2020

# Plastic stream monitoring in river-based areas

BACHELOR THESIS

MARTIJN GENET

# Colophon

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| **Date:** | January 6, 2020 |
| **Status:** | Final version |

# Preface

I am proud to present my bachelor thesis ‘Plastic stream monitoring in river basin areas’. This thesis research has been conducted in Cần Thơ, Vietnam and consisted of two approaches to track plastic convergence areas in a river adjacent to the city of Cần Thơ. This research is written as the final assignment for concluding my study Land and Water management at Hogeschool Van Hall Larenstein located in Velp, the Netherlands. This Bachelor Thesis is written in a time span from August till the end of December and during this time I had the pleasure to work with a lot of mentionable and memorable people. The bachelor thesis is about plastic in a river located in Vietnam and during the research I have been staying in the city of Cần Thơ. During my stay I was welcomed by Steven Starmans, ex-employee at Hogeschool Van Hall Larenstein who is now working in Cần Thơ on developing a circular park which promotes a circular economy and usage of waste products. I would like to thank Steven and his partner Thanh for all the help they provided with working with the local government and making me feel at home in Cần Thơ.

I also would like to thank Jeroen Rijke from the professorship of Sustainable River Management at the Hogeschool Van Hall Larenstein who made it possible to do my bachelor thesis abroad and provided me with a subject that I really enjoyed researching.

Hereby I would like to thank my internal supervisor Peter Groenhuijzen for the great guidance and support during this bachelor thesis. I could not have completed this research without his cooperation. I have also received wise advice from my friends and family. Moreover, they supported me morally during the writing process. Finally, I want to thank my parents in particular. Their wisdom and motivational words helped me to bring this thesis to a successful conclusion.

I wish you much reading pleasure.

Martijn Genet

Amsterdam, 6 January 2020

# Summary

Plastic pollution is a worldwide problem and affects the environment in harmful ways. This research focusses on reducing plastic pollution in rivers and preventing plastic pollution to reach oceans by determining an efficient approach to find convergence areas where plastic catching is the most optimal. For this research a case area is chosen for conducting research on plastic streams in a river that was representative for one of the eight large rivers in Asia that together are responsible for 80% percent of all the plastic entering the oceans every year. The case area that has been chosen is a side branch of the Mekong river delta and is named the Sông Cần Thơ. The aim of this research is to find an approach for finding convergence areas in rivers where plastic catching is the most efficient and the local activities that are part of a river are not affected. Two approaches have been used to determine plastic convergence areas in the Sông Cần Thơ.

The first approach consists of forming a theoretical prediction on plastic flow in the Sông Cần Thơ. The theoretical prediction is based on information found from the desktop research and a modelling phase to get an indication on the water flow in the Sông Cần Thơ. The theoretical prediction resulted in a line that represents the prediction of the course of the plastic, and is based on the meandering flow of the river.

The second approach for finding plastic convergence areas in the Sông Cần Thơ consisted of the development of three tracking devices. The tracking devices use GPS to track the location of plastic and these have been tested in the Sông Cần Thơ area on reliability and precision. To find the Convergence areas a field research is conducted in which two of the three tracking devices where used to track plastic in the Sông Cần Thơ. The two tracking devices that have been chosen for the field research give information on the location of plastic but also on what happens to the plastic at a certain moment and location. The results of the field research showed that there are four aspects that alter the course of plastic flow in a river and these are the flow of the river (in the case of the Sông Cần Thơ this is a strongly meandering flow), the tidal affects, the wind that is present and the density of boat traffic that is present on the river.

The plastic was predicted in the theoretical prediction to follow the meandering flow of the river but through the results of the field research it could be seen that the plastic was greatly affected by the ship traffic and the tidal affects that where present on the Sông Cần Thơ.

The research concludes that there are aspects that are difficult to predict and therefore using tracking devices to find convergence areas is more efficient and gives more insight in the different factors affecting plastic flow. The usage of the two used tracking devices shows the best results and is favourable for finding plastic convergence areas in other rivers.

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# 1 Introduction

## 1.1 Context

Plastic is a highly versatile product and is broadly used throughout the packaging industry. The plastics that are used and produced by the packaging industry are mainly bottles, trays, boxes, cups and vending packaging. The prices of plastics are low and can be produced in big quantities.

The economic growth in the world has led to the usage of alarming amounts of plastics. These amounts of plastics result in a growing amount of plastic waste. The quantities of plastic waste cause new problems in terms of waste management. Although most western countries have set up systems to separate waste, including plastics, the cost of recycling plastics is more expensive than making new plastics (Buisinessinsider, 2016). Because recycling is more expensive than producing new plastics, plastics get stored on big heaps and are disposed of by burning throughout the world. In non-western countries there are less facilities in terms of waste management and therefore plastics end up in waterbodies or on the sides of roads. The plastics that end up in waterbodies and on the sides of the road will be in the streets, lakes, rivers or oceans for centuries because degradation of plastic takes a long time.

Over the past decades of plastic usage, the debris in the oceans reaches alarming amounts. The big heaps of plastics that are floating through the oceans will be there for centuries because plastic doesn’t degrade quickly. Plastics that are undergoing degradation become very small particles and eventually become the size of small sand grains, which are called microplastics. The microplastics pose a threat to marine life and could enter the (marine) food chain.

## 1.2 Background information

In 1982, scientists started tracking drifting buoys that float with the currents just like plastics. The buoys where outfitted with GPS (Global Positioning Service) and GPRS (General Packet Radio Services) that broadcasted a short message every six hours about where they are and conditions of the water in that location. With this information scientists have been able to create a statistical model of the surface pathways of our oceans (Sebille, 2012).

The drifter buoy program resulted in predictions on how plastic streams will flow for the next 1000 years. The predictions for 50 years are shown in Figure 1. The 4 pictures shown in Figure 1, show the start of the drifter buoy program (a) and the prediction for plastic convergences areas in 1(b), 10 (c) and 50 (d) years.

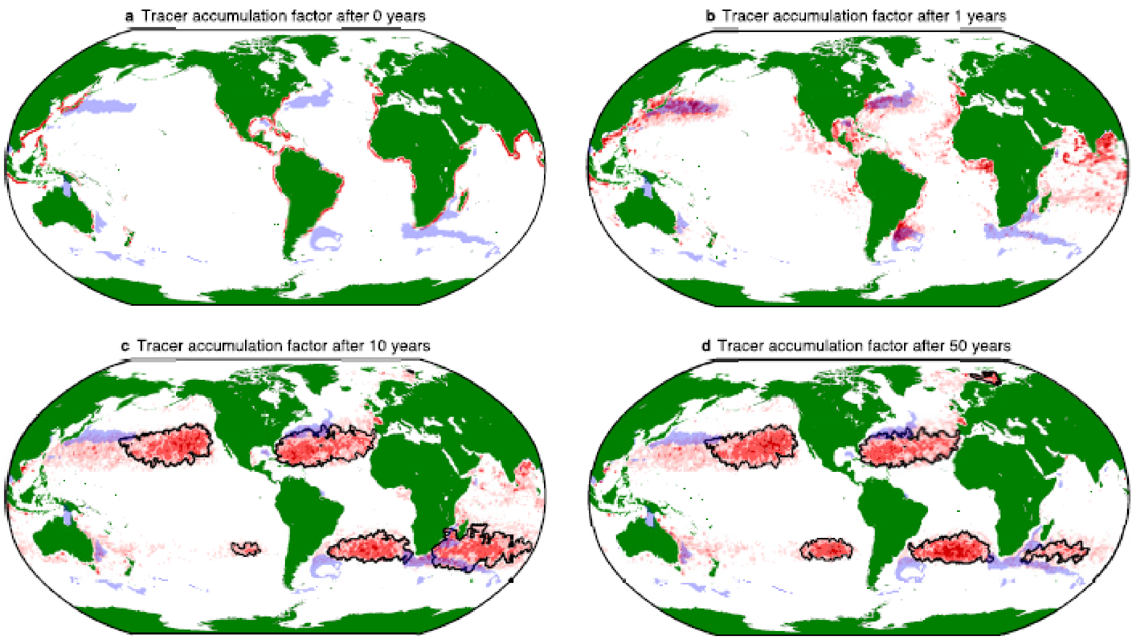



*Figure 1 The locations and sources of the six garbage patches. (Sebille, 2012)*

The data found by the drifter buoy program has given vital information on the way that plastics flow through the oceans, which can be used to reduce the plastic pollution in the oceans. The data and statistical analysis that could predict the future of plastic stream flows has shown that there are currently five garbage patches in the oceans around the world and a new one will be formed in the nearby future (as shown in Figure 1). The data gathered by the drifter buoy program are vital for the clean-up of plastic pollution on the oceans because convergence areas can be located where plastic catching is the easiest and most efficient. To clean up these plastic convergence areas Boyan Slat, a former student of the Technical University of Delft (TU Delft) in the Netherlands, started designing a method to clean up the oceans from plastic waste in 2012. The plastic catcher he came up with is a floating device with long arms on either sides that is shaped in a 'V' form, which can catch and store plastic on the oceans.

## 1.3 Problem definition

Most of the plastics that are now in the oceans are coming from the ten biggest rivers in the world. Eight of these rivers are located in Asia and therefore Asia is a good place to start reducing plastic waste entering the ocean. The Mekong river (as shown in Figure 2) is one of the eight Asian rivers that are big contributors to plastic pollution in the oceans. Every year more than eight million tons of plastic ends up in the ocean. About 90 percent of this plastic waste is carried into the oceans by ten large rivers of which one is the Mekong (Schmidt, 2017). The plastics in the rivers are not only harming marine life but are negatively influencing local life near the rivers as well. The plastics in the rivers have a negative impact on fishery and overall water quality.

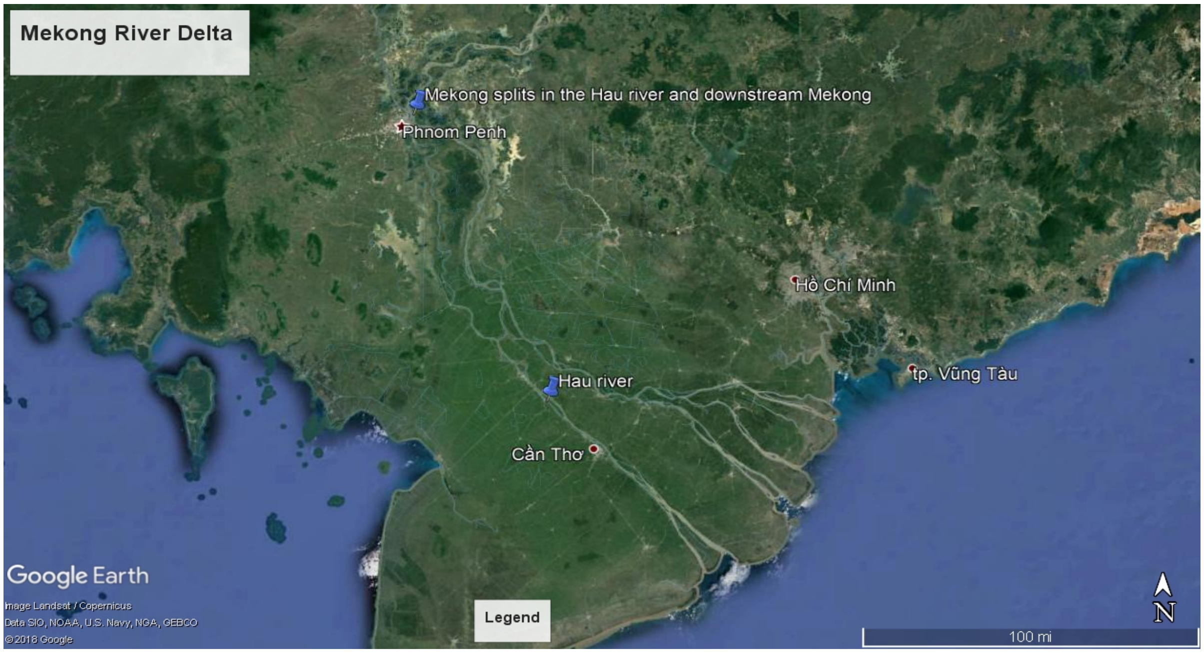



*Figure 2 Overview of the Mekong delta*

Because plastic pollution forms a threat to the environment, plastic needs to be removed to reduce its negative effects in a river. Data on how plastic behaves in river basin areas are scarce and this makes catching plastic in rivers ineffective. Research on plastic in rivers is one-sided and only focuses on measuring how much plastic is deposited by rivers. The data collected from the measurements of plastic output by a river can be used to calculate the effectiveness of a plastic catcher but cannot show how the plastic catcher can be more effective. To determine what the optimal location is for a plastic catcher, data has to be collected about how plastic behaves in rivers and where plastic streams converge. These convergence areas are not currently mapped but would form vital input on deciding the efficient location for plastic catching.

The drifter buoy program shows that mapping the full scale of the plastic streams in the oceans is very difficult to achieve. Rivers have the same problem in terms of predicting plastic streams. The uncertainty in data on plastic predictions in oceans or rivers such as the Mekong is high. Less than 1% of the plastics float on the surface of the Mekong river, the other 99 percent of the plastic floats underneath the water surface (Hackney, 2019).

Although the share of plastic pollution that floats on the surface is small, the data that can be gathered from the surface or close to the surface can give more insight on how plastic behaves in a river. The insights that can be gained from enhancing predictions on plastic streams in a river can help finding an optimal location for a plastic catcher which can reduce plastic pollution in rivers and reduces the amount of plastic that enters the ocean. Because plastic degrades over a timespan and eventually becomes microplastics, which harms the environment even more, it is desirable to catch plastics in an earlier stage, in which plastic is not yet degraded. Although it is more desirable to catch plastic in an earlier stage such as in a river basin area, different complexities will occur because of the more confined areas of river basin areas which results in a higher density of traffic on a river that can influence plastic streams. For example, the shipping routes that are part of large river systems such as the Mekong are used for the transportation of goods, which is important for the local but also the national economy. To find locations where plastic catching is optimal but does not affect shipping routes is an obstacle that will occur more often in a river basin than in oceans. Although plastic catching in a river basin is desirable, more research needs to be conducted to find locations for plastic catchers to catch as much plastic as possible without harming transport, tourism, fisheries and other local activities.

## 1.4 Research goal

The aim of this research is to develop an effective approach for tracking plastic in the Mekong river that can contribute to the transcending goal of reducing plastic pollution in the Mekong river. To find effective methods for plastic tracking a side branch of the Mekong river is chosen as the research area, as shown in Figure 3. The side branch that is chosen as the research area is the Sông Cần Thơ and is an important contributor to the plastic waste output of the Mekong river delta.

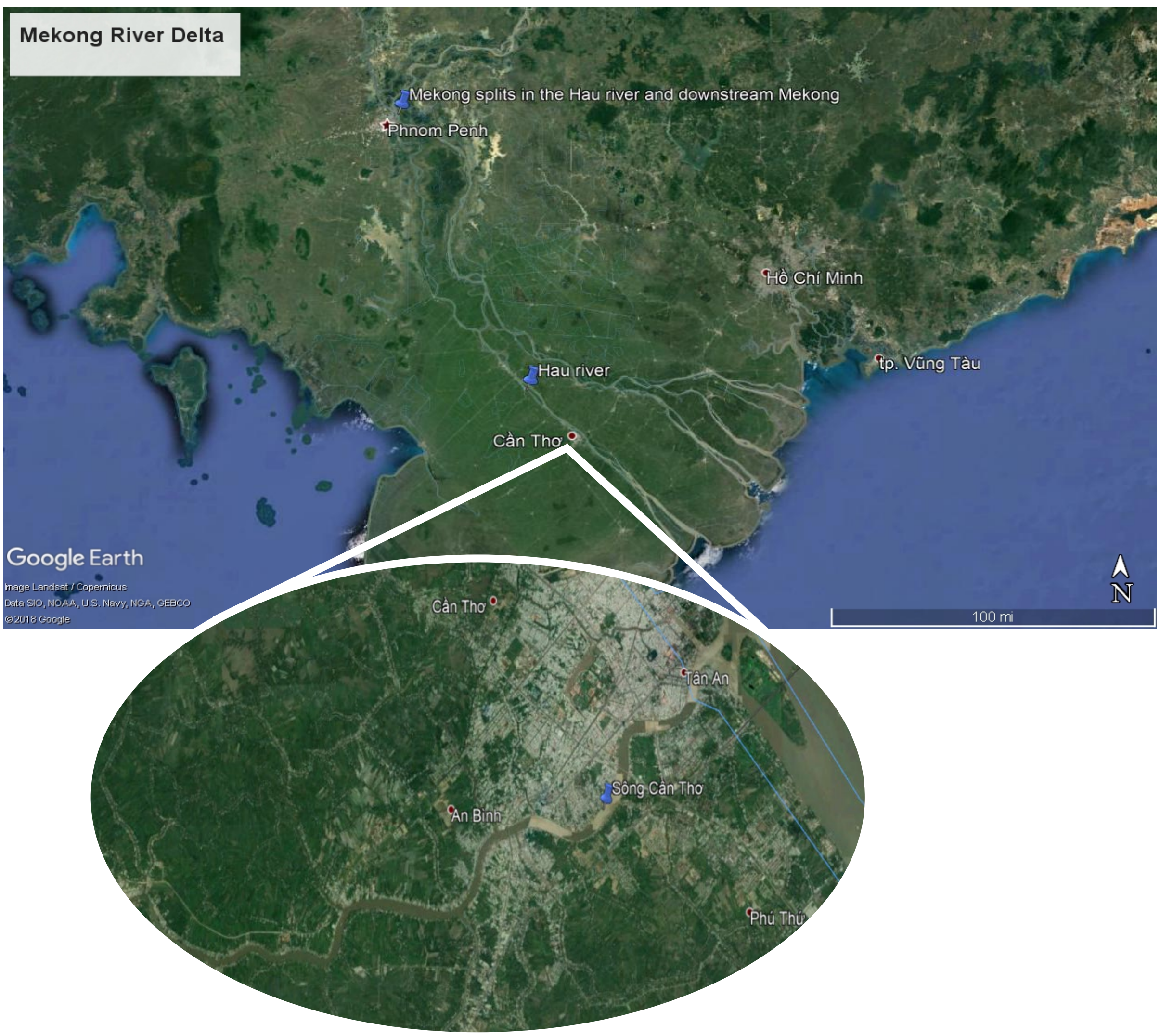



*Figure 3 Overview of the Mekong delta region and the Song Can Tho*

The relatively small size of the Sông Cần Thơ makes this side branch a good choice for developing an approach for plastic tracking. The size of the Sông Cần Thơ makes it possible to test the approaches on plastic tracking in the Mekong delta, within a smaller and confined area.

