl_CONCTTE_STBUo | o | 17695.00 | 15265.00 | 16650.00 | 16593.88 |
| Meuse | Cl_CONCTTE_VOLKb | b | 104.00 | 62.00 | 65.00 | 69.58 |
| Meuse | Cl_CONCTTE_VOLKo | o | 59.00 | 54.00 | 57.00 | 56.93 |
| Meuse | Cl_CONCTTE_HVH25 | 2.5 | 13981.00 | 1881.00 | 4378.00 | 5320.73 |
| Meuse | Cl_CONCTTE_BRB25 | 2.5 | 147.00 | 85.00 | 91.00 | 91.98 |
| Meuse | Cl_CONCTTE_BRB65 | 6.5 | 308.00 | 82.00 | 88.00 | 90.58 |
| Meuse | Cl_CONCTTE_KDD50 | 5 | 97.00 | 76.00 | 84.00 | 84.60 |
| Meuse | Cl_CONCTTE_KRY40 | 4 | 175.00 | 79.00 | 106.00 | 109.97 |
| Meuse | Cl_CONCTTE_KRY55 | 5.5 | 179.00 | 83.00 | 110.00 | 114.36 |
| Meuse | Cl_CONCTTE_LEK25 | 2.5 | 1739.00 | 97.00 | 397.00 | 467.29 |
| Meuse | Cl_CONCTTE_LEK50 | 5 | 1761.00 | 97.00 | 448.00 | 530.15 |
| Meuse | Cl_CONCTTE_LEK70 | 7 | 2353.00 | 88.00 | 466.00 | 582.54 |
| Meuse | Cl_CONCTTE_BOM20 | 2 | 146.00 | 80.00 | 83.00 | 83.87 |
| Meuse | Cl_CONCTTE_SPI25 | 2.5 | 2594.00 | 72.00 | 80.00 | 324.04 |
| Meuse | Cl_CONCTTE_SPI45 | 4.5 | 2928.00 | 71.00 | 81.00 | 366.65 |
| Meuse | Cl_CONCTTE_SPI90 | 9 | 4312.00 | 69.00 | 81.00 | 505.96 |
| Schelde | Cl_CONCTTE_MRGb | b | 18045.00 | 17746.00 | 17978.00 | 17970.55 |
| Schelde | Cl_CONCTTE_OS4b | b | 19127.00 | 15730.00 | 16311.50 | 16505.71 |
| Schelde | Cl_CONCTTE_OS4o | o | 19239.00 | 14593.00 | 16257.00 | 16553.48 |
| Schelde | Cl_CONCTTE_SPUIb | b | 466.00 | 450.00 | 455.00 | 455.81 |
| Schelde | Cl_CONCTTE_SPUIo | o | 471.00 | 448.00 | 455.00 | 456.46 |
| Schelde | Cl_CONCTTE_BAALb | b | 13370.00 | 9539.00 | 11551.50 | 11645.34 |
| Schelde | Cl_CONCTTE_BAALo | o | 13553.00 | 10266.00 | 11946.50 | 11901.72 |
| Schelde | Cl_CONCTTE_OVHAb | b | 15316.00 | 13033.00 | 14175.00 | 14170.08 |
| Schelde | Cl_CONCTTE_OVHAo | o | 15229.00 | 13004.00 | 13999.00 | 14039.49 |
| Schelde | Cl_CONCTTE_TWZZb | b | 15482.00 | 10967.00 | 14600.00 | 14407.81 |
| Schelde | Cl_CONCTTE_TWZZo | o | 16293.00 | 14461.00 | 15776.00 | 15697.05 |

