Flash floods in Cebu: monitoring, modelling and preventing

Additional thesis

N.J. Hoogendoorn
M.B.L.M. Kasteel

Delft University of Technology

Additional thesis

Flash floods in Cebu: monitoring, modelling and preventing

by
N.J. Hoogendoorn
M.B.L.M. Kasteel

November 2022

An additional thesis submitted to the Delft University of Technology in partial fulfillment for the degree of
Master of Science
in Civil Engineering specialised in Water Management.

N.J. Hoogendoorn
M.B.L.M. Kasteel: *Flash floods in Cebu: monitoring, modelling and preventing* (2022)

The work in this thesis was carried out in the: Water Resources Center in the University of San Carlos in Cebu City, Philippines

Supervisors: Ir. W.M.J. Luxemburg
Dr. Ir. O.A.C. Hoes

Preface

”Flash floods in Cebu: monitoring, modelling and preventing”. This is the work of two civil engineering master students in Water Management at Delft University of Technology. This work has been made for their additional thesis in collaboration with the Water Resources Center (WRC) from the University of San Carlos in Cebu city. WRC is an apolitical water consulting foundation that aims to make the water resources in Cebu accessible, reliable and sustainable to the community, government units and businesses.

We would like to thank our supervisor, Ir. W.M.J. Luxemburg, which made together with Ir. Maria Nenita Jumao-as our whole participation for this project possible and gave us valuable advice throughout the project. We are also very thankful to our second supervisor, Dr. Ir. O.A.C. Hoes, who guided us in the making of the model and gave us very useful feedback. Then we would also like to thank the whole amazing office at WRC (especially Sherman Maga, Julius Anthony Daclan, Emmanuel Nicholas James Labuen, Marcelino Palanas) who were an amazing help for our research project. Also we would like to mention the special assistance we got throughout the whole project from two last year civil engineering bachelor students of the San Carlos University of Cebu, Mary Dominique Oñate and Ma. Urlricke Pilapil.

We want to thank M. van der Doelen with his Bachelor thesis “Flash flood attenuation”. His great work has been useful to clarify the key factors of gabion dams in attenuating floods.

Last but not least, this project has been made possible thanks to grants of different funds. These funds were FAST TU Delft (”Funding Ambitious STudents”), Delft Global Initiative and Students4Sustainability. Because of the generosity of these funds we were able to actually go the Philippines and leave the measuring materials behind, this way the the research could be pursued after we left.

Abstract

Flash floods are a damaging and recurring problem in Cebu city, Philippines. Very little data is known about the intensities and precipitation amounts and the resulting river discharges. This research project firstly aims to gather as much data as possible on precipitation and river discharges that could cause the floods, it focuses on a small catchment in the city called the Mahiga catchment. Data is gathered by installing three tipping buckets and two trail cameras. The cameras were able to calculate the river discharges using an innovative open-source program called OpenRiverCam. Thanks to this program a hydrograph can be made of the river for each precipitation event. The used cameras were trail cameras of the Brand Bushnell. During this project it was concluded that, due to their unreliability, using trail cameras with OpenRiverCam is really not recommended. Security cameras with a Raspberry Pi are more suited. Due to bad luck with the weather and faulty material only three different hydrographs could be made during our time abroad (10 weeks). These hydrographs however remained useful for the second part of this research project.
The second part consists of modelling the discharge of the Mahiga catchment to different precipitation amounts using HEC-RAS. HEC-RAS is a computer program meaning Hydrologic Engineering Center's River Analysis System. The model has been calibrated using the gathered precipitation data from the tipping buckets and the discharge results from OpenRiverCam. Graphs have been made about discharges and accumulated volumes and rating curves. The accuracy of the model is reasonable but should be improved using more discharge events. What stood out was the high infiltration rate and the fast response time of the Mahiga catchment. In section three, the results from the HEC-RAS model are used to understand the impact gabion dams make on reducing the peak flow in the Mahiga creek.
The third part summarises the effectiveness of the gabion dams in preventing flash floods. Unfortunately there is no 'real' flash flood event captured by the tipping buckets, so three precipitation events are used based on analog measurements of a tipping bucket nearby the catchment. The gabion dams are tested on a maximum precipitation intensity of 35 mm/h, 30 mm/h and 25 mm/h with a total amount of 40 mm. Higher amounts of total precipitation are realistic, but have a larger time duration and are not considered flash floods anymore. The volume that gabion dams can retain is too little for these large amounts of precipitation and are therefore not in the scope of this report. The results show that with at least five gabion dams, the peak flow reduces for all above mentioned precipitation intensities, but for the 35 mm/h it is getting less effective. The model also showed that the effectiveness is very dependent on the volume that can be retained by the dams. Maintenance of the gabion dams is therefore of crucial importance especially with the large amount of sediments and debris in the creek.