This research aims to find an approach that can predict or measure plastic convergence areas in a river, where plastic can be caught efficiently. Although the aim of this research is to find an approach for plastic tracking in rivers, this research will focus on the case of the Sông Cần Thơ. The convergence areas in rivers are the most optimal locations for a plastic catcher in a river and by doing this research, knowledge can be gained that can be applicable to other (bigger) rivers, such as the Mekong.

The Hogeschool Van Hall Larenstein is a University of applied sciences with the ambition to gather knowledge on sustainability subjects such as plastic waste reduction. Because the Sông Cần Thơ is a big contributor to the plastic waste output of the Mekong river delta region, the Hogeschool Van Hall Larenstein is interested to conduct research on sustainability subjects such as plastic waste streams to catch plastic. The goal of the professorship of sustainable river management on the Hogeschool Arnhem Nijmegen (HAN) and the Hogeschool Van Hall Larenstein (HVHL), is to raise awareness on plastic waste and pollution to create a more sustainable future. This research is requested by the professorship to gain more knowledge about the possibilities and efficiencies of a plastic catcher in the Sông Cần Thơ area. The information gathered from this research can be used to further develop the expertise of the professorship and the Hogeschool Van Hall Larenstein. This knowledge can be used for implementing plastic waste reducing projects in the Netherlands but also in other places around the world.

## 1.5 Research questions

To accomplish the research goal the following main and sub research questions will be answered.

**Main research question:**
What is the most effective approach for determining plastic convergence areas in rivers?

Sub question:

1. What are the characteristics of the water flowing through the Song Cần Thơ?
2. What are relevant factors that determine plastic streams in rivers?
3. How will plastic flow through the Sông Cần Thơ theoretically?
4. Which practical methods can be deployed to track plastic flow in rivers?
5. What is the most suitable practical method for plastic tracking in de Sông Cần Thơ?
6. How effective is the theoretical prediction in comparison to the results of practical plastic tracking?

## 1.6 Itinerary

In chapter 2 is the methodology that is used for concluding this research is explained and illustrated. The third chapter consists of an overview of the research area and gives information that is a result of the desktop research that answers the sub question 'What are the characteristics of the water flowing through the Sông Cần Thơ?'. The fourth chapter answers the second sub question 'what are relevant factors that determine plastic streams in rivers?' with the results of desktop research and from field measurements that give insight in the aspects that alter plastic flow in a river. The fifth chapter explains the developed tracking devices that can measure plastic streams in a river, which answers the sub question 'which practical methods can be deployed to track plastic flow in rivers' and 'What is the most suitable practical method for plastic tracking in de Sông Cần Thơ'. In the sixth chapter a comparison will be made between two approaches for finding convergence areas and answers the fifth and the sixth subquestions which are 'What is the most suitable practical method for plastic tracking in de Sông Cần Thơ?' and 'How effective is the theoretical prediction in comparison to the results of practical plastic tracking?'. In the last chapter of this research the conclusions and recommendations will be explained and the main research question will be answered. In the appendixes is an overview on how a model is created to predict water streams in the case area, an overview on how the tracking devices are developed and the results of the field research that has been conducted with these devices.

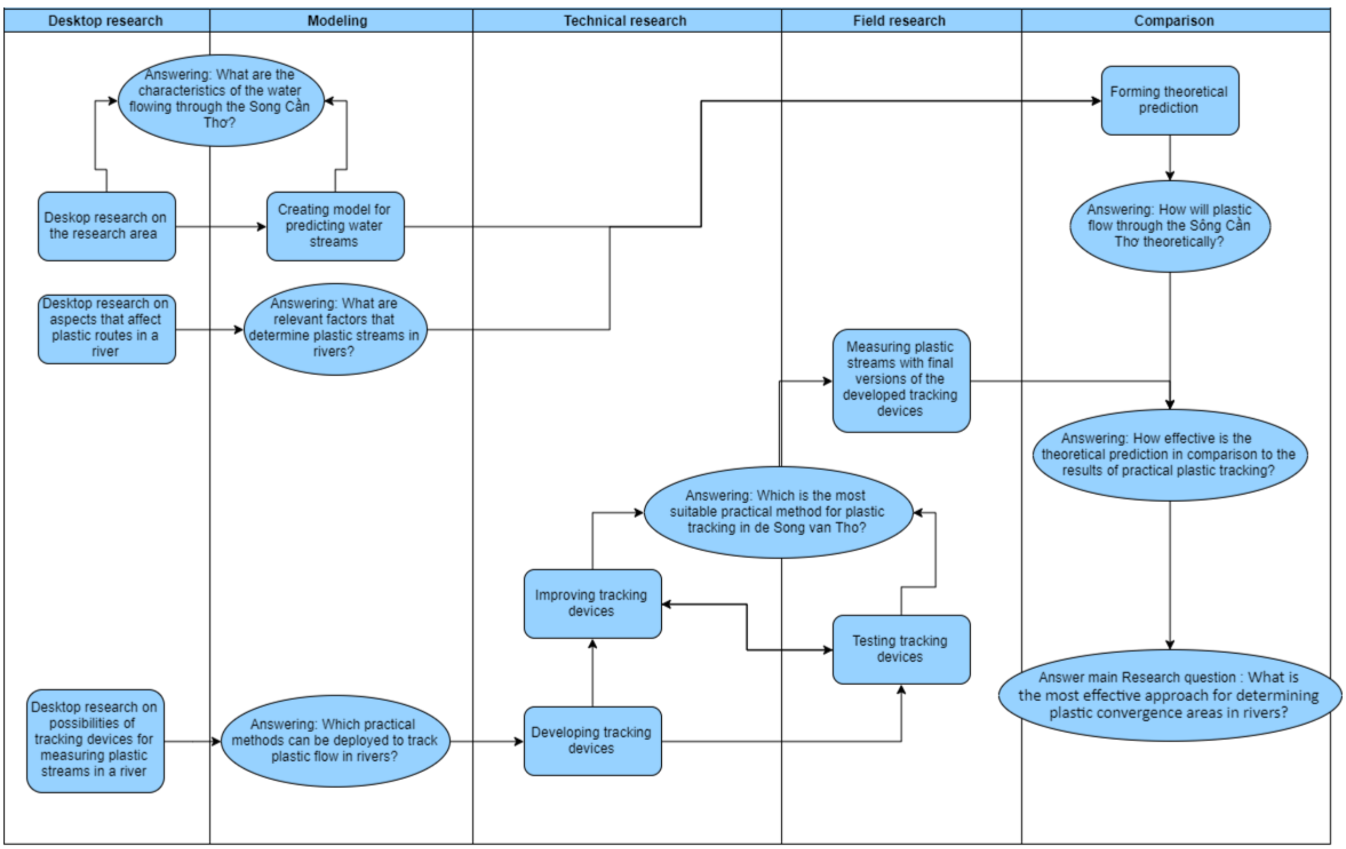
# 2 Methodology

In this chapter the methodology for this research is presented. This research consists of multiple phases in which different research methods have been applied. Various research methods have been used to answer the sub questions, which together lead to the answering of the main question.

## 2.1 Flowchart

During this thesis research various research methods are used to structure the research and eventually answer the main and sub questions as listed in chapter 1.4. This research is conducted in phases which answer the sub questions, as is shown in Table 1. During this research five different research methods have been used to gather the information needed to answer the main research question. The different research methods will be explained in the following paragraphs.

*Table 1 Different research methods and phases and how these answer sub and the main research questions*




## 2.2 Desktop research

During this research a desktop research is conducted to gather background information on multiple subjects. The information gathered during the desktop research is used throughout the research as information that is necessary for conducting all the following research steps.

The desktop research consists of a literature research to gather information about the Sông Cần Thơ, aspects that affect routes that plastic travels through a river and the possibilities for developing a tracking device for measuring plastic streams in the Sông Cần Thơ.

To gather the information that is necessary for conducting the research steps that have been described in Table 1, different sources have been used. The literature that is used during this research consists of previously conducted research that is found on ResearchGate and the information found on this source is mainly used for the gathering of information on the Sông Cần Thơ, aspects that alter plastic flow and the possibilities surrounding plastic tracking devices. During this research information is also gathered through meetings with professor Van Tri, Vice Dean of Modelling and Integrated Water Recourses Management at the University of Cần Thơ.

## 2.3 Modelling

The information that is gathered during the desktop research gives basic information about the flow characteristics of the Sông Cần Thơ. The information that is gathered by the desktop research gives a slight insight in how the river flows. This data is used as input for creating a hydrological model to enhance insight in flow characteristics. The model is created using HEC-RAS 5.0 which is a hydrological tool that can create a 2D model of a river such as the Sông Cần Thơ. The model that is created during this research phase is built using the HEC-RAS user manual, as is found on the website of HEC-RAS. The creation of the model that predicts flow characteristics of the Sông Cần Thơ is documented in appendix 2.

## 2.4 Technical research

The technical research that is conducted during this research consists of the development of three different tracking devices. The development of the tracking devices is based on the information found in the desktop research and consists of a design and improve phase in which the tracking devices are developed, tested and improved. Every tracking device that will be developed will undergo a series of tests and after these tests the it will be decided which tracking device is most efficient and reliable for measuring convergence areas of plastic streams on the Sông Cần Thơ river.

## 2.5 Field research

The developed tracking devices that are going to be used for measuring plastic streams in the Sông Cần Thơ are used to find convergence areas in the Sông Cần Thơ. To perform the measurements on the Sông Cần Thơ an application for a permit with the people committee of Cần Thơ is filled (as shown in appendix 5). The application procedure consists of a Vietnamese letter of intent and is filed in threefold to the people committee. The field research consists of multiple days on a boat of which the tracking devices will be used and monitored from the boat. The boat is hired through contacts that are provided by the external supervisor of this research. After conducting the field research, the data that is collected is visualized using Google Earth and is interpreted. The interpretation of the results of the field research consist of comparing the aspects that alter plastic flow as found through the desktop research and the measurements.

## 2.6 Comparison

To answer the main research question a comparison is made between two different approaches for determining the convergence areas in a river. The first approach consists of a theoretical prediction that is made based on the created model and information found in the desktop research. The second approach that is used during this research uses the tracking devices as developed during this research. The information found is compared with a focus on how similar or contradictory the results of both approaches are.

## 2.7 Validity and reliability

To ensure that the research will be repeatable the technical research and the creation of the model is documented in appendices 2 and 3. During the technical research the reliability and validity of the outcome is enhanced by repeated improvement phases in which the validity of the results is analyzed. The accuracy of the tracking devices was tested to improve the reliability of the results. The measurements that are part of the field research give information about plastic streams on a certain time and date and therefore only give guidelines for plastic movement in the Sông Cần Thơ on that specific moment. Although the measurements are not representative for plastic streams on other days, the information gained through these measurements support the goal of finding aspects that alter plastic streams and contribute to the likelihood of convergence areas in a river such as the Sông Cần Thơ. Validity is further increased through the fact that the field research consists of multiple days of measurements and therefore gives more detailed insight in the variations that can occur in the plastic stream than a single measurement. The desktop research consists of the usage of various sources and during this research the information provided by these sources is seen as viable. The information that is used for this case study about the Sông Cần Thơ forms the base for gathering insight on plastic flow in other rivers and therefore can be generalized to other rivers.

# 3 Sông Cần Thơ

This chapter will present the results of the desktop research and the modelling phase of this research. The information provided in this chapter will give an overview of the research area and the flow characteristics of the Sông Cần Thơ and will answer the first sub question.

## 3.1 General information

The Cần Thơ river (in Vietnam known as Sông Cần Thơ) is a river that is part of the Mekong river delta region. The Sông Cần Thơ originates in the inland on the west side of the Hau river and ends in the Hau river as can be seen in Figure 4. The Hau river is one of the main branches of the Mekong river and ends in the South Chinese sea. The Hau river splits from the Mekong near Phnom Peng (Cambodia) and is therefore part of the Mekong river delta region.


*Figure 4 Overview of the Sông Cần Thơ*

**Tidal effects**

The Sông Cần Thơ is connected via the Hau river to the sea and the sea has a big impact on the water levels in the Sông Cần Thơ. The Sông Cần Thơ has strong tidal effects which result in 1,5 meter water level difference between high and low tide.

*Figure 5 Photos of flooding season in the city of Can Tho*

**Climate**

South Vietnam knows two seasons consisting of the winter season that is also known as flooding or rainy season and summer season. During the flooding or rainy season floods in the mainland are very common, as can be seen in Figure 5.

## 3.2 Functions of the river

The Sông Cần Thơ is a river that is closely connected to the city economically but is also cause for the fertile agricultural sector upstream of the river. Because the river is influencing both the urban and the rural economy. The water quality is important for maintaining the rich agricultural benefits of the area as well as for the touristic endeavours within the area.

The Mekong river delta is a well-known place when visiting Vietnam. The Mekong river delta, although it is well known, is not often visited by backpackers but more often by families. The main touristic sight is the Chang Rai floating market. This floating market is a big touristic venue for the region and is reason for tourists to come to Cần Thơ. Shown in Figure 6 is a touristic ship that takes people to the floating market.

*Figure 6 Touristic ship*

The city of Cần Thơ is city that doesn't have a big industrial presence. The production of materials and food that is located outside of the city is transported by boat to the city of Cần Thơ. The roads in Vietnam are relatively bad and therefore transport over land is not favourable. Transport on the Sông Cần Thơ is therefore a good solution and mainly consists of transport vessels (as shown in Figure 7). The river also is used for leisure and for fishery, but this sector is mainly focussed on small commercial companies which operate with one or two boats at a time.

Apart from the economical function of the Sông Cần Thơ the river is used as a water source for farming and irrigation of farming land upstream from the city of Cần Thơ. The floods caused during the rainy season deposit fertile sediment on the agricultural lots and provide a good soil for growing local fruits and rice. The sediment that causes the land to be fertile is the reason for the flourishing agriculture, which is one of the most thriving sectors in Vietnam.

*Figure 7 Transport ship*

## 3.3 Plastic pollution

Plastic pollution forms a threat to the environment. Plastic needs to be removed to reduce its negative effects in a river such as the Sông Cần Thơ. Plastic pollution damages the touristic sector and reduces the water quality which is harmful to the agricultural sector. Plastic pollution is harmful to the environment because plastic degrades over a timespan and effectually becomes microplastics which harm the environment. It is more desirable to catch plastics in an earlier stage where it is not yet degraded. Although it is more desirable to catch plastic in an earlier stage such as in a river basin area, different complexities will occur because of the more confined areas of river basin areas which results in a higher density of traffic on a river that can influence plastic streams. For example, the shipping routes that are part of every large river systems such as the Mekong serve as transportation of goods which is important for the local but also the national economy. To find locations where plastic catching is optimal but does not affect shipping routes is an obstacle that can occur in a river basin but less on the oceanic level. Although plastic catching in a river basin is more desirable more research needs to be conducted to find locations for plastic catchers to catch as much plastic as possible while at the same time but keep the local economy, tourism, fisheries and other local activities intact.

## 3.4 Flow characteristics

The desktop research on flow characteristics of the Sông Cần Thơ resulted in the information provided in Table 2. The information displayed in Table 2 is a result of found values and the discharges and cross-sectional area of the river are calculated as described in appendix 1. The data found in the desktop research shows that the tidal affects are strong and the difference in discharge between high and low tide is almost 800 $m^3/s$.

*Table 2 Hydrologic characteristics of the Sông Cần Thơ*

| | | |
|---|---|---|
| Cross-sectional area of the stream | 2516 | m2 |
| Average Velocity | 1.05 | m/s |
| Velocity (low tide) | 1.2 | m/s |
| Velocity (high tide) | 0.9 | m/s |
| Average discharge | 2641.8 | m3/s |
| Discharge (low tide) | 3019.2 | m3/s |
| Discharge (high tide) | 2264.4 | m3/s |

The flow characteristics as described in in Table 2 are used for the creation of the model and give more insight in the flow pattern of the Sông Cần Thơ. The model that is created using the steps taken as described in appendix 1, gives insight in the water flow in the Sông Cần Thơ. The results of the model (as shown in Figure 8) are created using the average discharge and the average known water levels in the Sông Cần Thơ. The model shows that the water velocity is upstream higher than downstream and that the water is losing velocity while flowing through the river. This is in fact not true but is a result of the calculations that the model performs. The results of the model gives an indication of the water stream flow of the Sông Cần Thơ.

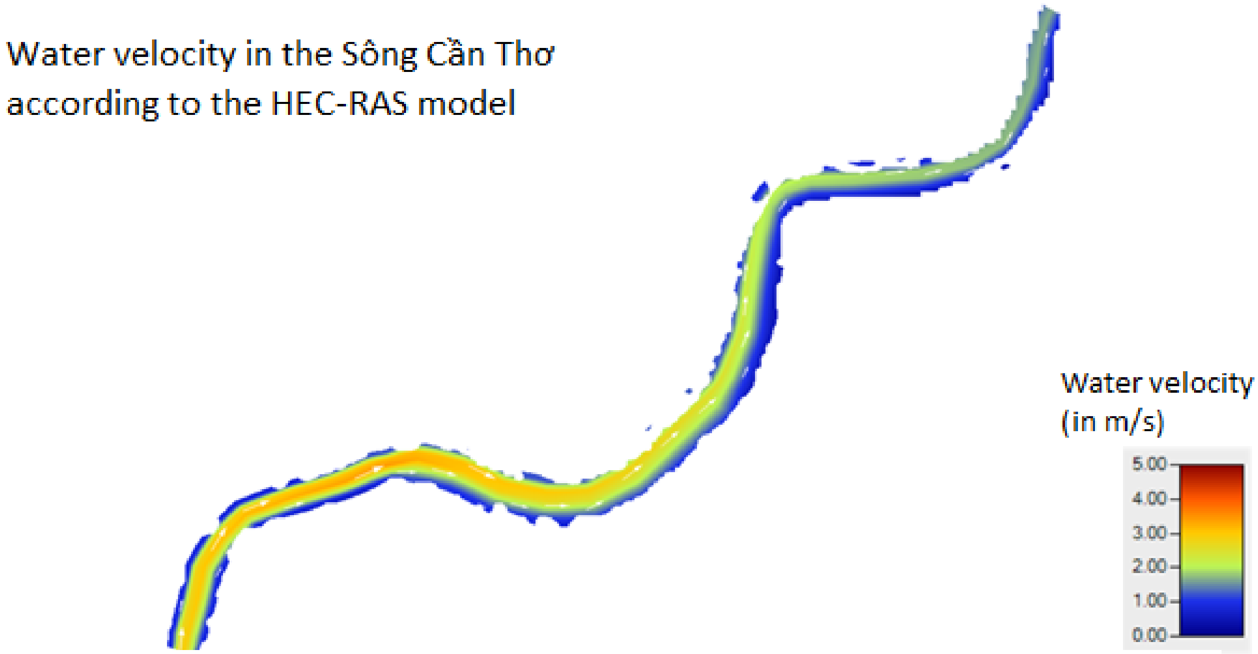


*Figure 8 Results of HEC-RAS model, showing the water velocity in the Song Can Tho*

The creation of the model and the information found by the desktop research answer the first sub question: 'What are the characteristics of the water flowing through the Song Cần Thơ?' partially with the flow patterns shown in figure 8 and partially with the information provided in Table 2.