Source: Rijkswaterstaat,2019

*Salinity in different depth in Meuse and Schelde*

| Tide | | | | |
|---|---|---|---|---|
| Delta | Location | Max(cm) | Min(cm) | Difference(cm) |
| Meuse | Europahaven | 138.57 | -56.71 | 195.29 |
| Meuse | Hoek van Holland | 128.29 | -51.86 | 180.14 |
| Meuse | Tennesseehaven | 136.86 | -54.29 | 191.14 |
| Meuse | Maassluis | 120.86 | -45.86 | 166.71 |
| Meuse | Hellevoetsluis | 76.43 | 43.43 | 33.00 |
| Meuse | Stellendam outside | 153.71 | -76.14 | 229.86 |
| Meuse | Hit north | 73.86 | 41.43 | 32.43 |
| Meuse | Vlaardingen | 133.29 | -39.29 | 172.57 |
| Meuse | Geulhaven | 129.86 | -40.00 | 169.86 |
| Meuse | Maeslantkering sea side | 115.57 | -68.43 | 184.00 |
| Schelde | Oosterschelde 04 | 169.86 | -127.57 | 297.43 |
| Schelde | Cats outside | 175.00 | -143.57 | 318.57 |
| Schelde | Stavenisse | 167.71 | -136.29 | 304.00 |
| Schelde | Bergse Diepsluis west | 194.00 | -157.57 | 351.57 |
| Schelde | Marollegat | 200.43 | -162.29 | 362.71 |
| Schelde | Roompot inside | 140.00 | -119.00 | 259.00 |
| Schelde | Breskens | 222.43 | -179.86 | 402.29 |
| Schelde | Borssele | 238.57 | -187.86 | 426.43 |
| Schelde | Overflow from Hansweert | 200.43 | -162.29 | 362.71 |
| Schelde | Scissors of the North | 286.86 | -216.57 | 503.43 |
| Schelde | Bath | 284.57 | -219.43 | 504.00 |
| Schelde | Bale corner | 283.86 | -211.29 | 495.14 |
| Schelde | Terneuzen | 244.57 | -190.57 | 435.14 |

Source: Rijkswaterstaat,2019

*Flow velocity of old and new Meuse*

Source: Rijkswaterstaat,2019


Source: Rijkswaterstaat,2019

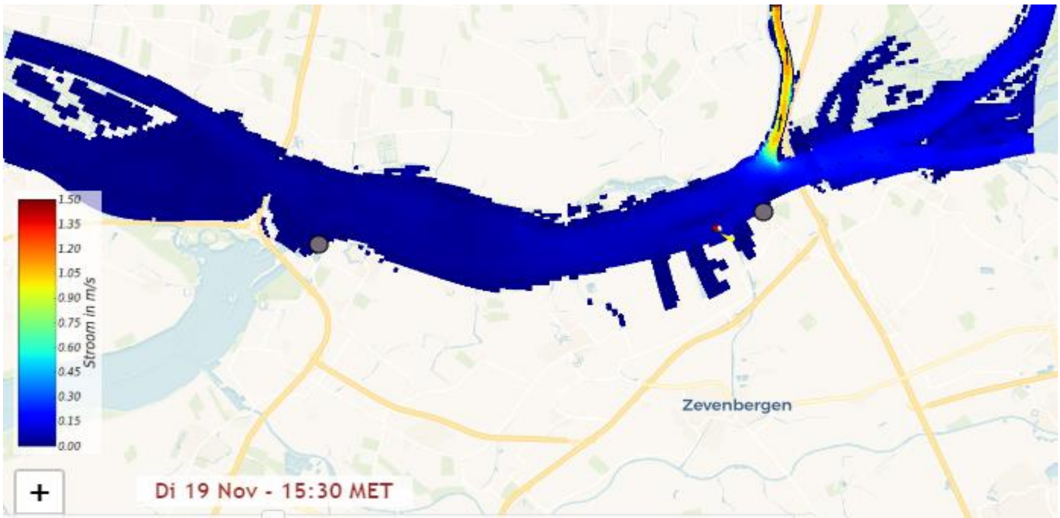

Source: Rijkswaterstaat,2019


Source: Rijkswaterstaat,2019


Source: Rijkswaterstaat,2019

*Flow velocity of old and new Meuse*


Source: Rijkswaterstaat,2019




Source: Rijkswaterstaat,2019

Ibm. (n.d.). Rijkswaterstaat Waterinfo. Retrieved from https://waterinfo.rws.nl/#!/nav/publiek/.

## B. Locations

In this appendix, locations 2, 3, 4, 5 and 8 will be discussed.