Contents

List of Figures

1. Introduction

1.1. Background

In the Philippines, flash floods are a continuous problem. The tropical climate with extreme rainfall intensities, together with the typhoons, causes a sudden increase in the rivers which is hard to control. In the rainy season, this sudden increases causes floods and landslides in the villages and cities. According to I.Harris et al. [2020] the risks from floods are exacerbated by change in land use such as urbanization and logging. In the City of Cebu this is an urgent problem and the municipality therefore wants to attenuate these floods and the flood peaks. A common way to reduce the flood and the flood peaks is applying gabion dams. Gabion dams are made of a mesh weir 'baskets' with stones in them. They are a good value for money and are a typical solution applied in several rivers in the Philippines. Before the municipality will invest in the gabion dams it is important to know the effectiveness of the gabion dams and the municipality consulted the Water Resources Center for that.
In 1994, the Water Resources Center worked already on a joint project together with the Belgian Government about the use of gabion dams. From their report [Water-Resources-Center, 1994] a couple of conclusions can be used. Firstly, gabion dams are very effective in trapping sediments. Already after one rainy season it will be full and has to be cleaned. However, the Belgian report did believe in the will and power of the local community to clean the gabion dams from sediments when this is done under proper guidance. By selling, the sediments to construction companies it becomes profitable for the community to dig it out. Secondly, according to the report, the gabion dams have a negligible impact on the control of large floods because they cannot retain large amounts of water. But for this research, gabion dams are not designed to reduce the large floods. Instead they will be used to reduce flash floods, which have a much smaller return period compared to large floods, but still cause nuisance in the city.

1.2. Problem analysis

At the moment of writing this thesis (August 2022), the city of Cebu is planning to install gabion dams in several different catchments. Except that very little research has been done about the efficiency of the dams in the specific context of the catchments in Cebu. Additionally, little to no data is known about precipitation, discharge and catchment characteristics in the specific area. Installing water-retaining construction without adequate prior research can lead to a very limited efficiency, and thus a substantial waste of money. This research paper aims to quantify the reduction of flash floods using gabion dams by modeling them in a small test catchment, namely the Mahiga catchment.
The first part of the research project is to gather as much data as possible about the precipitation amount and intensities, discharge of the rivers, topography, river cross-sections

and slopes. Multiple fieldwork were done to gather this information in the Mahiga catchment. The second part consists of modeling gabion dams in the Mahiga catchment using the program HEC-RAS.

1.3. Research question

The goal of the study is to determine and quantify the efficiency of gabion dams in the Mahiga creek in Cebu city, the Philippines. The main research question of this thesis is: *"Do gabion dams have an impact in attenuating flash floods in the Mahiga catchment?"*. Specifically, the objective is to model the effect in HEC-RAS using self-acquired discharge and precipitation data of the Mahiga catchment. The main research question will be answered based on the answers from the following sub questions:
- *How can the discharge be determined of the river using trail cameras?*
- *How does the discharge in the Mahiga catchment react to different kinds of precipitation intensities?*

1.4. Structure

In chapter 2 the Mahiga catchment and precipitation information are studied and described. With this information three locations have been chosen to install three tipping buckets which is explained in chapter 3. Additionally an extensive explanation is given about the choice of the cameras, the location, the installation process and the collection of data. With the video recordings from the cameras, the discharge can be calculated. This has been done in chapter 4 using the open-source computer program called OpenRiverCam. By combining this discharge information with the gained collected data from the tipping buckets, different hydrographs can be made. These hydrographs are used to calibrate the model in HEC-RAS and this model is than used to determine the effectiveness of five gabion dams. Lastly, the conclusions and recommendations for further research are given in chapter 5 and 6.