# 4 Aspects of plastic flow

This chapter shows the results of the desktop research and the field testing and gives insight in the aspects that are leading or alter the flow of plastic in a river. This chapter will answer the second subquestion in Table 3. In Table 3 the various aspects that alter the course of plastic in streams are displayed. This table shows the results of the desktop research but also addresses how these correlate to the findings from the field research as shown in chapter 6.2. The colour of the bottles shown in the last column show how much the plastic is affected by the aspect named in the first column. In the following paragraphs the data found in the desktop research and the fieldresearch (as described in chapter 6) are named and these form the foundation for the results stated in Table 3.

*Table 3 Aspects that affect plastic streams in a river*

| **Aspect** | **How does it affect plastic?** | **How much does it affect plastic streams?** |
|---|---|---|
| Meandering river | Meandering rivers cause the plastic to move along the outside corners of the river where the flow velocity is the strongest. |  |
| Tidal affects | Tidal affects are cause by high tide and low tide and cause plastic to move backwards and to towards the banks of the river. |  |
| Wind | Wind affects the speed of plastic but does not affect the flow in another direction opposed to the meandering flow of a river. |  |
| Shape | The shape of plastic does influence the plastic stream but minimally and differs small from when in a flowing river |  |
| Ships | Ships alter the course that plastic flow in a way that can oppose the meandering flow in a river. The affect of ships causes plastic to stay at a side of the river and not to cross a river. |  |

## 4.1 Meandering river

The oceanic plastic streams are measured during the drifter buoy research that has been going on since 1982 (MacPhee, Caryl-Sue, 2014). The research about the drifter buoys shows that plastic follows the oceanic current which can be defined as the strongest flow that is present in the ocean. This information can be translated to a river and results in the meandering aspect. The plastic flows with the strongest current and therefore will follow the meandering flow of a river such as the Sông Cần Thơ. Although this assumption on plastic flow following the highest velocity is not yet extensively researched, this is highly likeable. During the desktop research almost no information could be found on plastic streams in rivers, only information could be found about the oceanic plastic streams.

Test results of measurements conducted during this research show that plastic indeed follows the fastest flowing part of the river and therefore it can be concluded that of all the aspects that are explained in this chapter the stream with the highest velocity dictates the flow of plastic the most.

## 4.2 Tidal affects

Research about tidal affects in the Mekong river delta region and the Sông Cần Thơ shows that the tidal affects that are present and can fluctuate strongly. This causes the water to move upstream of the river when high tide is present. The research on ocean tide modelling for urban flood risk in the Mekong delta show at point ‘a’ as shown in Figure 10 and Figure 9 that the water speed becomes zero at high tide.

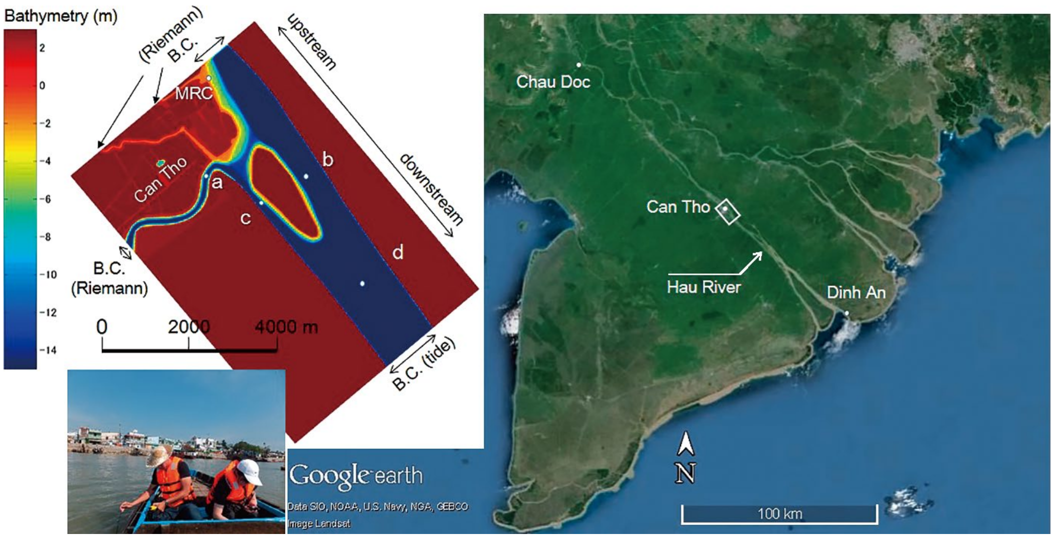



*Figure 9 Locations of the water velocity and water levels measurements conducted  in the Song Can Tho (Takagi, Le Tuan, & Nguyen Danh, 2016)*

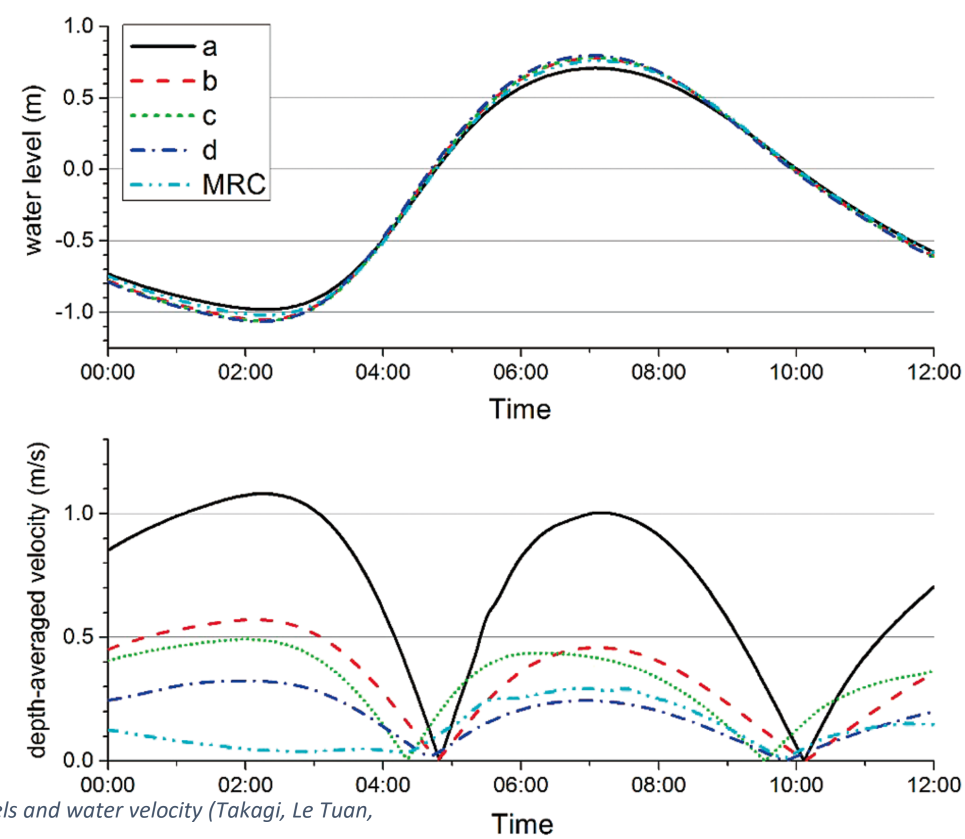



*Figure 10 Corresponding water levels and water velocity (Takagi, Le Tuan, & Nguyen Danh, 2016)*

The affects of the tidal changes where visible during the field research. The measurements on plastic flow where conducted from 5 in the morning till 12 in the afternoon and therefore the morning high tide was visible. The plastic moved a little bit backwards and shifted on a horizontal axis mostly to the right bank of the river. The fact that the plastic moved to the right bank was a result of the interference caused by ships as named in subchapter 4.4.

## 4.3 Wind

The affects of wind on near surface plastic streams have been researched in the study 'the effect of wind mixing on the vertical distribution of buoyant plastic debris' that is conducted in 2012 (Kukulka, Proskurowski, & Moret-Ferguson, 2012). This states that the plastic that is located sub surface will not be influenced by wind vectors and therefore this would be obsolete for sub surface plastic streams. The study shows that when catching plastic in the oceans the amount of plastics caught at a certain moment was influenced by the force of the wind at that time. Based on surface and subsurface observations during this study the amount of plastic concentrations that where measured using surface tow measurements depend on wind speed (Kukulka, Proskurowski, & Moret-Ferguson, 2012). Plastic pieces that are vertically distributed are mixed due to wind and therefore wind has an effect on plastic streams in rivers.

To take wind streams in account for surface plastic streams the wind vectors are monitored during this research. In chapter 6 the results of the measurements in the Sông Cần Thơ river are described. Deviations are monitored by and compared to wind data that is acquired by windy.com (Can Tho Airport, 2019), a website that shows real time wind speeds on different locations and therefore can be necessary to take into account when comparing measurements and the theoretical predictions in a later phase of the research. The measurements showed that wind mainly influences the speed of the plastic but does not contribute to the displacement of plastic, opposed to the meandering flow of the plastic.

## 4.4 Shape

The shape of plastic is important for the flow the plastic in the river. Articles like the 'washed up shoe mystery' that is published in the 'de Volkskrant' show that objects with different shapes behave differently in water streams. This article describes biologist Mardik Leopold who describes a phenomenon where left and right valves of shellfish with two valves wash up on different stretches of beach. This phenomenon is shown as well with shoes. Findings from beaches on the island Texel state that 68 left and 39 right shoes have been found. On the Scottish Shetland Islands there were 63 left and 93 right shoes found. These findings demonstrate that the shape of an object defines the trajectory of the way it flows through a streamflow.

Although the theory on different shapes is not yet researched, it is plausible because of the different examples that are shown through findings. The research is only focused on oceanic transport of different objects and therefore there is uncertainty if this is also the case for rivers.

During the measurement conducted with the tracking devices only the shape of a plastic bottle is used. This is done because the plastic bottle is the only shape that could be made water tight, so the shape can have affect but is not tested in this research. The shape and or size of plastic can possibly alter the course of plastic and therefore can be researched in a follow-up research.

## 4.5 Ships

The studies that have been found during the desktop research are mostly focused on plastic streams in oceans and therefore the effect that ships have on plastic flow is not yet researched because on the oceanic scale the plastic streams are less influenced by ships.

During the measurements the effect of ships passing the tracking device had great impact on the way that plastic flowed through the river. Plastic is moving through a river following the meandering path of the river and should cross the river at some point because the flow velocity is higher on the outside corners. The effect of passing ships was that it prevented plastic from crossing the river and caused it to stay on the side of the bank that it was already on. Also, stationary ships affected the plastic stream during some measurements, but this caused a minor alteration to the routes found in other measurements. After a while, the plastic ended up flowing on the same route as plastic measurements on other days.

# 5 Tracking devices

The development of the tracking devices resulted in three devices that use GPS location services that can track plastic streams in a river. The different devices all have the same objective, which is to give insight in how plastic moves when subjected to aspects that occur in a river. The different devices that have been developed consist of the following:

- Tracking device 1: GPS Datalogger built with an Arduino
  A device built and coded to store GPS data on an SD Card
- Tracking device 2: Phone with datalogging capabilities
  A phone that uses a specialized application for monitoring and saving GPS information
- Tracking device 3: Application for collecting GPS information and documenting visual findings
  An application that can be used when on a boat following plastic and store information on events that occur when plastic flows through a river

The three devices have been tested as part of the field research and are improved to become more efficient or more affective at validating location data. In the following subchapters the results of the test phases have been briefly presented.

## 5.1 Tracking device 1

The development of the GPS Datalogger built with an Arduino resulted in three versions of coding that have been implemented to improve the initial version of coding. The coding of the GPS datalogger resulted in improvements made to the reliability and precision of location awareness of the device.

To test the device a series of tests has been conducted. The first test was of the first version of the code as given in appendix 2 and this test resulted in the route as track displayed in Figure 11. The test results show promising results at first glance, but when zoomed in on the track (as shown in Figure 12) it can be concluded that there are problems with the precision of the tracking device. The track is going through houses while the test is only conducted on the roads and the tracking shows corners which were not made during testing.

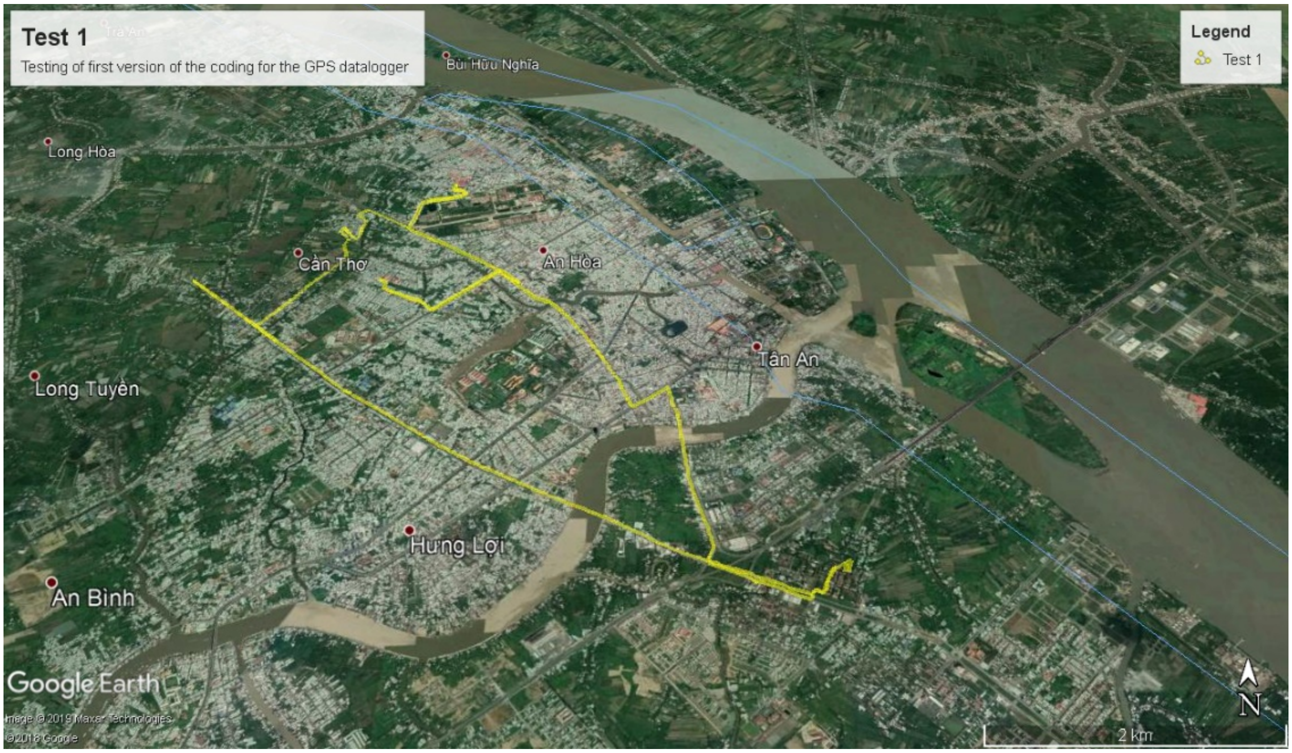



*Figure 11 Testing first version of coding for GPS datalogger*


*Figure 12 Zoom in on test results of first version of coding for GPS datalogger*

After the findings from the first test a new version of the coding is written, which was tested during a motorbike drive. The test results shown in Figure 13 show various colored lines which give information on the precision of the measurement by displaying the amount of satellites that where connected during that time. The results of the second version of coding are more fluent than the first version as can be seen in Figure 14. Also, an improvement can be seen in which the accuracy of the location service has been improved compared to the first version.

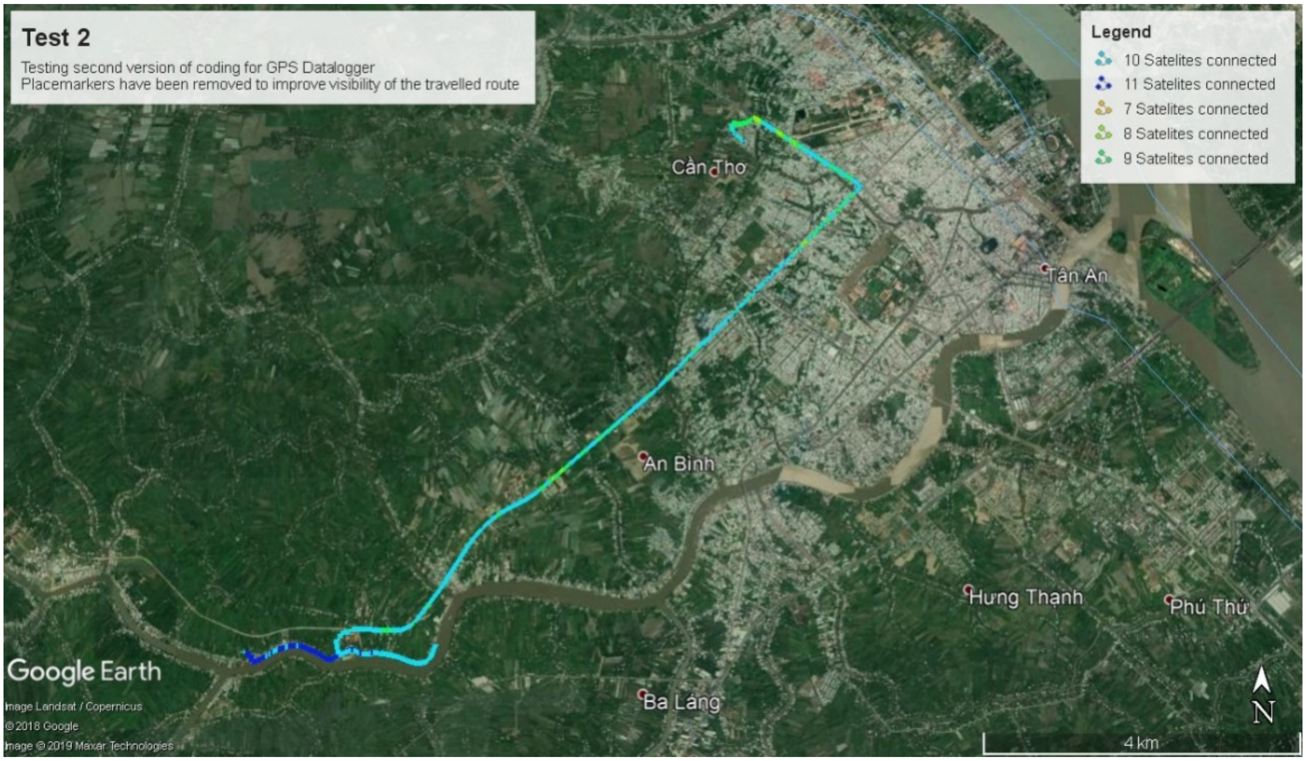



*Figure 13 Testing the second version of coding for GPS datalogger*


*Figure 14 Zoom in on test results of second version of coding for GPS datalogger*

After testing the second version of the coding, improvements have been made to the coding to enhance the validation process of the GPS datalogger. The third version caused problems in terms of memory availability of the tracking device. Because the third version of the coding caused for memory overflow the reliability of the tracking device became a problem and this is visible in Figure 15. During the testing of the third version of the GPS datalogger the route to the Cần Thơ university has been tracked and as can be seen in Figure 15 the measurement stopped near the beginning of the measurement.