### B.1. Location 2: Rozenburg

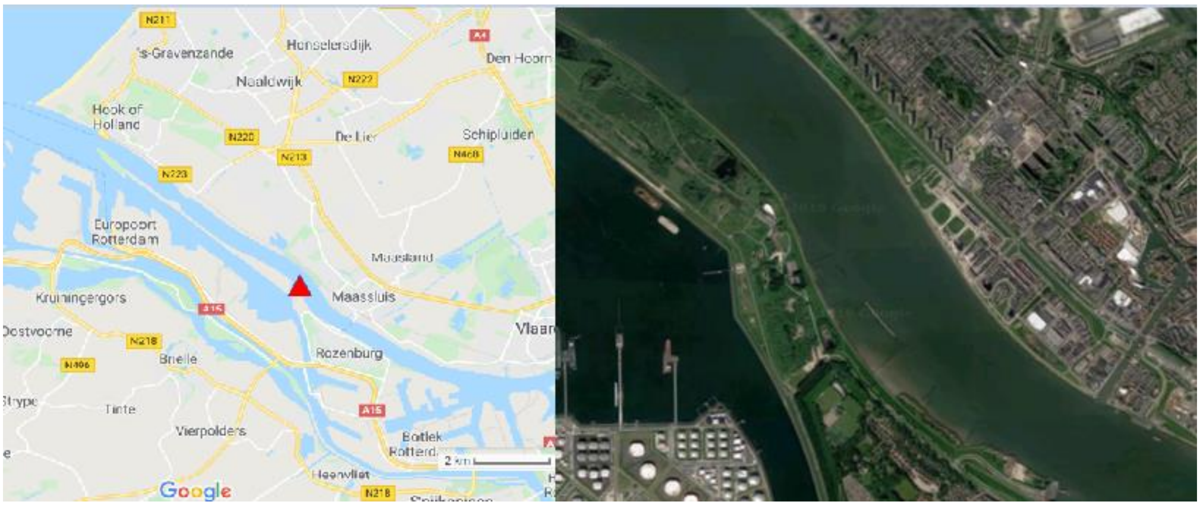


*Figure 17 Area of interest for location 2*

**Location description**

This location is chosen due to its favourable positioning for citizen science. It is located next to Maassluis and Rozenburg, making it accessible for civilians to conduct frequent measurement here. There are two channels at which measurements can be taken; Nieuwe Waterweg and Caland channel.

**Parameters of influence**

*Water velocity and discharge:* With an average maximum discharge for the Nieuwe Waterweg of 6300 $m^3/s$, a lot of plastics could pass through this area. The average maximum velocity of 1,2 m/s is one of the highest of all the locations, but it is still significantly lower than average for a river of this size. *Anthropogenic activity:* The upper channel is connected to the Meuse and has Maassluis and Rozenburg close to it, with a total of 45,000 inhabitants. The lower channel is connected to the Port of Rotterdam and will be heavily influenced by the shipping industry. The channel is excavated deeper so that ships can navigate safely through the channel.

**Hypothesis Assessment**

Due to the low velocity in these channels hypothesis 1 can be tested in this area. Flow velocities will be extra low on the outside of the curveature of the river. Hypothesis 2 can be tested on the sand depostition at the outer part of the curve, visible in Figure 17. Due to a lot of anthropogenic activity in both of the channels, hypothesis 5 can also be tested in this area.

**Plastic distrubution and measurements**

Due to low velocity and high discharge in this channel, it is likely that a lot of higher density macro plastics will precipitate at the bottom of the riverbed. Also, lower density floating macro plastics can get trapped in the outer curve of the Nieuwe Waterweg and form sediments at the sandy sediments. Land measurements at the sandy deposition and measurements of water column are recommended at this area.