2. Study site

2.1. Cebu

Cebu is an island located in the central Visayas, it has a long, thin and elongated shape with mountains in the middle ranging from the north to the south of the whole island. The capital of the island is Cebu city, one of the most populated city in the Philippines with around 1 million inhabitants. Due to its elongated shape and big topographical differences is Cebu in general more prone to intense and fast variations in precipitations. The city of Cebu is at the east coast and it also lays at the foot of the mountain, this again is a reason why the city has intenser precipitations. Cebu City can be divided into different catchments as illustrated in figure 2.1. For the scope of this project, only the Mahiga sub-catchment will be studied. More information about this catchment will follow in section 2.2.

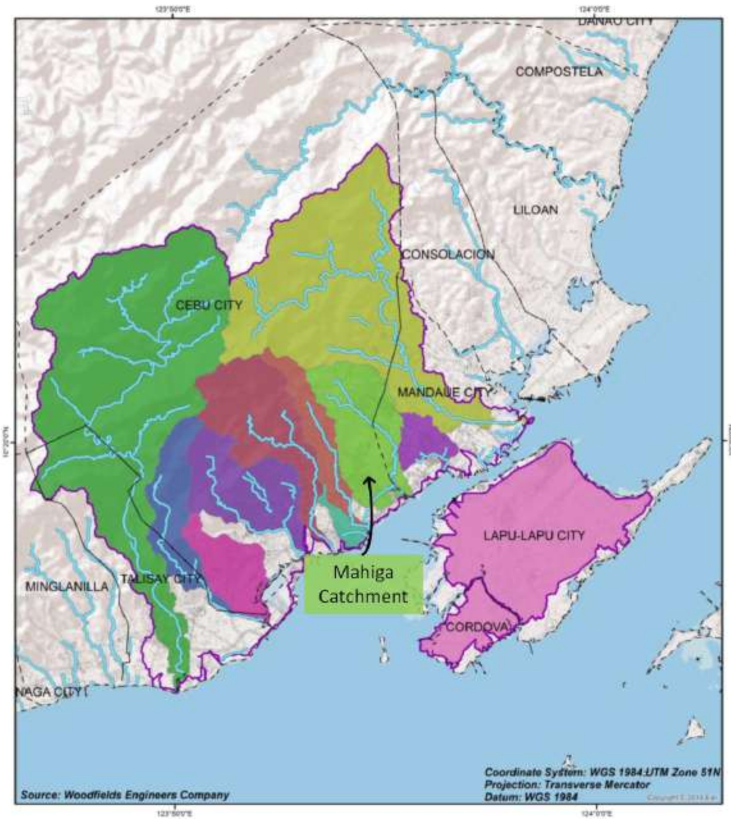


Figure 2.1.: Different catchments in Cebu City

2.1.1. Frequency analysis

The Water Resources Center (WRC) is located at the campus of the University of San Carlos and records in Talamban, since 1999, the daily precipitation above their office. This information is very useful to get an idea on the amount of precipitation at the study site, which is close to the WRC (1.5 kilometers). For unknown reasons no data was recorded from 2004 to 2010 and sometimes there is missing data of a couple of months during a year. But in general there is approximately 12 years of data available about daily precipitation above the WRC as seen in figure 2.2. Using this data, a precipitation probability curve has been made in figure 2.3. This curves shows the probability of the amount of rain that will fall in a day when there is a precipitation event.