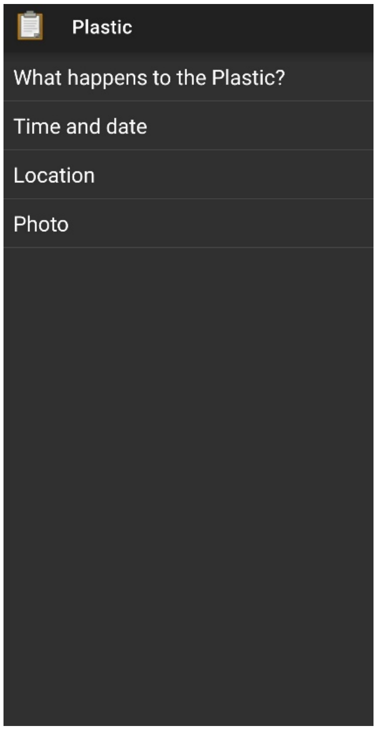

*Figure 15 Testing the third version of coding for GPS datalogger*

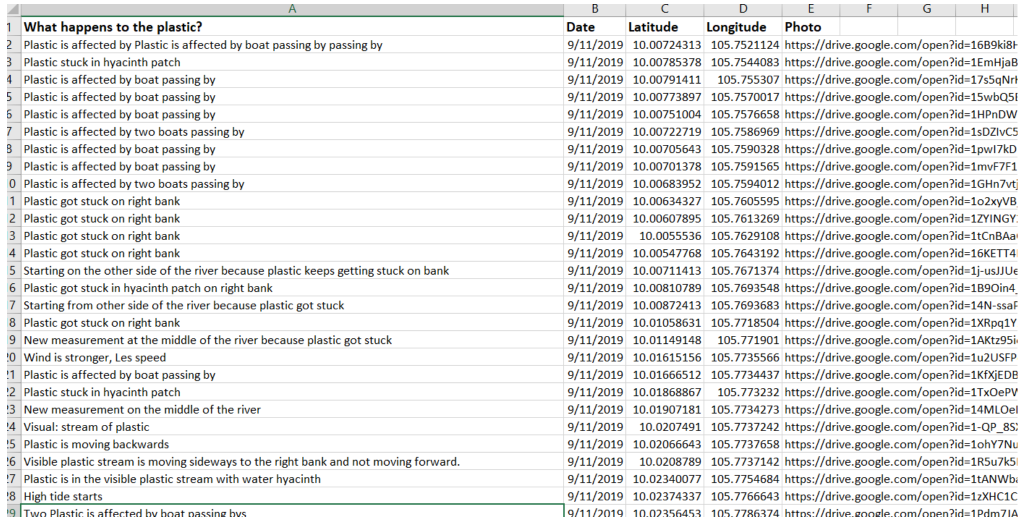
## 5.2 Tracking device 2

The second developed tracking devices uses the tracking ability of a phone to collect location data. A phone has more processing memory than the tracking device and therefore the reliability of tracking plastic with a phone is more reliable. The testing of this tracking device resulted in a correct showing of the tracked route and showed to be very reliable.

## 5.3 Tracking device 3

The third tracking device that is developed is an application that is filled in on a phone using a form as shown in Figure 17 and Figure 16. The results of the application form are automatically uploaded to a database on Google Drive and are visualized as shown in Figure 16. This application form has the benefit that it does not only collect GPS data but can also collect or give information on other events that happen when measuring on a river, such as when plastic gets stuck, objects that affect plastic streams or other visual findings.



| What happens to the plastic? | Date | Latitude | Longitude | Photo |
|---|---|---|---|---|
| Plastic is affected by Plastic is affected by boat passing by passing by | 9/11/2019 | 10.00724313 | 105.7521124 | https://drive.google.com/open?id=16B9ki8H |
| Plastic stuck in hyacinth patch | 9/11/2019 | 10.00785378 | 105.7544083 | https://drive.google.com/open?id=1EmHjaB |
| Plastic is affected by boat passing by | 9/11/2019 | 10.00791411 | 105.755307 | https://drive.google.com/open?id=17s5qNrI |
| Plastic is affected by boat passing by | 9/11/2019 | 10.00773897 | 105.7570017 | https://drive.google.com/open?id=15wbQ5I |
| Plastic is affected by boat passing by | 9/11/2019 | 10.00751004 | 105.7576658 | https://drive.google.com/open?id=1HPnDW |
| Plastic is affected by two boats passing by | 9/11/2019 | 10.00722719 | 105.7586969 | https://drive.google.com/open?id=1sDZIvC5 |
| Plastic is affected by boat passing by | 9/11/2019 | 10.00705643 | 105.7590328 | https://drive.google.com/open?id=1pwI7kD |
| Plastic is affected by boat passing by | 9/11/2019 | 10.00701378 | 105.7591565 | https://drive.google.com/open?id=1mvF7F1 |
| Plastic is affected by two boats passing by | 9/11/2019 | 10.00683952 | 105.7594012 | https://drive.google.com/open?id=1GHn7vtj |
| Plastic got stuck on right bank | 9/11/2019 | 10.00634327 | 105.7605595 | https://drive.google.com/open?id=1o2xyVB |
| Plastic got stuck on right bank | 9/11/2019 | 10.00607895 | 105.7613269 | https://drive.google.com/open?id=1ZYINGY |
| Plastic got stuck on right bank | 9/11/2019 | 10.0055536 | 105.7629108 | https://drive.google.com/open?id=1tCnBAa |
| Plastic got stuck on right bank | 9/11/2019 | 10.00547768 | 105.7643192 | https://drive.google.com/open?id=16KETT4 |
| Starting on the other side of the river because plastic keeps getting stuck on bank | 9/11/2019 | 10.00711413 | 105.7671374 | https://drive.google.com/open?id=1j-usJJUe |
| Plastic got stuck in hyacinth patch on right bank | 9/11/2019 | 10.00810789 | 105.7693548 | https://drive.google.com/open?id=1B9Oin4_ |
| Starting from other side of the river because plastic got stuck | 9/11/2019 | 10.00872413 | 105.7693683 | https://drive.google.com/open?id=14N-ssaF |
| Plastic got stuck on right bank | 9/11/2019 | 10.01058631 | 105.7718504 | https://drive.google.com/open?id=1XRpq1Y |
| New measurement at the middle of the river because plastic got stuck | 9/11/2019 | 10.01149148 | 105.771901 | https://drive.google.com/open?id=1AKtz95i |
| Wind is stronger, Les speed | 9/11/2019 | 10.01615156 | 105.7735566 | https://drive.google.com/open?id=1u2USFP |
| Plastic is affected by boat passing by | 9/11/2019 | 10.01666512 | 105.7734437 | https://drive.google.com/open?id=1KfXjEDB |
| Plastic stuck in hyacinth patch | 9/11/2019 | 10.01868867 | 105.773232 | https://drive.google.com/open?id=1TxOePV |
| New measurement on the middle of the river | 9/11/2019 | 10.01907181 | 105.7734273 | https://drive.google.com/open?id=14MLOeI |
| Visual: stream of plastic | 9/11/2019 | 10.0207491 | 105.7737242 | https://drive.google.com/open?id=1-QP_8S |
| Plastic is moving backwards | 9/11/2019 | 10.02066643 | 105.7737658 | https://drive.google.com/open?id=1ohY7Nu |
| Visible plastic stream is moving sideways to the right bank and not moving forward. | 9/11/2019 | 10.0208789 | 105.7737142 | https://drive.google.com/open?id=1R5u7k5I |
| Plastic is in the visible plastic stream with water hyacinth | 9/11/2019 | 10.02340077 | 105.7754684 | https://drive.google.com/open?id=1tANWba |
| High tide starts | 9/11/2019 | 10.02374337 | 105.7766643 | https://drive.google.com/open?id=1zXHC1C |
| Two Plastic is affected by boat passing bys | 9/11/2019 | 10.02356453 | 105.7786374 | https://drive.google.com/open?id=1Pdm7JA |

*Figure 16 Results of the application form*

*Figure 17 Form from the application*

## 5.4 Final tracking devices

The test results of the three tracking devices show that tracking device 2 and 3 are the most reliable and could be most easily used for measuring plastic streams in the Sông Cần Thơ. The problem that occurred while developing tracking device 1 was a problem that could not be fixed while in Vietnam but this tracking device is the cheapest and has the most potential because the coding can be enhanced and therefore improve the overall tracking process.

The usage of the third tracking device in combination with tracking device 1 or 2 result in a measurement of plastic flow as shown in Figure 18. The combination of these tracking devices give insight in what happens to the plastic at a certain moment and this gives broad insight in aspects that alter plastic streams in a river.


*Figure 18 Information gathered during a measurement by the application in combination with tracking device 2*

# 6 Plastic flow in the Sông Cần Thơ

In this chapter the effectiveness of the aforementioned tracking approach is compared to a theoretical prediction on plastic streams in the Sông Cần Thơ. The goal of the comparison is to gain information on how affective both the approaches are in finding convergence areas in a river. The comparison gives insight in the pros and cons of both approaches.

## 6.1 Theoretical prediction

As a result of the findings from the desktop research and the model that is created for predicting the water stream flow in the Sông Cần Thơ, a theoretical prediction is formed on plastic flow in the Sông Cần Thơ. The theoretical prediction is a result of combining the information that is presented in chapter 5 about the findings from the literature review on aspects that alter the course of plastic streams and the model that has been created. The main force that moves the plastic stream is the meandering flow of the Sông Cần Thơ and therefore the meandering flow of the river is used as the base for the theoretic prediction.


*Figure 19 Theoretical prediction on plastic flow in the Sông Cần Thơ*

The theoretical prediction, as shown in Figure 19 shows the route that is predicted for plastic in the Sông Cần Thơ.

## 6.2 Results of field research

The measurements that are conducted on the 9th, 11th, 12th and 14th of November 2019 are presented in Figure 20. The results of the measurements show that convergence areas not only can consist of specific locations but can also consist of lines where plastic accumulates.

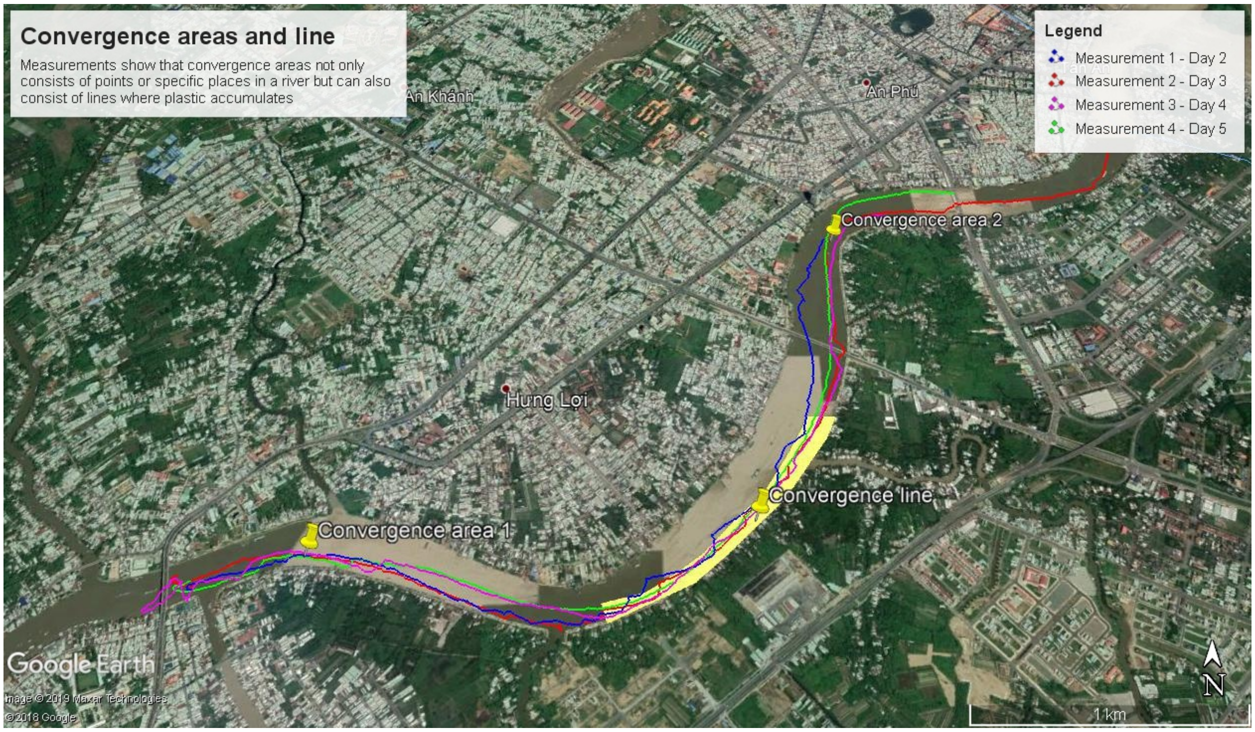



*Figure 20 Convergence areas and line*

As showed in Figure 20 the routes of plastic that travels through the river differs every day, influenced by aspects stated in chapter 4 and therefore it can be concluded that plastic is undergoing different levels of interference that moves it into different ways.

## 6.3 Comparison

In Figure 21 the measurements and the theoretical prediction are visualized. The measurements and the theoretical prediction show both similarities as well as small differences. Especially at the first corner the plastic was predicted to follow the outside corner of the river, which did not happen during the measurement. Because the plastic was measured in the morning from the starting point at the floating market a lot of touristic and transport ships altered the course of the plastic and forced it to follow the inner corner. After the first corner the plastic stream as measured and the theoretical prediction follow the same path, until the plastic came to the first bridge. At the first bridge the plastic moved in different directions every day, but there was a very visible high-density stream on the river of plastic and hyacinth. The plastic stream that is measured and predicted shows similarities after the first corner and the plastic deviates some days because of daily changes in the amount of ships, the wind or tidal effects.

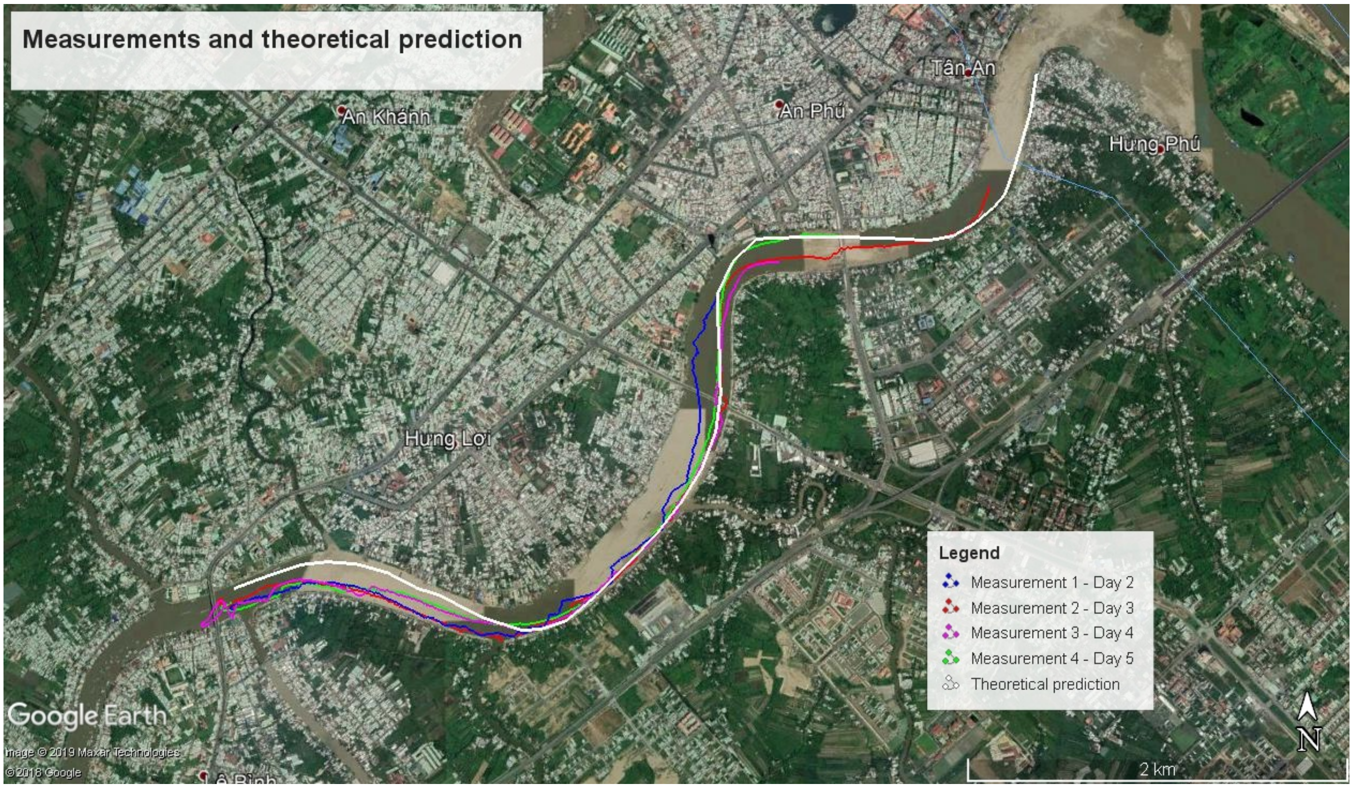



*Figure 21 Measurements and theoretical prediction*

All measurements show that the plastic follows a meandering pattern which is interrupted by ship traffic on the Sông Cần Thơ. The blue line shows that the plastic flow moves across the river at the first bridge on the day where boat traffic was the least. The crossing of the river by the plastic was predicted by the theoretical model, but did only occur on this specific day. This shows that the plastic streams are greatly affected by the boat traffic on a river like the Sông Cần Thơ.