## B.2. Location 3: Vlaardingen

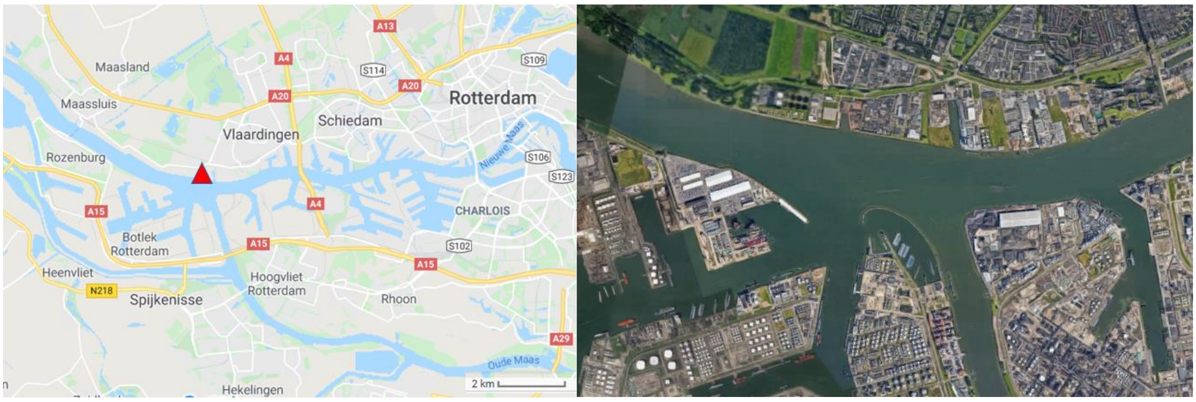



*Figure 18 Area of interest for location 3*

**Location description**

This location was selected as it is in the middle of an industrial area. A lot of chemical plants, a reclamation depot and a water treatment plant are located here, which makes this area a more possibly concentrated place for plastics. The presence of a curve and many branches here are also a reason this location was chosen.

**Parameters of influence**

*<u>Wind Influence</u>:* The wind direction was 192 degree direction relative to true North at the Verkeerscentrale Rotterdam with a speed of 5.26 m/s in average. However, in front of the location at Geulhaven Radarpost (the barrier), the wind speed was low (0.05 m/s) and in a 19 degree direction relative to the true North.

*<u>Flow and discharge</u>:* The discharge of the Nieuwe Maas has a high level of 6300 $m^3/s$ but with a low level of velocity (1 m/s). There is a great possibility that plastics would go through this area. As the existence of a curve, the river flows faster on the convex bank and slower on the concave bank.

*<u>Anthropogenic</u>:* Chemistry industry (such as: Odfjell Netherlands, LBC Rotterdam B.V) and waste recycling industry (such as Recycling Combination REKO BV) are located in this area.

**Hypotheses Assessment**

First, due to the high discharge and low velocity of the Nieuwe Maas, high dense macro plastics will accumulate on riverbed. Besides, plastic is more likely to deposit on convex banks. From these findings, hypothesis 1 can be assessed. Secondly, hypothesis 3 can be assessed by measuring the quantity of plastic at Geulhaven. Lastly, near to lots of industries, there could be higher plastic existence, which could be a verification of hypothesis 4.

**Plastic distribution and measurements**

Due to the low salinity gradient, it is plausible to measure at each layer of water column. For relatively low tidal influence, there could be few plastics accumulated on the riverbank. Therefore it is recommended to focus more on water column using sampling methods of diving and netting monthly. Also, the wind coming from south to north makes it possible that plastic debris accumulate on the surface water especially near convex bank which can be measured in citizen science.

**Field trip to location 3**

There was a field trip organized to this location. From this field trip, hypothesis 3 can be verified. Due to the low tide influence here, not many plastics were visible on the river bank. It was clear that many industries had an influence on this area, and it could be possible that these industries have a big influence on the plastic accumulation in the water column at this location. It was also noticed that more measurements should be done in the vertical water column instead of only on the river bank.