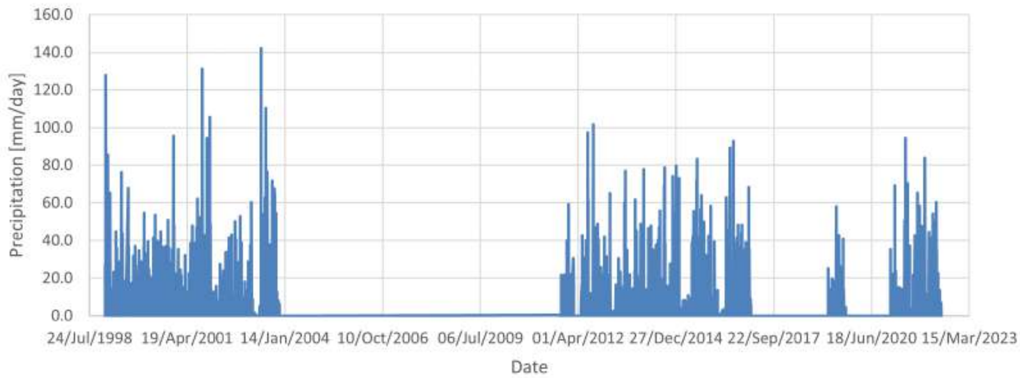


Figure 2.2.: Data abouty the daily precipitation above WRC

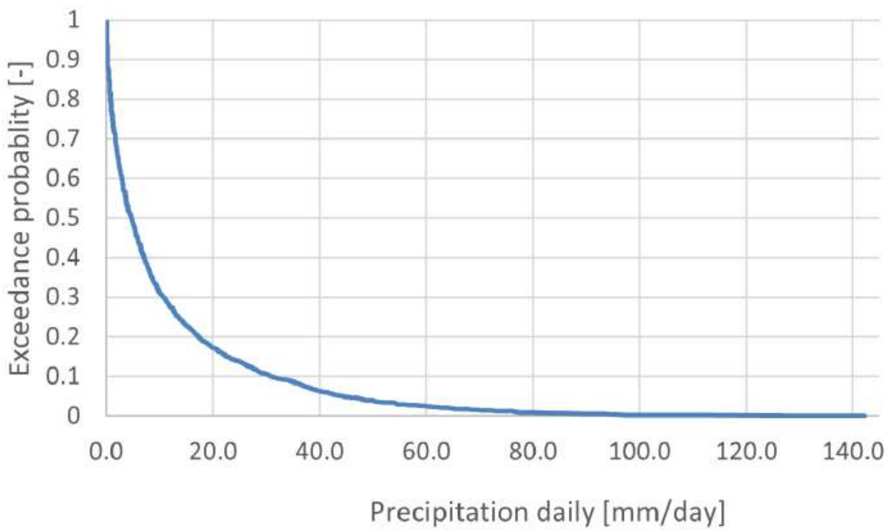


Figure 2.3.: Data about the daily precipitation above WRC

Frequency analysis are very useful for the design of dams. The objective of a frequency analysis is to obtain information on how often a precipitation event with a certain intensity occurs. The data of figure 2.2 has been processed and from there a frequency analysis was made. This has been done by firstly dividing the daily precipitation into classes of 10 mm/period. Then for each class, the number of times that an event is greater or equal to the precipitation depth of the bottom of the class is computed. Next the average rate of occurrence r (1/year) is calculated, note that it is not equal to probability of occurrence. The frequency scale (i.e., return period) is equal to T = 1/r. A plot is made in figure 2.4 where the precipitation amount is associated with its return period. Note that the x-axis is in log scale. A trend line has also been made, this is going to be useful for subsection 2.1.2. It is also possible to calculate the probability of having a certain number of events exceeding an amount of precipitation by using the Poisson distribution below.