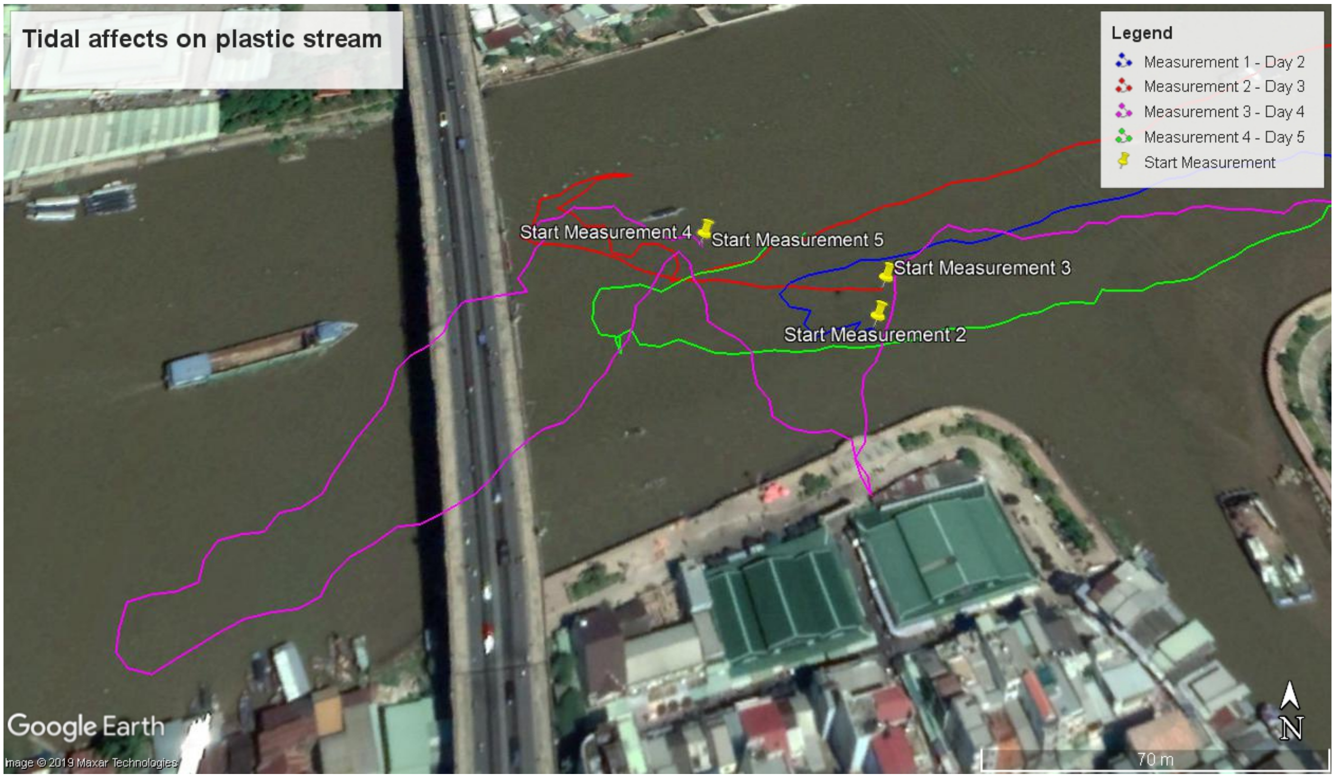



*Figure 22 Tidal effects on plastic stream*

The tidal affects where measured in the morning at the start of almost every measurement as can be seen in Figure 22. The pink measurement showed the most interference through tidal effects and shows that the plastic is moving backwards but is pushed to the right bank by boat traffic. Other measurements showed also interference through tidal effects. This resulted in going backwards and not so much to the sides, as is seen in the pink line. The wind was monitored every day and showed that on the second and fourth day the plastic was moving slower than other days. However, it did not show large deviations in the route the plastic travelled compared to other days. This indicates that plastic is affected by the wind, but only in speed. Wind did not alter the route of the plastic traveling through the river.

# 7 Conclusions and recommendations

In this chapter the main question of this research will be answered and a conclusion will be presented bearing the insight gained from this research. In this chapter there is a reflection on the aspects that could be improved about the methods that are used and the overall research methodology and finally there is a section with recommendations that could be implemented in further research.

## 7.1 Conclusion

This research concludes that the usage of tracking devices is an effective approach for finding convergence areas in a river. The usage of a tracking device, although it is more time consuming than for exampling modelling the plastic flow, is more efficient and gives more insight in the different aspects that alter plastic streams in a river.

Although the results of the field research show similarities to the theoretical prediction, the results of the field research sometimes differ from it. The information on how different aspects alter plastic streams are the foundation for an approach to locate convergence areas in a river. Especially the density of boat traffic on a river has large impact on the way that surface plastic moves through a river. The presence of tidal waves is monitored and shows that plastic is affected by the tidal affects but this research could not conclude if this has any effects or if the plastic catcher is greatly impacted by the tidal affects. What this research did conclude however, is that convergence areas are present in the Sông Cần Thơ and that these convergence areas are optimal locations for catching plastic. The convergence areas are located near the banks of the river and therefore would form ideal locations for catching plastics without interfering in the boat traffic and or other activities that are conducted on the river.

The Sông Cần Thơ is a river that is smaller and more confined than for example the Mekong river, but the aspects apply to the Mekong as well. The aspects found in research on wider rivers, such as the Mekong, will show different effects on plastic, for example because the plastic flow will be less affected by ships on a wider river. But the affects of for example ships affecting plastic will still be a factor.

The results of this research show that the tracking device can be used for different rivers, but that it is not preferable to use only one tracking device. This research shows that a combination of two types of tracking devices is the best solution to measure and/or find convergence areas of plastic waste. The combination of an application in order to collect external factors that affect plastic streams and a tracking device which measures the way that plastic flows give a good representation of what happens when plastic flows through a river. The application or tracking device 3 that is used in this research gives meaning to the measurement conduct with the tracking devices 1 and two who only collect location data on plastic in a river. The usage of the combination of tracking devices gives information that helps to determine if the measured plastic streams are affected by factors that occur only on that day, such as a large ship passing by, or are representative for a longer period of time.

## 7.2 Recommendation

The information found using the tracking device gives input that can be used to improve the ability to create a model that can predict plastic convergence areas. To improve the ability to model plastic convergence areas can be seen as more efficient for future plastic convergence areas, because using tracking devices is more time consuming and therefore the ability to predict plastic streams with a model is better for finding convergence areas in other rives.

This research focussed on reducing plastic pollution in a river by catching plastics. But the plastic pollution problem is caused by the local inhabitants of a certain area and therefore the plastic pollution can also be reduced by changing the minds of the locals. The reduction of plastic pollution is therefore not only a case of catching but starts with the mindset of people. During the stay in Vietnam another catcher is visited upstream the Hau river, where the locals that operate the catcher found that by using a plastic catcher the amount of plastic that locals throw in the water is reduced. The reduction of littering plastic in the river is a result of the visual presence of the catcher. This shows that, next to technological solutions, sociocultural factors are also important for plastic pollution reduction in rivers.

## 7.3 Discussion

This research is mainly composed of practical research and therefore resulted in a great deal of problem solving. The problems that occurred during the research where mainly created by external factors. In this subchapter four different obstacles that occurred during the research are named.

**Development of tracking devices**
The research started by developing a tracking device which was built by the researcher in the Netherlands and further improved in Vietnam. The improvement phase resulted in different versions of coding which caused for an overload of the GPS Datalogger. Because the improvement phase was conducted in Vietnam the obstacles could not be overcome and resulted in a dead end for the GPS Datalogger. The backup methods (the GPS Datalogger phone and the visual findings tool) where good alternatives but where not cost efficient and therefore not ideal solutions.

**Measurement strategy**
Although there is a lot of boat traffic on the Sông Cần Thơ, shipping is privatized and can only be arranged by a shipper in the tourist sector. The rental of a boat caused problems in terms of costs but also in time that the measurements that could be conducted. Eventually the measurements could only be conducted during 5 AM and 12 AM.

**Financial needs**
The technical and the field research that have been conducted had to be simplified because the funds for the research came from the student. During this research it would have been preferable to do more field research to get a clearer picture on how plastic moves through a river but this did not fit in the research budget. Also, the creation of the tracking devices was costly and therefore the tracking device could be improved with more funds.

**Permits**
Corruption is a problem in Vietnam and therefore getting a permit implied offering a 'gift' to the people committee of Cần Thơ. The gift consists of an envelope with money and this is normally a necessity for getting a permit. Because the researcher had limited funds the process of getting the permit took a lot of time and this was cause for less time for the field research.

# 8 Bibliography


Adafruit. (2019). Arduino memory management issues. Retrieved from https://learn.adafruit.com/assets/8127

Blom, J. (n.d.). Arduino Shields. Retrieved from https://learn.sparkfun.com/tutorials/arduino-shields/all

Buisinessinsider. (2016, April 5). The one thing that makes recycling plastic work is falling apart. Retrieved from https://www.businessinsider.com/low-oil-prices-hurt-plastics-recycling-2016-4

Can Tho Airport. (2019, November). Wind Vectors and Speeds. Can Tho, Vietnam. doi:https://www.windy.com/station/ad-VVCT?10.085,105.712,8,i:pressure

Chow. (1959). Manning's n for Channels. Retrieved from http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm

Dr. Nguyen Hieu Trung. (2017, June 16). *100 Resilient Cities*. Retrieved from Can Tho: https://www.100resilientcities.org/cities/can-tho/

Google Earth. (2019, April 4). Overview of Hau river and Song Can Tho.

Hackney, D. C. (2019, Juli 2019). Hull researchers head to the Mekong to tackle plastic pollution. (T. Barret, Interviewer) Retrieved from https://environmentjournal.online/articles/hull-researchers-head-to-the-mekong-to-tackle-plastic-pollution/

I.W. Nortier, P. d. (n.d.). Fluid dynamics.

I.W. Nortier, P. de Koning. (1996). Fluid dynamics.

Kukulka, T., Proskurowski, G., & Moret-Ferguson, S. (2012, April 3). The effect of wind mixing on the vertical distribution. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2012GL051116

MacPhee, Caryl-Sue, M. (2014, October 4). Subtropical Gyres and Associated Ocean Currents. Retrieved from https://www.meted.ucar.edu/index.php

Meulen, L. V. (2019, June 26). Tackling Plastic Polution in the Mekong Delta.

Moore, C. (2008, March 14). Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Retrieved from https://www.sciencedirect.com/science/article/pii/S001393510800159X?via%3Dihub

Parker, L. (2019, Februari 22). Ocean Trash: 5.25 Trillion Pieces and Counting, but Big Questions Remain. Retrieved from https://www.nationalgeographic.org/news/ocean-trash-525-trillion-pieces-and-counting-big-questions-remain/3rd-grade/

Professor Van Tri. (2019, October 16). Information on the Song Can Tho. (M. Genet, Interviewer) Can Tho.

Schmidt, D. (2017, October 17). Rivers carry plastic debris into the sea. Retrieved from https://www.ufz.de/index.php?en=36336&webc_pm=34/2017

Sebille, E. V. (2012, September 20). Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Retrieved from https://www.researchgate.net/publication/234002610_Origin_dynamics_and_evolution_of_ocean_garbage_patches_from_observed_surface_drifters

T. Kukulka, G. P.-F. (2012, April 3). The effect of wind mixing on the vertical distribution of buoyant plastic debris. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2012GL051116

Takagi, H., Le Tuan, A., & Nguyen Danh, T. (2016, March). Ocean tide modelling for urban flood risk assessment in the Mekong Delta. Can Tho. Retrieved from https://www.researchgate.net/publication/297554884_Ocean_tide_modelling_for_urban_flood_risk_assessment_in_the_Mekong_Delta

USGS. (2000, November 22). SRTM 1 ARC-Second Global DEM. *Digital Elevation* . Can Tho, Vietnam. Retrieved from https://earthexplorer.usgs.gov/

WWF. (2018, August 30). Should we prioritise tackling plastic pollution in rivers? Yes, and…. Retrieved from https://medium.com/wwftogetherpossible/should-we-prioritise-tackling-plastic-pollution-in-rivers-yes-and-5cb68f07ee40

# 9 Appendix

# Appendix 1 – Modelling phase

The model that is created during the modelling phase of this research, is made with HEC-RAS 5.0. HEC-RAS 5.0 is a program that can create 2D hydrologic models that can be used to gain more insight in water velocities and water stream flow lines in a river.

The model is built by combining three programs, the programs that are used are:

1. ARCMAP 10.6
2. HEC GEO-RAS 10.6
3. HEC-RAS 5.0

**ArcMap and HEC GEO-RAS**
ArcMap is a Geographic information system (GIS) program that can be used to visualize data. ArcMap is used during the creation of the model for pre-processing data in order to create the model in HEC-RAS. To pre-process the data in ArcMap, a tool is used to transform data to ensure that all the prerequisites made by the HEC-RAS program are met. The tool that is used for pre-processing the data in ArcMap is made by the United States Army Corps of Engineers (USACE), just as HEC-RAS and is called HEC GEO-RAS. HEC GEO-RAS is a tool that is helpful for building layers in the ArcMap environment that can be imported in HEC-RAS with ease. The different aspects of pre-processing the data and how the data is gathered is displayed in the following paragraphs.

**Digital Elevation Model**
A Digital Elevation Model (DEM) is a model that stores data on heights and location. A DEM is a 3D representation of a surface that can be used for many different applications. In the case of the Water system analysis, the data that the DEM contains can for example give information on the depth of a river or the heights of the banks.

HEC-RAS uses digital elevation models to gather information on the bathymetry and land heights surrounding the river and uses this data to determine the way that a river flows or floods. A DEM is a prerequisite for the HEC-RAS velocity and stream (centre) lines features to work and is therefore essential for building the hydrological model.

The digital elevation model that is used for building the hydrologic model is a model that is gathered from the United States Geological Survey (USGS) Earth Explorer tool (USGS, 2000). There was not much data available for the Cần Thơ region therefore the Shuttle radar Topography mission (SRTM) data is used. Nasa did a worldwide survey in 2000 that took 11 days in which NASA captured a 30-meter digital elevation model of almost the whole world. The data gathered on this NASA mission is measured with a 30 by 30 grid which means that the height data is not precise and therefore is not very reliable. Because this data also does not contain the river bottom the digital elevation model is only used as a base height and for location awareness.

The SRTM data is projected in the 'WGS_CGS_1984' coordinate system that had to be altered because the SRTM data contained only degree data and was not projected in meters. HEC-RAS uses another coordinate system, 'NAD_1983_StatePlane_California_III_FIPS_0403_Meter', in order to start building the model a new coordinate system had to be found in which both different coordinated systems could be transformed in. Eventually the 'WGS_1984_ARC_System_Zone_01' had been chosen because this projected coordinate system was compatible with both the 'WGS_CGS_1984' and the 'NAD_1983_StatePlane_California_III_FIPS_0403_Meter' coordinates systems and the measurement units are in meters.

**Centre- and bank-lines and flow paths**

After adding the DEM to the ArcMap with the HEC GEO-RAS environment the boundaries of the river have been defined. The boundaries of the river are defined with three different line types that can be created with the HEC GEO-RAS toolbox. When the different layers have been created, the ArcMap draw toolbox can be used to draw the lines. The following layers with the following lines are created:

- Centreline
  The centreline tells the HEC-RAS program which rivers or tributaries there are that are connected to the main river branch. In the case of the model that is built for the Sông Cần Thơ only the main river is built because of a lack of cross-sectional data of the side branches that is needed as a prerequisite about the different branches of the Sông Cần Thơ.
- Bank lines
  Bank lines are used to define the banks of a river and the boundaries of the river. For the model created for the Sông Cần Thơ the bank lines have been created on both the right and left embankment.
- Flow paths
  The flow paths that are used for creating the model give information on what the flow direction is of the river. HEC-RAS uses three different flow path types (Channel, Right and Left side of the river). The flow paths are first drawn and afterwards have been assigned with the correct flow path type.

**XS cut lines**

The last part of pre-processing the data so it can be imported consists of creating XS cut lines (cross sections) which can be created for a certain interval to which a certain width of the cut lines can be defined. The XS cut lines that will be created are made 3D by combining the XS cutline data with the DEM file, this results in a 3D path of the river. For this research the 'create XS cut lines' feature of the HEC-RAS toolbox is not used, but the XS cut lines have been created manually. In total there have been made 4 XS cut lines that are in line with the river data that has been provided by professor Van Tri

**HEC-RAS**

After pre-processing the data using ArcMap and the HEC GEO-RAS toolbox the data can be exported to a .RAS file. The .RAS file can then be imported in HEC-RAS for building a model. The following paragraphs describe how the model is built after pre-processing the data.

**Changing geometry**

The DEM file is made from a satellite images and therefore the water in the river is a flat service, but in order to create a model of the river, the bottom of the river has to be added to the geometry of the river. Because the cross sections are created from the XS cut lines the cross sections contain the height as given by the DEM that the height information is created from.

To create a representation of the river bottom underneath the flat surface of what was water in the created XS cut lines made during the pre-processing in ArcMap and HEC GEO-RAS. The bathymetry of the Sông Cần Thơ that was provided by professor Van Tri is used to create a geometry of the river that is more representative for Sông Cần Thơ. The bathymetry data that was provided by professor Van Tri consisted of 5 cross sections of which 4 are used for building the model because one was not located in the research area. The 4 cross sections that are used during the built of the model are shown in Figure 23.