## B.3. Location 4: Haringvlietweg, near Hellevoetsluis

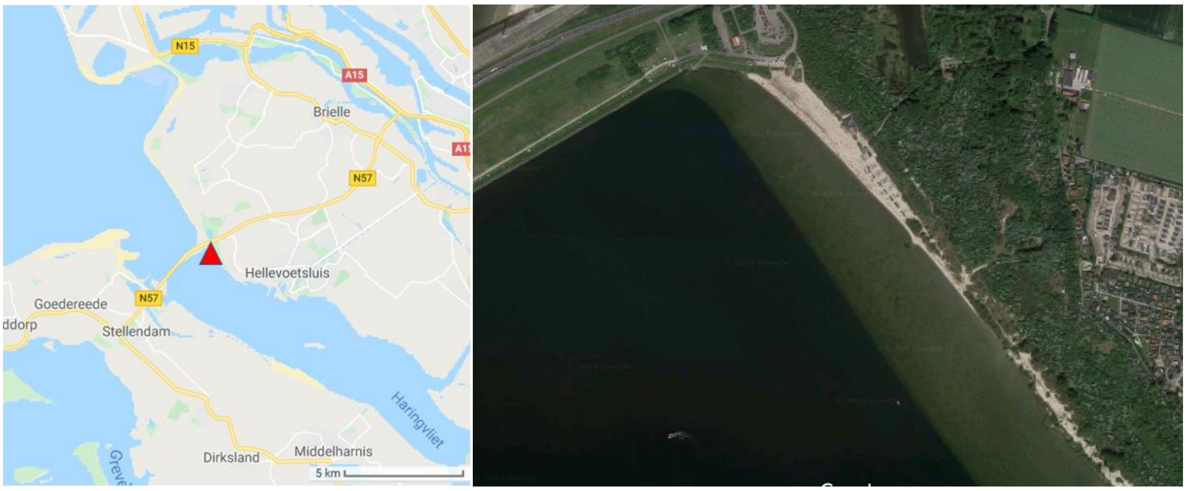



*Figure 19 Area of interest for location 4*

**Location description**

The reason for selecting this location is the presence of the sluices. The sluices are most commonly only open for 3 quarters. When the sluice is closed, the water is almost stagnant while the water is running with a low velocity in opening hours.

**Parameters of influence**

*Wind Influence:* The wind direction was 197 degree direction relative to true North with a speed of 6.33 m/s in average. The Haringvlietweg can be determined to be the downwind site of the estuary.
*Velocity:* The velocity of this location depends on the opening and closing of the sluices. When the sluice is open, a higher speed (0.5 m/s) will be measured. On the contrary, when the sluice is closed, the water could be rather more stagnant. Generally speaking, the velocity here is relatively low.
*Anthropogenic:* This location is hugely influenced by the sluices. It could influence both water flow and discharge.

**Hypothesis Assessment**

Firstly, hypotheses 1 is relevant. For the low velocity here, higher density plastics could settle at the bottom of the river bed. But, the presence of the sluices makes it more complicated as the opening sluices in the lower part could affect the accumulation of plastics. Secondly, as the estuary in the downwind side, hypotheses 3 could be assessed. Thirdly, the influence of sluices verifies the hypotheses 4. When the sluices are closed, plastics are more likely being collected on riverbed.

**Plastic distrubution and measurements**

Salinity here is relatively low, so it is recommended to measure all layers in water column when the sluices are closed. It is recommended to measure only the surface layer and the middle of the water column during the opening time of sluices because the river will pass through the lower part of the sluices. Due to the closing and opening time of sluices, the measurements can be done weekly. For the wind coming from the south, the accumulation place should be in the upper part of the map, where measurements can be done monthly.

## B.4. Location 5: Willemstad

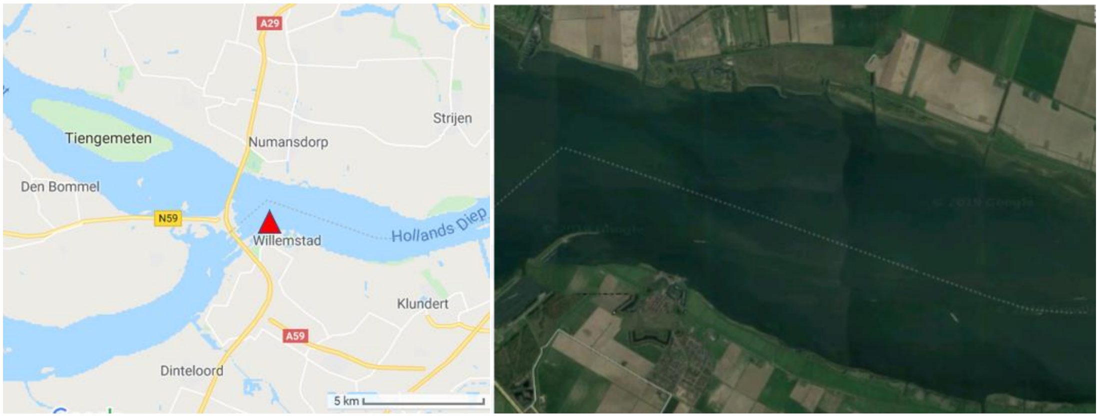



*Figure 20 Three possible locations for citizen science near Willemstad*

**Location description**
Willemstad, a historical town and popular tourist attraction, is chosen because it is at a river junction with high discharge and it is located at a downwind area.