$P(c\, events\, in\, interval\, t) = exp(-rt) * \frac{((rt)^c)}{c!}$

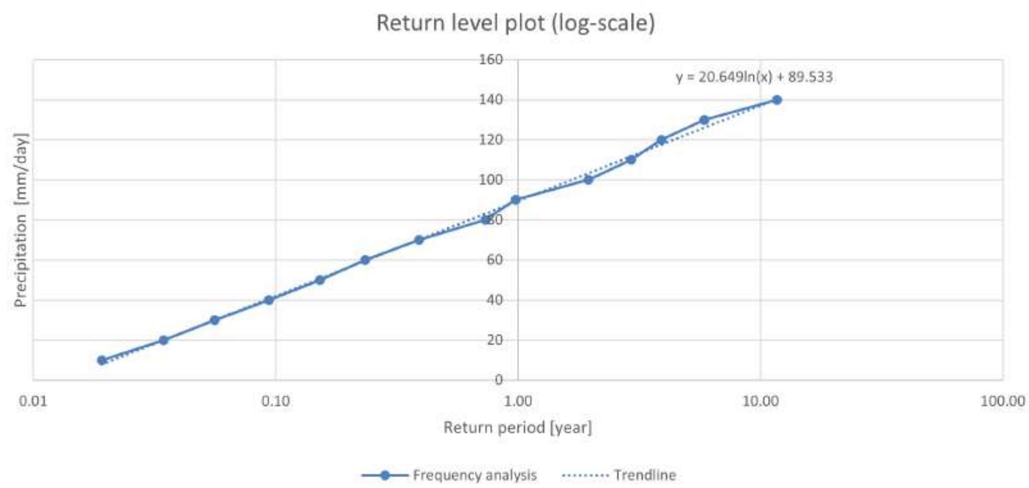


Figure 2.4.: Frequency analysis

2.1.2. Extreme value analysis

With a frequency analysis it is difficult to estimate the intensity of events that have a longer return period compared to the period of observation. In order to get more reliable estimates of extremes with higher return periods, an extreme value analysis can be made. In the case of flash floods, it is only interesting to look at precipitations amounts with a return period shorter than 1 year. So an extreme value analysis for flash floods is not useful. However, it remains interesting to look at the results because it gives a nice indication of the type of rains that can be expected in the city of Cebu on the bigger scale.

In general there are two main methods: Block Maxima (BM), where the block is usually taken as 1 year and the Metastatistical Extreme Value (MEV) method, which uses all rainy days in a block to infer block maxima. In the BM method there is the Gumbel and GEV manner. Note that in all methods it is assumed that the observed values belong to a statistical distribution. Additionally there is the full series method, this uses a trendline in the frequency analysis to extrapolate the return periods. Explaining every method in depth goes beyond the scope of the research project. A lot of research can be found about these methods. In conclusion, if the return period is shorter than the length of the observation series (approximately 12 years) it is be better to rely on the full series result. It is not recommended to use the GEV method for a return period larger than twice the observation series (so for max T = 24 years). But in these period GEV is a better data fitter, MEV on the other hand, is more smooth and has an MEV error = 20% for very large return periods and outperforms GEV for larger return periods.

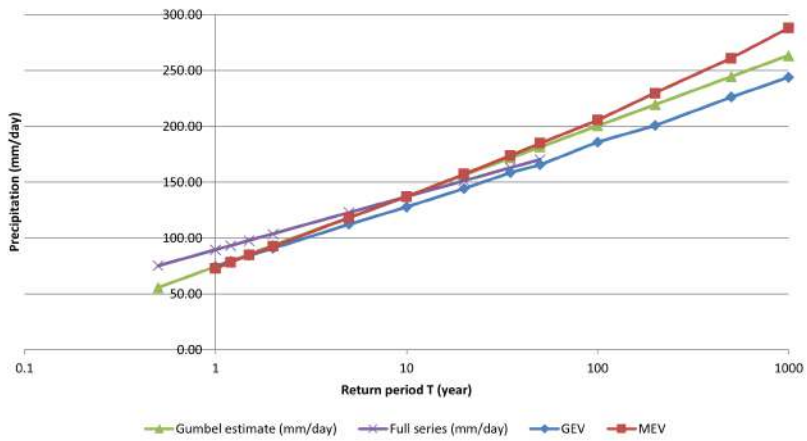


Figure 2.5.: Extreme value analysis

2.2. The Mahiga catchment

Upstream of Cebu City there is a mountainous area called ”Busay”. In the Busay area there are several creeks flowing into Cebu City, namely the Guadalupe, the Bulacao, the Kinalumsan and the Mahiga creek. The height above sea level at the top of the catchment is around 700 meter and has a relatively steep slope before entering Cebu City. In Cebu City itself the slope is very moderate. The precipitation that falls upstream in the catchment is flowing very fast into the city. As earlier mentioned this research will focus on the (upstream part of the) Mahiga creek, because the municipality has plans to build the gabion dams in this creek. The catchment of the Mahiga creek is also known as the Subangdaku catchment and is shown in figure 2.1.