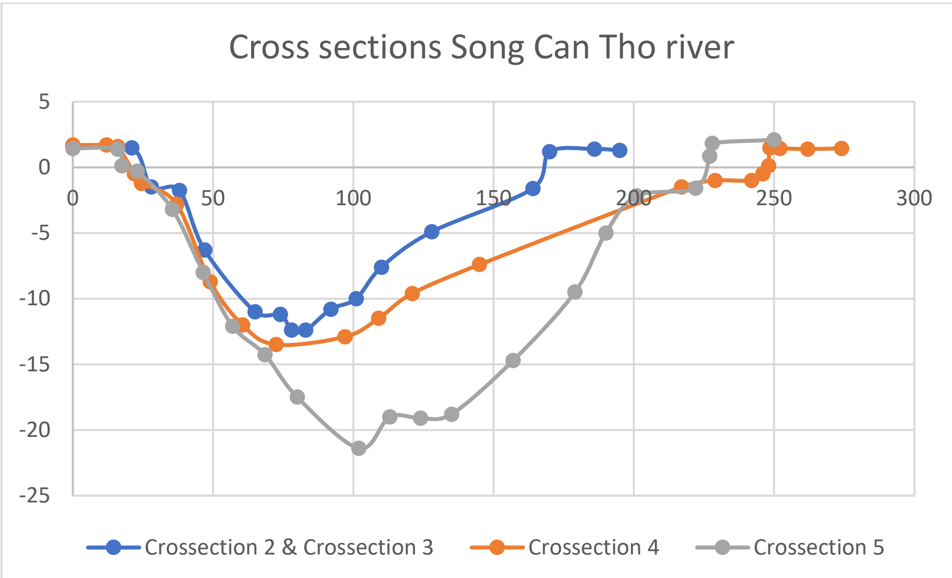



*Figure 23 Cross sections of the Sông Cần Thơ (Professor Van Tri, 2019)*

**Interpolation**

The lack of bathymetry information on the Sông Cần Thơ river causes gaps in the rivers geometry and therefore is not enough to build a model for determining the water stream flow in the Sông Cần Thơ. Because there is not enough bathymetry data to create a sufficient representation of the river geometry an interpolation is made using the HEC-RAS interpolation tool to fill the gaps between the altered cross sections. The HEC-RAS interpolation tool works by calculating the difference between two known cross sections within a reach (river branch) and changing the shape gradually. By interpolating the known cross sections of Sông Cần Thơ, a 3D surface is built which can be used to perform calculations on with the HEC-RAS steady flow analysis tool.

**Roughness coefficients**

The roughness of the sides of a river effect the velocity of water in a river and therefore roughness coefficients are added to the model to create a representable model. HEC-RAS defines a cross section into three different parts where three different roughness coefficients can be filled in for. The three roughness coefficients are for the following three parts of a cross sections:

- Left bank
- Channel
- Right bank

Because the Sông Cần Thơ river does not contain any flood banks, therefore it is only affected by the roughness coefficient of the Channel. The Roughness coefficients used in HEC-RAS expressed in Manning's N values and the determination on the value that is used are based on the reference table for Manning's N values for channels as shown in Table 4. For the roughness of the Sông Cần Thơ is a value of 0.040 chosen because the river doesn't consist of a stony river bottom but has pools and shoals, this assumption was provided by professor Van Tri.

*Table 4 Reference table for Manning's N values (Chow, 1959)*

| Type of Channel and description | Minimum | Normal | Maximum |
|---|---|---|---|
| 1. Main channel | | | |
| A. Clean, straight, full stage, no rifts or deep pools | 0.025 | 0.030 | 0.033 |
| B. Same as above, but more stones and weeds | 0.030 | 0.035 | 0.040 |
| C. Clean, winding, some pools and shoals | 0.033 | 0.040 | 0.045 |
| D. Same as above, but some weeds and stones | 0.035 | 0.045 | 0.050 |
| E. Same as above, lower stages, more ineffective slopes and sections | 0.040 | 0.048 | 0.050 |
| F. Same as "D" with more stones | 0.045 | 0.050 | 0.060 |
| G. Sluggish reaches, weedy, deep pools | 0.050 | 0.070 | 0.080 |
| H. Very weedy reaches, deep pool, or floodways with heavy stand of timber and underbrush. | 0.075 | 0.1 | 0.150 |

**Steady flow analysis**

After pre-processing and adjusting the input for the model, HEC-RAS needs information on the water that is in the river. The pre-processing, the adjustments that where made on the rivers geometry and the adding of the river's roughness coefficients consist of information about the river that can be seen as information about a river without water in it. The last step in building the model is giving information on the water in the river.  The final information that is needed to create the model in HEC-RAS consists of the rivers discharge and water levels.

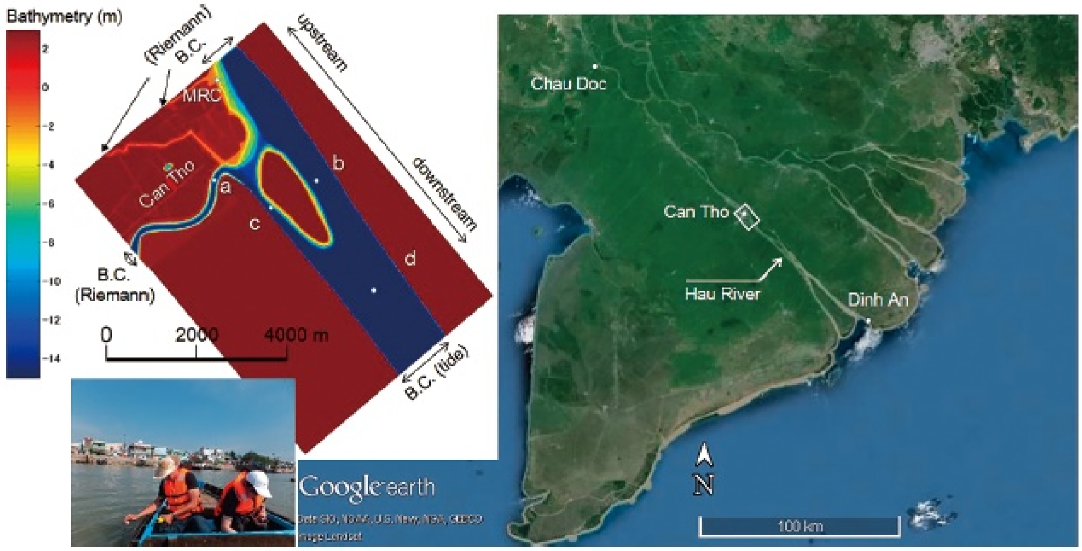



*Figure 24 locations of water velocity measurements (Takagi, Le Tuan, & Nguyen Danh, 2016)*

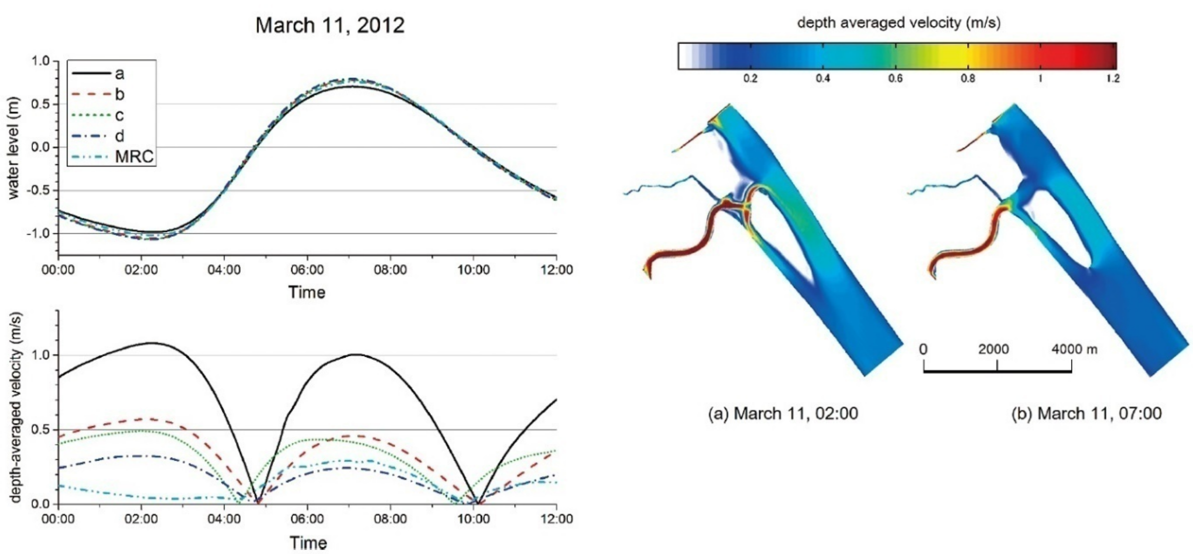



*Figure 25 Results of water velocity measurements (Takagi, Le Tuan, & Nguyen Danh, 2016)*

**Discharge**

The discharge of the river is calculated from information that is given through two different sources. The first sources were the cross-section information as provided by professor Van Tri. And the second source was a research that was conducted to model the urban flood risk as a result of ocean tidal waves. The area of cross section 5 is used and the average water speed as shown in Figure 25 to calculate the discharge of the Sông Cần Thơ.

# Appendix 2 – Development of the tracking devices

In this appendix the development of the tracking devices will be explained. The tracking devices are used to measure plastic streams in the Sông Cần Thơ and therefore needs to collect and store location data that can be used to visualize the way that plastic flows through a river.

To track plastic in the Sông Cần Thơ river a device needs to be developed that can float on or near the surface just as plastic does. The tracking device needs to gather location information and this data is used to visualize the route that the plastic has travelled over the time of a measurement in the Sông Cần Thơ river.

To gather information on plastic streams in the Sông Cần Thơ river a tracking device is built. The building of this tracking device consisted of two phases:

- Building the tracking device
- Coding the tracking device

In this chapter the design and the different choices that are made during the development of the tracking device are explained.

**Tracking device**
The Tracking device has to record data. The term for a device that gathers data is a datalogger. In essence a datalogger is an electronic device that records data. Dataloggers can be built in many different ways and can fulfil different purposes. A datalogger can for example be used to measure air or water quality. A datalogger is built with a motherboard, which is the ‘brains’ of the datalogger. The motherboard is a sort of computer that makes the calculations of different sensors that can be attached to the motherboard. A datalogger is in fact a small computer that measures conditions of the attached sensors that measure real time states of reality.

**Satellite navigation**
A satellite navigation system consists of a network that is formed by multiple satellites that float across the medium orbit of the earth, also known as a constellation. Using these different floating satellites an autonomous geo-spatial position can be determined. Satellite navigation works by emitting radio signals which allows small electronic receivers to determine a location (longitude, latitude and altitude). The radio signals that are send by the satellites, send time data to a receiver when the receiver and the satellite are in a clear line of sight of each other.

An electronic device that is fitted with a receiver is able to track the position of the electronic device and therefore collect data on the whereabouts of the device. The electronic device can also provide the current local time of the electronic device with high precision by calculations.

There are currently two global navigation satellite systems (GNSS) available that have worldwide coverage.
The two GNSS that can be used to track a device worldwide are:

- Global Positioning System (GPS)
- GLObal Navigation Satellite System (GLONASS)

**Satellites**
The GPS concept is based on time and the known position of GPS specialized satellites. The satellites carry very stable atomic clocks that are synchronized with one another and with the ground clocks. Any drift from time maintained on the ground is corrected daily. In the same manner, the satellite locations are known with great precision. GPS receivers have clocks as well but they are less stable and less precise.

Each GPS satellite continuously transmits a radio signal containing the current time and data about its positions. Since the speed of radio waves is constant and independent of the satellite speed, the time delay between when the satellite transmits a signal and the receiver receives it, is proportional to the distance from the satellite to the receiver. A GPS receiver monitors multiple satellites and solves equations to determine the precise position of the receiver and its deviation from true time. At a minimum, four satellites must be in view of the receiver for it to compute four unknown quantities (three position coordinates and clock deviation from satellite time).

**GPS**
The global positioning System (GPS) is a GNSS that was fully operationalized for the public in 1994 and is therefore the oldest worldwide covering positioning system. GPS uses 24 satellites that operate at 6 different orbital planes at an altitude of 20.180 kilometre form the earth's surface. Each satellite sends out continuous radio signals which contains three to four codes and a navigation message. Each satellite sends a different coded message, this is called a Pseudo Random Noise (PRN) code. GPS was originally built for military purposes and eventually became available for the public. Nowadays the U.S. military still uses GPS and therefore there are two grades of GPS location precisions. The Precise Positioning Service (PPS) is till used by the military and the Standard Positioning Service (SPS) can be used by civilians.

**Tracking device 1: GPS datalogger**

The following paragraphs consist of the different design and improvement stages of building the first tracking device, a GPS datalogger. Before building and gathering the components for the datalogger that can measure plastic streams in a river, requirements have been drafted of the aspects that the datalogger has to possess:

- Robust and small design;
- Energy efficient but powerful GPS antenna;
- The ability to timestamp the data that is gathered by the GPS antenna;
- A SD Card slot needs to be on the GPS datalogger to save the collected GPS data;
- LED light indicators that show when the device is on, the device is writing on the SD Card and when the GPS datalogger has a consistently good connection with satellites.

**Robust and small design**
There are two options when it comes to building a GPS datalogger. The building of a datalogger can be done by placing all the components on a perf-board (perforated prototyping board) and wire wrapping the wires into the designated holes on the perf-board, as shown in Figure 26 it is visible that the wiring

that is used for these prototyping boards fits loosely in the prototyping holes. A problem occurs when the wires are touched because they can come lose but to fix this a wire wrapping technique can be used to broaden the wire at the bottom of the prototyping board. If the wires are broadened at the bottom of the perfboard the wires would not come lose as easily.

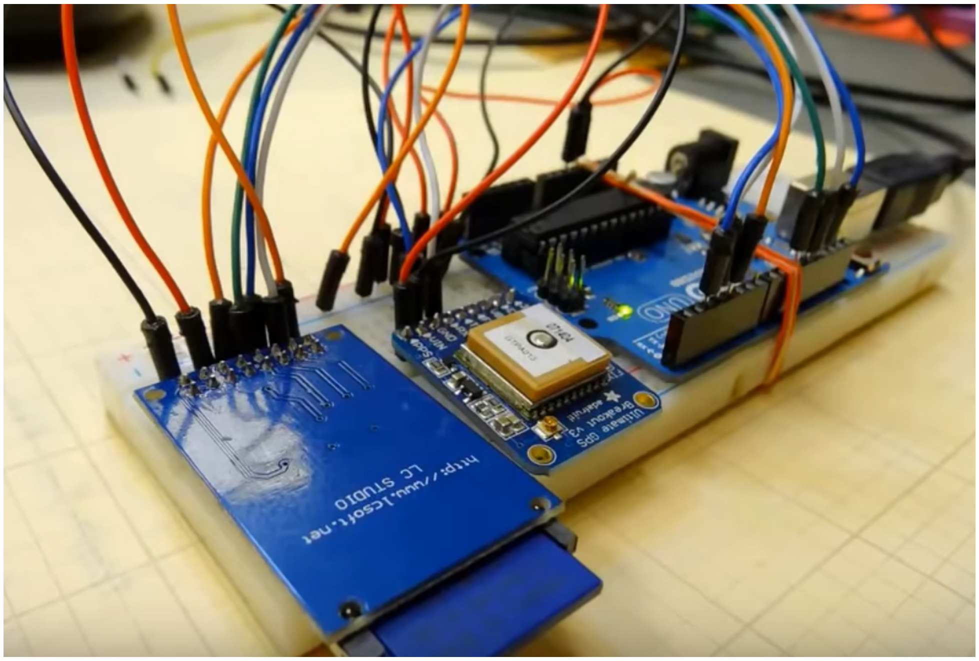



*Figure 26 Perfboard with wire rapping*

Another option for building a datalogger is to use a shield that fits on a motherboard of choice. A shield has the advantage that everything can be soldered and they cannot easily be damaged or come lose. An example of a shield is shown in Figure 27, because as can see a shield clicks into the motherboard the size will reduce opposed to the prototyping board and the datalogger will become more robust.

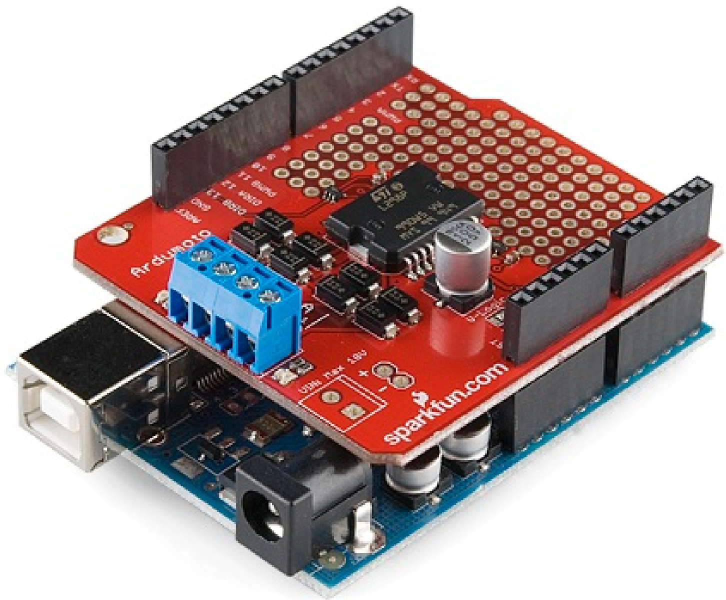



*Figure 27 Datalogger shield (Blom)*

The problem with wire wrapping is that when a wire comes loses no data is collected. This is a risk when measurements on the Sông Cần Thơ take very long, because you can only find out that the device was not measuring at the end of the measurement when you get the datalogger out of the water.

**Energy efficient but powerful GPS Antenna**
On the shield there is a GPS Antenna connected that can receive radio waves send by GPS Satellites. This information can be translated in a location, speed and altitude data. To measure these radio waves there is a wide variety of different GPS Antenna's available. Because the GPS datalogger must be small and robust the size of the GPS antenna needs to be small and energy efficient. The energy efficiency is important because the GPS datalogger may not be on an empty battery during a measurement in the Sông Cần Thơ. On the other side, the data collected by the GPS antenna has to be precise as possible.

The GPS antenna that has been chosen to fit the needs of the GPS datalogger the most is the MTK3339 produced by Adafruit. This GPS antenna is different from other manufacturers because of its ability to track 22 satellites on 66 different radio channels at the same time. The benefit of this GPS antenna is that it is Real Time Control (RTC) compatible which will be explained in the next paragraph. The GPS module is very power efficient and can be used with a 20mA on 3.3 volt which means it can run for about 10 hours on a 9 Volt battery which is widely available in stores and therefore it is accessible to buy new ones when there is doubt about the amount of power left in the battery.

**The ability to timestamp the data that is gathered by the GPS antenna**
The time between GPS radio waves and the time that it takes to process the GPS data is essential for a good location service. The ability of the GPS datalogger to measure these time differences is essential and this can be done by the GPS antenna. To enhance the time measurements of the GPS datalogger a module called Real Time Control (RTC) is necessary.

The RTC module that is installed on the GPS datalogger tracks the time on the specific moment that data is received on the GPS antenna and can therefore compensate the time it takes to process the data by the GPS antenna and use the time that is recorded by the RTC module. The RTC module is always on even when the device is off. When the device is turned on and the first GPS signal is received the time that is on the RTC module will adjust and this helps to get a better understanding of location. The time that is used by the RTC module is always UTC and therefore not the real time in Vietnam. The time real time in Vietnam is found by adding 7 hours to the UTC time.