**Parameters of influence:**
*Flow velocity and discharge*: First of all, the river Hollands Diep splits into the Haringvliet and a second branch that connects to the Oosterschelde. Figure 20 shows that the discharge into the Oosterschelde branch is much smaller than the Haringvliet. This suggests that there is a high discharge at the Willemstad location because at this point, the river has not yet split into two. When considering the flow velocity across the width of the river, the highest flow velocity is expected in the middle of the river and lower velocity at the riverbanks. In combination with the geographical shape of the shoreline, the upper banks of the Hollands Diep river can form a trap for plastic debris and result in an area of plastic accumulation.
*Salinity and wind*: The salinity ranges from 57 mg/L at the surface to 70 mg/L at the river bed. Thus, the salinity gradient is nearly constant across the vertical water column. The tidal difference at this location is 32 cm. This is the lowest difference between low and high tide out of all locations. Therefore both salinity and tidal difference are of minimal influence on the plastic accumulation. At this location, there is no data available on the wind direction and wind speed. By interpolating the data on wind direction from the other locations, it can be assumed that the wind direction is North-North East.
*Anthropogenic influences*: Willemstad is an urban area which can be a source of plastic litter by humans into the water. The approximate urbanised area also comes in useful when taking citizen science measurements.

**Hypothesis Assessment**
Due to the geographical irregularities at the upper banks, it would be interesting to test for hypothesis 2. However, information of the wind speed should be known before deciding whether hypothesis 3 should be investigated here.

**Plastic distribution and measurements**
Possible measurements for citizen science could be taken by boat to the upper part of the river to collect manual samples of plastics, as shown in yellow on Figure 20. The sampling should be done at the surface of the water to test for macro plastics being transported by wind. Measurements in the water column should also be conducted to get an indication of how much plastic debris is transported by the water flow.

## B.5. Location 8: Terneuzen

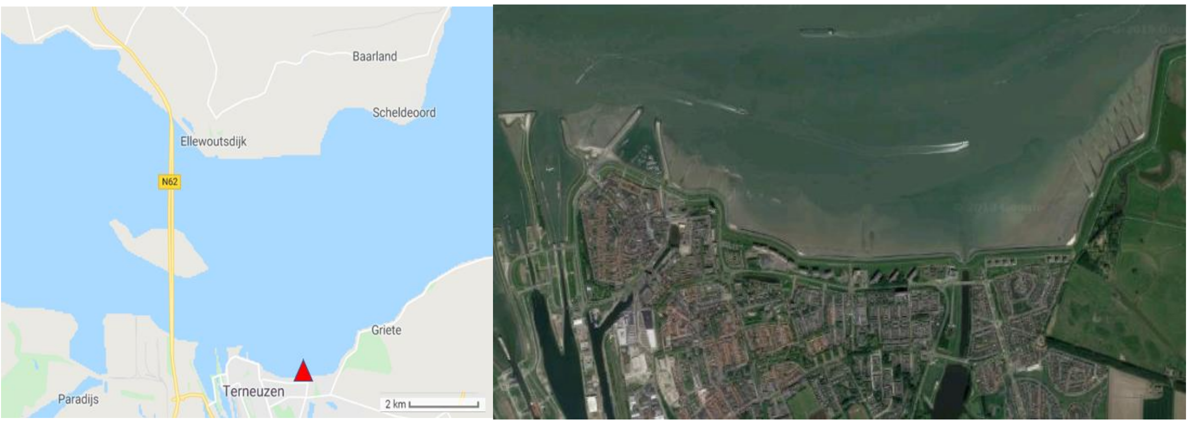



*Figure 21 Area of interest for location 8*

**Location description:**
This location was chosen as it is right in the middle of the salt-water interface and it is in the middle of a recreational area.

**Parameters of influence:**
*Wind:* Terneuzen is considered as an upwind site since the wind is from south direction. Therefore, it is predicted that the wind parameter will not influence much in this location.
*Salinity:* There is an interface of salt water and freshwater. Due to the density difference, the bottom water is extremely salty and the surface water is of low salinity.
*Anthropogenic:* Terneuzen is a recreational area and can be a source of plastic pollution.
*Flow velocity and discharge:* There is no data of flow velocity and discharge in this area. It can be assumed there is little fluctuation in flow velocity and discharge is small during the year since there is no inflow of fresh water.