The area of the Mahiga catchment is around 17.3 square kilometers, with a maximum height of around 350 meter and the tops are mostly rounded. Around 75 percent of the Mahiga catchment lays in the densely populated downstream part of Cebu City. Attenuation of the floods with gabion dams is therefore almost only possible in the upstream part of the Mahiga catchment. The upstream part consists of two main creeks. The branch on the west-side is always dry when there is no precipitation and the branch on the east-side has a very small constant discharge of around 0.011 m^3/s. The creek on the west-side will be called sub-creek 1 and creek on the east-side sub-creek 2. Sub-creek 1 has a length of around 1.700 kilometer and is currently more urbanized than sub-creek 2. The length of sub-creek 2 is around 2.2 kilometers and the width varies between 3 meters and 6 meters but is assumed to be 4 meters as a simplification for further calculations.

3. Materials and methods

3.1. Materials

3.1.1. Tipping buckets

Very few information about the precipitation amounts and intensities for Cebu City is publicly available. This is why three tipping buckets were brought from the Netherlands. They were lent by the Water Management department in the Civil engineering faculty of Delft University of Technology. The tipping buckets are the Onset HOBO Rain Gauge Data Logger RG3-M with a bucket size of 2mm, an example is shown in figure 3.1.

Figure 3.1.: Onset HOBO Rain Gauge Data Logger RG3-M

Location tipping buckets

Specific factors about the precipitation should be stated. The precipitation can be extreme locally, suddenly and intensely. This realisation happened when a very local and heavy rain was observed for the first time as seen in the figure in appendix A.1. This heavy rainfall was happening over a diameter of around 0.5km. These kind of super local rains are common here in the Philippines. Tipping buckets are only point measurements and the locality of the rainfall makes it hard to assume that the best estimation of the precipitation in the surrounding area is represented by the point measurement of the tipping bucket. Realising that the type of rains are very different here compared to Europe had a big importance on the strategic location of the tipping buckets in the catchment. Secondly, an important factor of influence for the location of the tipping buckets are the obstructions. It is common in the Philippines that the rain can be carried by the wind and falls almost horizontally (it is so common that it even has a name: ”salibo”). This is why it is extremely important that around the tipping buckets there are zero obstructions (e.g. trees, houses,...) that could hinder the rain. Lastly, another factor of influence for the location are the authorisations and safety of the equipment. It is always required to have written authorisation of the leader of the barangay (a barangay means ”an inner-city neighborhood”) before placing the tipping bucket in the area. The leader will then inform the local community of the benefits of the tipping bucket and this will greatly reduce the probability of vandalism.

Rain gauge 1

The first tipping bucket is installed close to the location where later the cameras are installed. Knowing at which exact moment precipitation fell above the cameras is useful because it gives a good indication which camera recordings are interesting for calculating the discharges. The first tipping bucket is installed on the roof of the house of the leader of the barangay, so the tipping bucket is very safe. A sturdy, very nice, custom-made support for the tipping bucket has been made by the WRC and can be observed in figure 3.2. The tipping buckets is at an altitude of 70 meters.

(a) Overview

(b) Set-up

Figure 3.2.: Rain gauge 1

Rain gauge 2

The second tipping bucket is installed in the gated-community of the elite population of Cebu called Maria Luisa. A special authorisation had to be requested to install the tipping bucket because it is not allowed to enter the neighborhood without permission. The tipping bucket is installed on a fence in the upstream part of the neighborhood. Some branches had to be cut down to clear any obstructions. The tipping buckets is at an altitude of 170 meters.

(a) Overview

(b) Set-up

Figure 3.3.: Rain gauge 2

Rain gauge 3

The third tipping bucket is installed on the most upstream part of the catchment. It is installed on the top of a big water storage tank. The tipping bucket is mounted on a concrete mold which is cemented to the tank to avoid someone of stealing it. The tipping buckets is at an altitude of 233 meters.

(a) Overview

(b) Set-up

Figure 3.4.: Rain gauge 3

Overview locations tipping buckets

The tipping buckets are allocated in a triangle so that most of the precipitation in the catchment is measured. The locations also have the advantage of distinguishing the two subcatchments from each other.