**SD Card**

The GPS datalogger is outfitted with a SD card slot on which the data can be saved and to provide enough storage for the data that is collected. The GPS data takes up a small space but the risk of overwriting data results in reliability issues and therefore the SD card slot is important as a counter measure.

**Coding the tracking device**

After building the GPS Datalogger, the device has been coded in a way that all the different components work together to correctly store the data that is needed. During the development of the coding for the device, three different version of the code have been written (as shown in appendix 3). The following three versions are described on how they have been made but also what the following version has to offer to gather better information.

- Version 1
  Version 1 consisted of code that uses the GPS data that is gathered by the GPS antenna and save this on the SD card which is validated when 4 GPS satellites are connected to the GPS datalogger. The code writes the incoming GPS data in a file with raw NMEA sentences (which are explained in appendix 4) and also saves the parsed data in a separate file that contains information about the precision of the GPS data.
- Version 2
  Version 2 of the code is an improvement on the first code but shares similarities. The second file that previously is written on the SD card containing the precision of the GPS data that is gathered instead writes data that can be imported in Google Earth to visualize the findings from the GPS datalogger.
  The data that comes in through the GPS antenna contains longitude and latitude data but in order to display this data, the data has to be transformed and this is added in the code so that it is made easier to display data.
- Version 3 (final version)
  Version 3 is the final version of the coding that is provided to the GPS datalogger. The final version of the coding is enhanced so that the files that are written don't overwrite when a new measurement is started. The code makes new files and therefore data can be stored more easily. In version 3 of the code there is also some lines added that tell information about what the GPS datalogger is doing so that it can be checked when plugged in to a computer. These line of code that describe what the GPS datalogger is doing is a failsafe for measurements and show the user that a measurement is started properly.

While the newest version of the code prevented corruption of data a new problem occurred. Because the GPS antenna kept getting data, the ability to temporarily store the incoming data caused problems and therefore the data could not be validated properly.

The memory problem that occurred as a result of the overflow of the temporary memory of the Arduino was caused by a problem that is specific for the motherboard that has been chosen. The management of the memory of an Arduino consist of three pools:

1. Flash memory (program space): Memory that is used for storing the coding that is created.
2. SRAM (Static Random-Access Memory): Temporary memory for storing and manipulating data that is a result of the coding
3. EEPROM: Memory space that can be used for storing long term information such as constants.

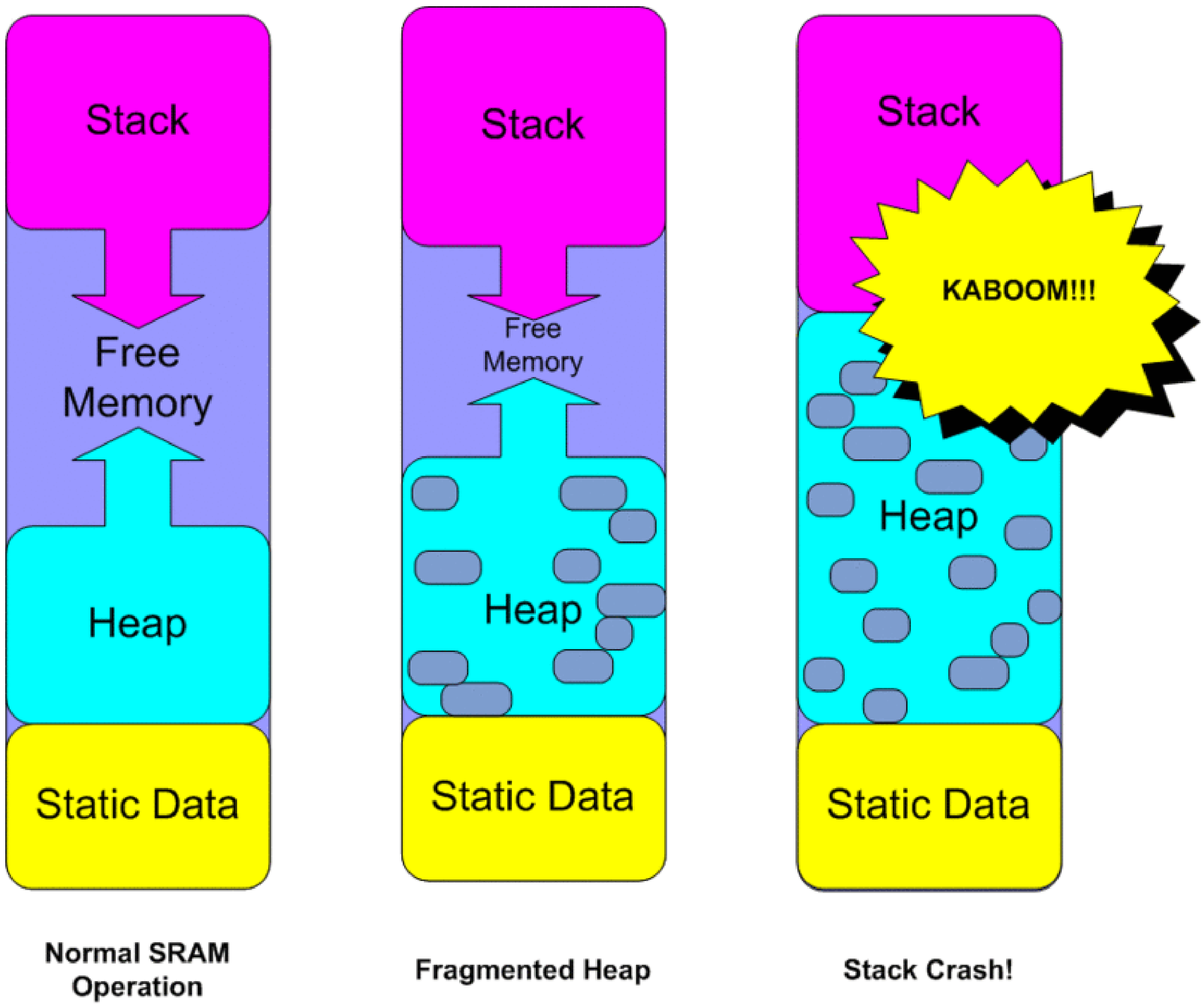



*Figure 28 Memory management issues (Adafruit, 2019)*

As shown in Figure 28 the GPS data flow that is triggered by the GPS antenna caused a problem with the heap of data that needed to be validated and therefore stability problems occurred. The memory of the used Arduino UNO is 2k (2048 bites) and the GPS Datalogger coding uses around 2000 bits to validate data. To save data to an SD card an additional 500 bites is needed to work stable. The memory problem is easily solvable by upgrading the Arduino UNO for a bigger model and by doing this upgrade the memory as well. For example, the Arduino Leonardo can be used which contains 2.5k (2560 bits) what would be sufficient but does not give a lot of room for improvement or enhancing the GPS Datalogger. The best solution to solve the memory problem is to upgrade to an Arduino MEGA which contains 8k (8192 bits) of memory which is far more than necessary but ensures the stability and the validation process of the incoming GPS data can be enhanced.

The stability of the GPS Datalogger was a problem but because this was at the time the only tracking device that had been developed and although problems might occur during a measurement the GPS datalogger is tried in the river one time. Unfortunately, the data was corrupted and could not be used. As a result of the test day two different tracking devices where developed.

**Tracking device 2: Phone with data logging capabilities**

The second method for tracking plastic in a river is built using an iPhone 7. The processing power and the built-in battery of a phone are ideal for tracking GPS data because the limitations of code are less than by the GPS datalogger.

The phone is outfitted with an application that stores and uploads GPS information in real-time to an online database. The application that has been chosen for developing GPS data logging on the phone is GPS tracks. There is a wide variety of apps that can be chosen but the GPS tracks app had some features that stood out. For example, the ability to back up data in real-time and exporting data immediately helps in processing and visualizing data afterwards.

Because GPS on a phone is not ideal for precision GPS position services a local SIM-Card is used in the phone to improve precision of the measurements.

**Tracking device 3: Development of an application for collecting visual findings on plastic stream**

The third method that was developed to gather information on the aspects that affect plastic streams in the river but also to gather information about when external factors influence the plastic stream. For example, when plastic gets stuck on the bank of a river the measurement of the previously mentioned tracking devices still continued but the data from when the plastic is moved to continue the measurement was lost and not visual in the previously mention tracking devices. To gather this information an Open Data Development Kit (ODK) is used to create a form that can be used to gather additional information on what happens to the plastic in the river but also can use location services to map plastic placement.

The form that has been created consists of 4 inputs, the inputs are the following:

1. What happens to the plastic?
2. Time and Date
3. Location
4. Photo

# Appendix 3 - GPS Datalogger Coding

**Version 1 of coding**

```
#include <Adafruit_GPS.h>
#include <SoftwareSerial.h>
SoftwareSerial mySerial(3, 2);
Adafruit_GPS GPS(&mySerial);

String NMEA1;
String NMEA2;
char c;

void setup()
{
  Serial.begin(115200);
  GPS.begin(9600);
  GPS.sendCommand("$PGCMD,33,0*6D");
  GPS.sendCommand(PMTK_SET_NMEA_OUTPUT_RMCGGA);
  GPS.sendCommand(PMTK_SET_NMEA_UPDATE_1HZ);
  delay(1000);
}


void loop()
{
readGPS();

}
void readGPS(){
  clearGPS();
  while(!GPS.newNMEAreceived()) {
  c=GPS.read();
  }
GPS.parse(GPS.lastNMEA());
NMEA1=GPS.lastNMEA();
while(!GPS.newNMEAreceived()) {
  c=GPS.read();
  }
GPS.parse(GPS.lastNMEA());
NMEA2=GPS.lastNMEA();
  Serial.println(NMEA1);
  Serial.println(NMEA2);
  Serial.println("");
}
void clearGPS() {
while(!GPS.newNMEAreceived()) {
  c=GPS.read();
  }
GPS.parse(GPS.lastNMEA());
while(!GPS.newNMEAreceived()) {
  c=GPS.read();
  }
GPS.parse(GPS.lastNMEA());

}
```

**Version 2 of coding**

```
#include <SD.h>
#include<SPI.h>

#include <Adafruit_GPS.h>
#include <SoftwareSerial.h>
SoftwareSerial mySerial(8,7);
Adafruit_GPS GPS(&mySerial);

String NMEA1;
String NMEA2;
char c;
float deg;
float degWhole;
float degDec;

int chipSelect = 10;
File mySensorData;


void setup() {

  Serial.begin(115200);
  GPS.begin(9600);
  GPS.sendCommand("$PGCMD,33,0*6D");
  GPS.sendCommand(PMTK_SET_NMEA_OUTPUT_RMCGGA);
  GPS.sendCommand(PMTK_SET_NMEA_UPDATE_1HZ);
  delay(1000);

  pinMode(10, OUTPUT);
  SD.begin(chipSelect);

  if (SD.exists("NMEA.txt")) {
    SD.remove("NMEA.txt");
  }
  if (SD.exists("GPSData.txt")) {
    SD.remove("GPSData.txt");
  }

}

void loop() {

  readGPS();

  if(GPS.fix==1) {
  mySensorData = SD.open("NMEA.txt", FILE_WRITE);
  mySensorData.println(NMEA1);
  mySensorData.println(NMEA2);
  mySensorData.close();


  mySensorData = SD.open("GPSData.txt", FILE_WRITE);

  degWhole=float(int(GPS.longitude/100));
  degDec = (GPS.longitude - degWhole*100)/60;
```

```
  degWhole=float(int(GPS.longitude/100));
  degDec = (GPS.longitude - degWhole*100)/60;
  deg = degWhole + degDec;
  if (GPS.lon=='W') {
    deg= (-1)*deg;
  }
  mySensorData.print(deg,4);
  mySensorData.print(",");

  degWhole=float(int(GPS.latitude/100));
  degDec = (GPS.latitude - degWhole*100)/60;
  deg = degWhole + degDec;
  if (GPS.lat=='S') {
    deg= (-1)*deg;
  }
  mySensorData.print(deg,4);
  mySensorData.print(",");

  mySensorData.print(GPS.altitude);
  mySensorData.print(" ");

  mySensorData.close();
  }

}

void readGPS() {

  clearGPS();
  while(!GPS.newNMEAreceived()) {
    c=GPS.read();
  }
  GPS.parse(GPS.lastNMEA());
  NMEA1=GPS.lastNMEA();

   while(!GPS.newNMEAreceived()) {
    c=GPS.read();
  }
  GPS.parse(GPS.lastNMEA());
  NMEA2=GPS.lastNMEA();

  Serial.println(NMEA1);
  Serial.println(NMEA2);
  Serial.println("");

}

void clearGPS() {
  while(!GPS.newNMEAreceived()) {
    c=GPS.read();
  }
  GPS.parse(GPS.lastNMEA());

  while(!GPS.newNMEAreceived()) {
    c=GPS.read();
  }
  GPS.parse(GPS.lastNMEA());
```

```
    while(!GPS.newNMEAreceived()) {
      c=GPS.read();
    }
   GPS.parse(GPS.lastNMEA());

}
```

**Version 3 of coding (Final version)**

```
#include <SPI.h>
#include <Adafruit_GPS.h>
#include <SoftwareSerial.h>
#include <SD.h>
#include <avr/sleep.h>

SoftwareSerial mySerial(8, 7);
Adafruit_GPS GPS(&mySerial);


#define GPSECHO  false
#define LOG_FIXONLY true

#define chipSelect 10
#define ledPin 13

File logfile;


void setup() {
  Serial.begin(115200);
  Serial.println("\r\GPS Datalogger by M.R.Genet");
  pinMode(ledPin, OUTPUT);
  pinMode(10, OUTPUT);

  if (!SD.begin(chipSelect)) {
    Serial.println("Card init. failed!");
  }
  char filename[15];
  strcpy(filename, "GPSLOG00.TXT");
  for (uint8_t i = 0; i < 100; i++) {
    filename[6] = '0' + i/10;
    filename[7] = '0' + i%10;
    if (! SD.exists(filename)) {
      break;
    }
  }

  logfile = SD.open(filename, FILE_WRITE);
  if( ! logfile ) {
    Serial.print("Couldnt create ");
    Serial.println(filename);
  }
  Serial.print("Writing to ");
  Serial.println(filename);

  GPS.begin(9600);
  GPS.sendCommand(PMTK_SET_NMEA_OUTPUT_RMCGGA);
  GPS.sendCommand(PMTK_SET_NMEA_UPDATE_1HZ);
  GPS.sendCommand(PGCMD_NOANTENNA);

  Serial.println("Ready!");
}
```

```
void loop() {
  if (! usingInterrupt) {
    char c = GPS.read();
    if (GPSECHO)
      if (c) Serial.print(c);
  }

  if (GPS.newNMEAreceived()) {
    char *stringptr = GPS.lastNMEA();
    if (!GPS.parse(stringptr))
      return;

    Serial.println("OK");a
    if (LOG_FIXONLY && !GPS.fix) {
      Serial.print("No Fix");
      return;
    }
    Serial.println("Log");

    uint8_t stringsize = strlen(stringptr);
    if (stringsize != logfile.write((uint8_t *)stringptr, stringsize))
//write the string to the SD file
        error(4);
    if (strstr(stringptr, "RMC") || strstr(stringptr, "GGA"))   log-
file.flush();
    Serial.println();
  }
}
```

# Appendix 4 – Explanation of used NMEA protocols

The RMC protocol consists of one line of text. The line of text explains the following:

$GPRMC,061756.084,A,1046.2479,N,10641.6542,E,0.16,117.95,280819,,,A*6B

| | |
|---|---|
| $GPRMC | Recommended Minimum sentence C |
| 061756.084 | Fix[1] taken at 06:17:56.084 Coordinated Universal Time (UTC) |
| A | Status A = active or V = void |
| 1046.2479,N | Latitude 10 deg 46.2479' North |
| 10641.6542,E | Longitude 106 deg 41.6542' East |
| 0.16 | Speed over the ground in knots |
| 117.95 | Track angle in degrees true |
| 280819 | Date – 28th of august 2019 |

The GGA protocol consists of one line of text. The line of text explains the following:

$GPGGA,061758.000,1046.2480,N,10641.6546,E,1,03,8.13,1.8,M,2.5,M,,*43

| | |
|---|---|
| $GPGGA | Global Positioning System Fix Data |
| 061758.000 | Fix taken at 06:17:58 UTC |
| 1046.2480,N | Latitude 10 deg 46.248' North |
| 10641.6546,E | Longitude 106 deg 41.9546' East |
| 1 | Fix quality: 0 = invalid<br>1 = GPS fix<br>2 = Differential GPS fix |
| 03 | Number of satellites being tracked |
| 8.13 | Horizontal dilution of position |
| 1.8,M | Altitude, Meters, above sea level |
| 2.5,M | Height of geoid (mean sea level) above WGS84 ellipsoid |

[1] GPS fix = when GPS data is validated with a fix quality of 1 or 2

# Appendix 5 – Approved research proposal and permit

CÔNG TY TNHH
THƯƠNG MẠI & DỊCH VỤ
**KIM DELTA**

Số: 0319/KD
*V/v khảo sát dòng chảy của rác thải nhựa trên sông Cần Thơ*

**CỘNG HOÀ XÃ HỘI CHỦ NGHĨA VIỆT NAM**
**Độc lập - Tự do - Hạnh phúc**

*Cần Thơ, ngày 11 tháng 10 năm 2019*

SỞ NGOẠI VỤ TP. CẦN THƠ
ĐẾN Số: 471
Ngày: 11/10/19
Chuyển:
Lưu hồ sơ số:

*Kính gửi:*

- Sở Ngoại vụ Thành phố Cần Thơ;
- Sở Giao thông Vận tải Thành phố Cần Thơ;
- Ủy ban nhân dân quận Ninh Kiều;

Với mong muốn góp phần vào việc làm giảm lượng rác thải nhựa trên sông Cần Thơ, công ty TNHH Thương mại & Dịch vụ Kim Delta có hợp tác với trường Đại học Khoa học Ứng dụng Van Hall Larenstein (Hà Lan) thực hiện một khảo sát nhỏ về dòng chảy của rác thải nhựa trên sông Cần Thơ, làm cơ sở cho việc xác định vị trí tối ưu để lắp đặt thiết bị bắt rác trên sông về sau này.

Để thực hiện khảo sát, chúng tôi sẽ đưa 1 máy ghi dữ liệu GPS vào trong chai nhựa 1 lít và thả trên sông. Máy ghi dữ liệu GPS sẽ lấy tọa độ những điểm mà nó trôi qua và biểu diễn trên bản đồ Google.