**Hypothesis Assessment**
Hypothesis 3 can be assessed in this location since it is a upwind place. It can be stated that, less proportion of low-density macro plastics accumulate at upwind sites compared to downwind areas. The observation can be made on the riverside. Hypothesis 4 can be tested here since there is a recreational area. It is assumed that there is more plastics in the water than areas with less human activities. The measurements can be taken in the water near the shore using net and diving methods. Hypothesis 5 can be assessed here. The density of plastics is different in the water column due to the interface of salt water and fresh water. The measurement should be taken in different depths.

**Plastic distribution and measurements**
Due to the upwind influence, the plastic debris which are thrown away by humans can be transported across the river and reach another riverside.

In this area, the interference of salt water prevents freshwater from transporting plastics as bedload. High dense plastics could settle down at the bottom salinity front and form a salt wedge. It' is assumed that low dense plastic accumulation occurs in the surface water while high dense plastics accumulate in the riverbed. Measurements should be taken at three levels of depths. Sampling should be done in the middle of the water and in the water near the recreational area. The flow velocity and discharge are relatively stable since there is no inflow. Hence, it is advised to take monthly measurements in this location using the diver and net methods.

# C. Team work

## C.1 Field trip pictures

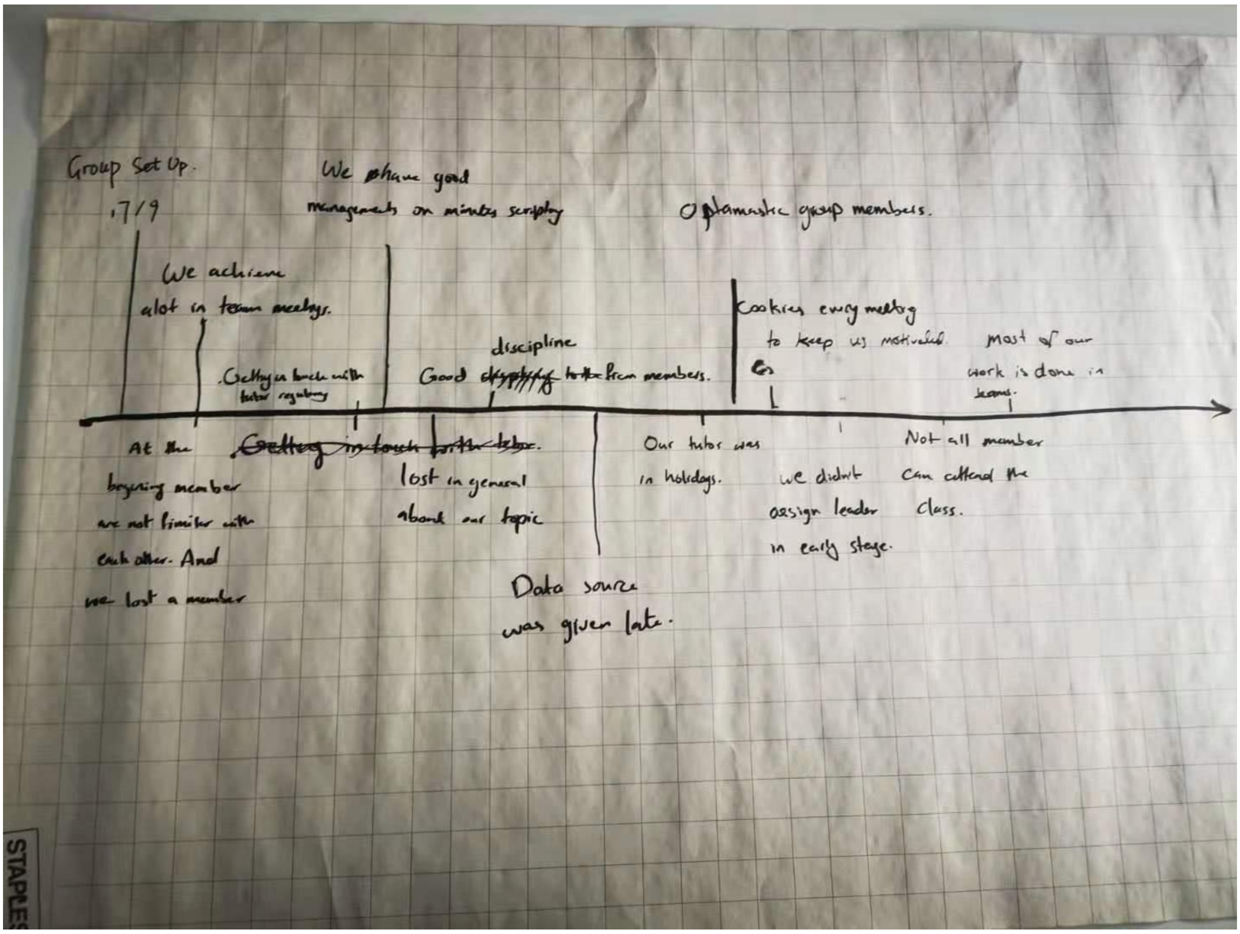
*Industries in vlaardingen*

*Plastic accumulated on riverbank*

*High tide line on riverbank*

## C.2 Story wall

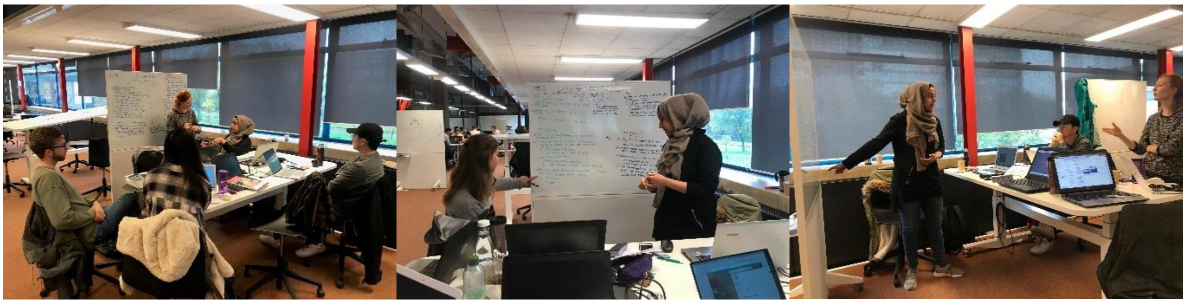
*Story wall of Plastic Fantastic team*



## C.3 Team Reflection

Evaluation and reflection on team work (team dynamics and development, adherence or changes to team policy and work plan)