Dự kiến nhóm thực hiện khảo sát gồm có:

1. ThS. Nguyễn Kim Thanh – Chuyên viên tư vấn cao cấp của Công ty TNHH Thương mại & Dịch vụ Kim Delta
2. Lucas Arjan van Casand – Sinh viên của trường Đại học Khoa học Ứng dụng Van Hall Larenstein.

Dự kiến thời gian khảo sát: kể từ ngày được sự phê duyệt của các Quý Cơ quan đến ngày 15 tháng 11 năm 2019.

Địa điểm thực hiện khảo sát: Khu đất ở đường Trần Ngọc Quế, quận Ninh Kiều, thành phố Cần Thơ, dọc bờ sông Cần Thơ, thuộc sở hữu của Công ty Cổ phần Nông nghiệp Công nghệ cao Trung An (Khu vực cạnh Viện dưỡng lão tại 22 Trần Ngọc Quế). Nhóm thực hiện đã liên hệ với lãnh đạo Công ty và đã được chấp thuận tiến hành khảo sát.

Chi tiết thực hiện: nhóm sẽ thuê một người địa phương có xuồng chèo. Người này sẽ chèo xuồng ra điểm bắt đầu, thả chai có GPS xuống nước, chèo xuồng theo sau thiết bị cho đến điểm cuối (lộ trình dự kiến như trong hình đính kèm).

Công ty TNHH Thương mại và Dịch vụ Kim Delta kính đề nghị Sở Ngoại vụ, Sở Giao thông Vận tải, Ủy ban nhân dân quận Ninh Kiều và Đoạn Quản lý đường thủy nội địa 12 xem xét và chấp thuận cho hoạt động này.

Công văn phúc đáp xin vui lòng gửi đến Văn phòng Công ty TNHH Thương mại và Dịch vụ Kim Delta theo địa chỉ: 162/34/20B Trần Quang Diệu, phường An Thới, quận Bình Thủy, thành phố Cần Thơ; hoặc email: thanh@kimdelta.org.

Trong quá trình xem xét, nếu có bất kỳ thắc mắc nào, Quý Cơ quan vui lòng email hoặc liên lạc với đại diện nhóm khảo sát là bà Nguyễn Kim Thanh theo số điện thoại: 0913771208.

Rất mong Quý Cơ quan tạo điều kiện để chúng tôi có thể hoàn thành khảo sát đúng tiến độ.

Trân trọng./.

**CTY TNHH THƯƠNG MẠI & DỊCH VỤ KIM DELTA**

Giám đốc

M.S.D.N: 1801103841 - C.T.T.N.H.H
CÔNG TY TNHH THƯƠNG MẠI & DỊCH VỤ KIM DELTA
Q. BÌNH THỦY - TP. CẦN THƠ

**Nhan Tuyết Trinh**

***Hồ sơ đính kèm:***

- Bản sao Giấy chứng nhận ĐKKD Cty TNHH Thương mại & Dịch vụ Kim Delta
- Bản sao hộ chiếu sinh viên Hà Lan

***Nơi nhận:***

- Như trên;
- Lưu: văn thư.

Hình 1: dự kiến đường đi của chai nhựa mang GPS

Người ký: Sở Ngoại vụ thành phố Cần Thơ
Email: songoaivu@cantho.gov.vn
Thời gian ký: 22.10.2019 16:27:02 +07:00

UBND THÀNH PHỐ CẦN THƠ
**SỞ NGOẠI VỤ**

**CỘNG HÒA XÃ HỘI CHỦ NGHĨA VIỆT NAM**
**Độc lập – Tự do – Hạnh phúc**

Số: 1676 /SNgV-HTQT
V/v chuyên gia nước ngoài đến tham quan và làm việc tại địa phương

*Cần Thơ, ngày 22 tháng 10 năm 2019*

Kính gửi:
- Công ty TNHH TMDV Kim Delta;
- Ủy ban nhân dân quận Ninh Kiều;
- Công an thành phố (PA01, PA03).

Căn cứ Quy chế quản lý thống nhất các hoạt động đối ngoại trên địa bàn thành phố Cần Thơ ban hành kèm theo Quyết định số 1274-QĐ/TU ngày 31 tháng 8 năm 2018 của Thành ủy Cần Thơ, Công văn số 0319/KD ngày 11 tháng 10 năm 2019 của Công ty TNHH TMDV Kim Delta về việc xin phép cho sinh viên nước ngoài thuộc trường Đại học Khoa học Ứng dụng Van Hall Larenstein (Hà Lan) đến thực hiện khảo sát, tại địa phương. Cụ thể:

+ *Thời gian:* **từ ngày 23/10/2019 đến ngày 15/11/2019.**

+ *Nội dung và địa điểm:* thông tin chi tiết thể hiện trên Công văn số 0319/KD ngày 11 tháng 10 năm 2019 của Công ty TNHH TMDV Kim Delta.

+ *Thành phần người nước ngoài*: Anh Lucas Arjan van Casand, quốc tịch: Hà Lan, số hộ chiếu: NW17DLJ39.

- Về nguyên tắc, Sở Ngoại vụ thống nhất việc Công ty TNHH TMDV Kim Delta hướng dẫn sinh viên nước ngoài đến thực hiện khảo sát tại địa phương. Đề nghị Công ty TNHH TMDV Kim Delta phối hợp với cơ quan, đơn vị có liên quan quản lý chặt chẽ hoạt động của khách nước ngoài đúng nội dung, mục đích và thời gian đã đề nghị tại Công văn nêu trên; kịp thời thông tin cho Công an thành phố, Sở Ngoại vụ nếu phát hiện mọi hoạt động ngoài phạm vi, mục đích đã đề nghị. Đồng thời, phối hợp với Ủy ban nhân dân quận Ninh Kiều trong việc đảm bảo an ninh, an toàn cho khách theo đúng quy định hiện hành.

- Sở Ngoại vụ xin thông tin đến Ủy ban nhân dân quận Ninh Kiều để phối hợp quản lý. Trân trọng./.

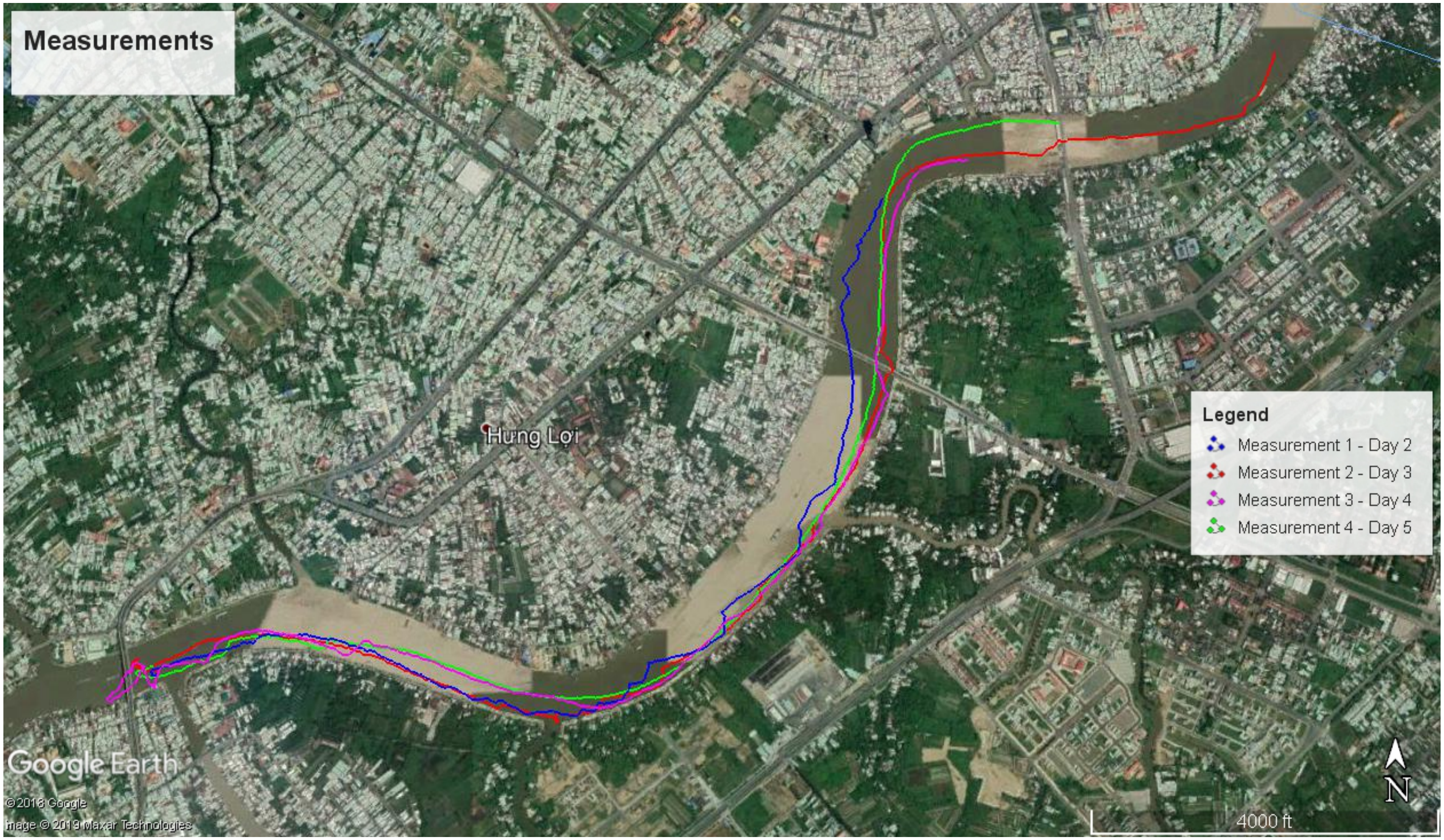
***Nơi nhận:***
- Như trên;
- Sở GTVT (đ/b);
- Sở TN&MT (đ/b);
- G/đ (để b/c);
- Lưu: VT, TY.

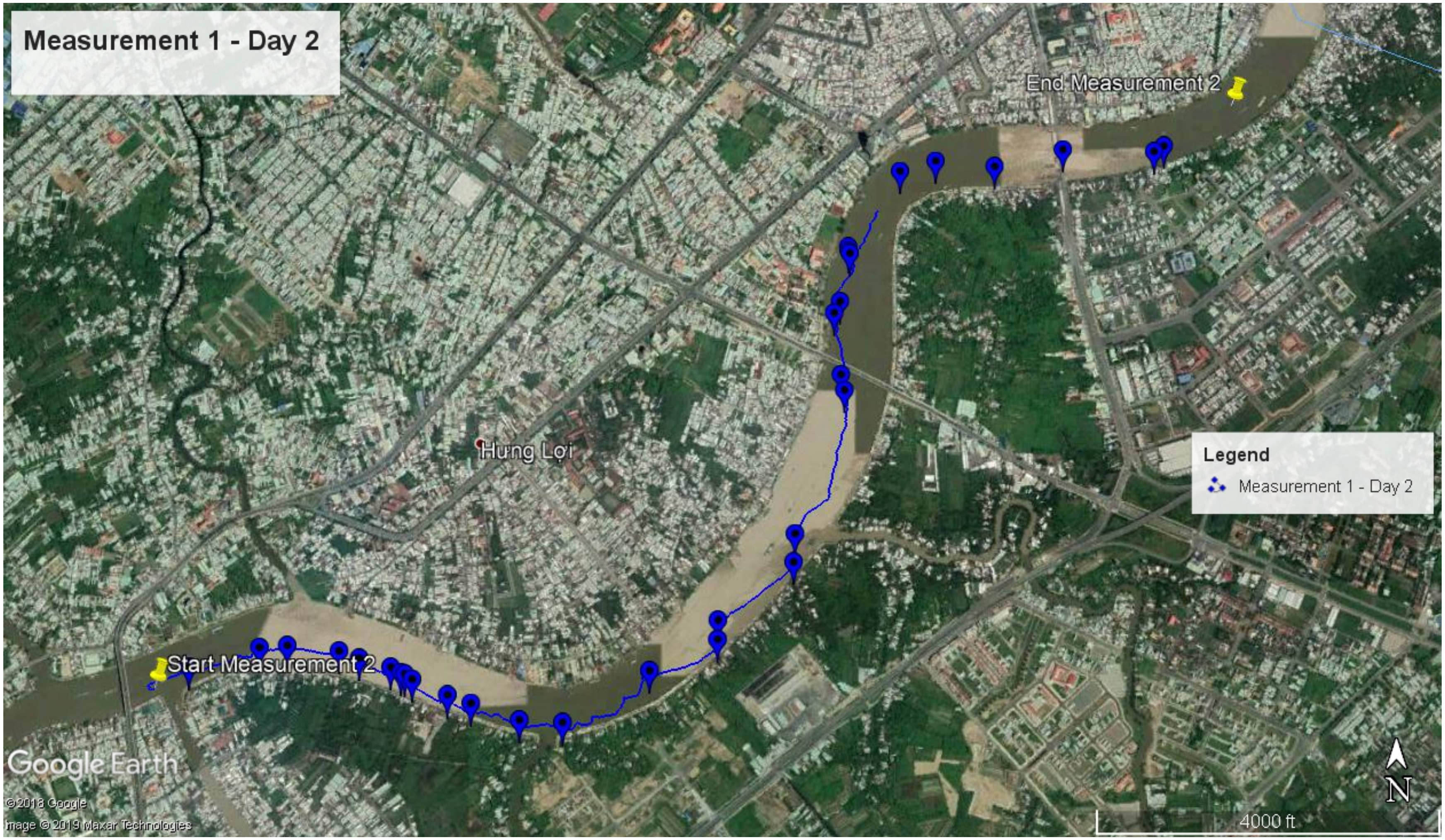
**KT. GIÁM ĐỐC**
**PHÓ GIÁM ĐỐC**

SỞ NGOẠI VỤ
CỘNG HÒA XÃ HỘI CHỦ NGHĨA VIỆT NAM
THÀNH PHỐ CẦN THƠ

**Mai Văn Phùng**

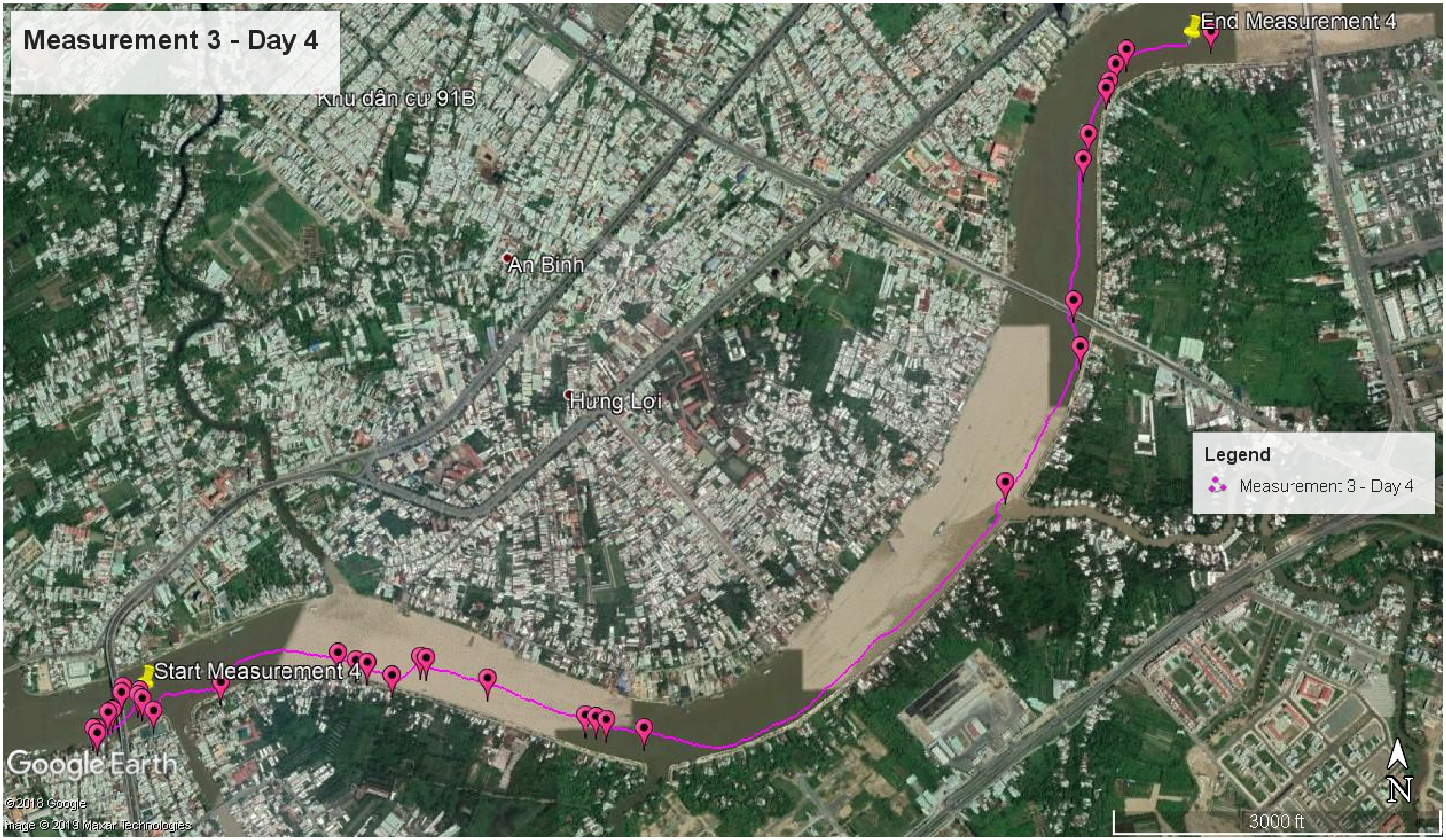
# Appendix 6 - Results plastic flow measurement





Measurement 1 - Day 2
End Measurement 2
Start Measurement 2
Hưng Lợi
Legend
Measurement 1 - Day 2
Google Earth
©2018 Google
Image © 2019 Maxar Technologies
4000 ft
N

Measurement 2 - Day 3
End Measurement 3
Hưng Lợi
Legend
Measurement 2 - Day 3
Start Measurement 3
Google Earth
© 2018 Google
Image © 2019 Maxar Technologies
4000 ft
N



Measurement 3 - Day 4
Khu dân cư 91B
An Bình
Hưng Lợi
Start Measurement 4
End Measurement 4
Legend
Measurement 3 - Day 4
Google Earth
© 2018 Google
Image © 2019 Maxar Technologies
3000 ft
N

Measurement 4 - Day 5
End Measurement 5
Hưng Lợi
Legend
Measurement 4 - Day 5
Start Measurement 5
Google Earth
© 2018 Google
Image © 2019 Maxar Technologies
4000 ft
N