Over the course of the past 3 months, the Fantastic Plastic team worked hard together on the system analysis of the Meuse and Schelde deltas. The journey has been a long rollercoaster during which we learnt a lot about our research area, but also about ourselves and working together as a team. The first obstacle we faced was when we received critical feedback on our Statement of Work (SoW). For us this was a wakeup call. The first thing we changed was to schedule weekly meetings on Wednesday morning with every time a different person bringing a snack. As a result we enjoyed new Chinese delicacies as well as Dutch speculaas, pepernoten or homemade banana bread. This new agreement worked well. In order to improve our SoW, we came together as a group to share all our knowledge and brainstorm on the scope of our research (see pictures below for an impression). This was a very good meeting in which we made good progress and also for the first time realised the division of roles within our team. We learnt how to cope with the cultural and language differences within our team. Overall, everyone enjoyed working together and we learnt from one another. The dynamics was good and after an intense group meeting a well-deserved lunch together kept the group spirit high!



After the refurbished SoW, the meetings were kept in place (except for exam weeks). This resulted in a good and friendly collaboration and improved communication. Until now, the roles were kept quite similar and this division worked well. The roles are stated below.

**Team Roles**
Renske – leader, completer
Feiyang – implementer (Ivar do Sul, 2013)
Shan – implementer
Lucas – completer, implementer
Eman – expert, motivator
Liselotte – leader, motivator

Before finishing the final report, we had a field trip to one of the locations to test whether we were on the right track for the results chapter and for determining the hypotheses. This was really fun to meet each other outside of the university. In Appendix B1, we have included some pictures which were taken during that fieldtrip.

We worked closely together with Sandra and she helped us a lot to improve our understanding of the aims and goals of this research and she helped us when we could not find any data. This helped a lot as we had to present our findings for Rijkswaterstaat. In the end, we managed to finalize a presentation before this deadline and we are very thankful that Sandra could present our findings to Rijkswaterstaat. We would also like to thank Sandra for her guidance throughout this project!