Figure 3.5.: Location of material (Google Earth Pro)

3.1.2. Camera choice

Cameras are used to estimate the discharges in the Mahiga creek. This is done using a open-source computer program called OpenRiverCam developed by Rainbow Sensing, this program is described in depth in the chapter 4.1. In this chapter an extensive explanation is given about the requirements, the choice of the camera, the location, the installation process and the collection of data. The cameras will make movie recordings to calculate the velocity of the water and this will be used to calculate the river discharge.

OpenRiverCam requires, to yield good results, that movies should last 5 seconds at a 1080p resolution and make at least 25 or 30 frames per second at 5 Mbps. The cameras should be able to turn on automatically, shot a video of 5 seconds and then turn off again. This should be repeated with a given time interval between 5 to 15 minutes depending on the intensities of the rain at the location. Ideally these cameras should also be able to shoot videos during the night or low light conditions, because during the floods the available light is often very low due to the thick clouds. An infrared night vision will do the job. The camera should also be weatherproof. An extra requirement in the case of the Mahiga creek is that the cameras should not be dependant of any power source due to the remoteness of the area.
The type of cameras that answer to all these requirements are trail cameras (cameras used

by hunters). They are usually placed in the remote part of the forests to monitor the animal population and turn on by a motion sensor. The problem is that monitoring a river using a motion sensor triggers the camera only in two scenarios: all the time or never. It depends if the camera considers the flow of water as movement but in either case it is not applicable for discharge measurement. Because if it films all the time the storage will be full very fast, the batteries will drain empty and the camera will overheat because it is not designed to film continuously all day long. So it requires a monitoring schedule where the camera turns on for around 10 seconds following a specific interval disregarding the motion sensor. This monitoring schedule is called a **field scan** or a plot scan.

First choice: Bushnell Nature view HD #119739

After a discussion with Rainbow Sensing it was decided to purchase two cameras from the brand Bushnell with the model number 119739. These cameras were bought beforehand in the Netherlands, the price of one Bushnell HD camera is 213 euro + 1 SD card of 32 GB of 29 euros. On paper the Bushnell HD camera responds to all the practical requirements (battery life, night vision, automated scheduled video making) except one; the video quality. Unfortunately during testing of the camera in the Philippines it was observed that the camera quality was only 720p instead of 1080p. This exact model should not have been bought. This was a mistake due to a misunderstanding and confusion. The camera is sold as making HD videos, which was true when the cameras were first sold in 2015. Except that today 720p is not classified as HD anymore, the reseller of the camera omitted to mention that it was 720p and a camera dating from 2015. We would have like to sent them back except that we were already in the Philippines, so it was unfortunately not possible. Luckily, the OpenRiverCam program can still function properly with 720p for small rivers which is the case of the Mahiga creek.

The two cameras were installed and up-and-running on the 25th of August 2020. Because of little rain and no flooding the cameras were checked one week later on the 2nd of September. Surprisingly and unfortunately on the 2nd of September it was observed that both cameras were not running. The cameras were immediately uninstalled and brought back to the office for further analysis. From there it was observed that camera 1 on the 29th of September at 05h00 started to make a video every minute twenty times and then at 05h20 shut down and did not turn on again. Same story for camera 2, on the 30th of September at 11h45 it made 20 videos in 20 minutes and at 12h05 shut down and did not turn again. By analysing the last videos made and seeing that no one touched the camera and the oddness of the problem for both scenarios, a vandalism scenario was completely excluded. The batteries were empty and there was still plenty of storage space available. At the office the cameras were reset and updated, batteries replaced and SD card formatted but it did not make any difference, the cameras did not turn on again. A hypothesis for the problem is that there was a software bug which lead the camera to make these 20 recordings in 20 minutes. Except that the camera is really not designed to handle this (the minimum interval for the field scan is one video every 5 minutes to avoid overheat). And this maybe led to overheating and caused a hardware problem and failure of the camera. Bushnell was contacted and they requested to send back the cameras, but this was only possible through the reseller in the Netherlands. This is why an alternative had to be found.

Figure 3.6.: Bushnell Nature view HD #119739

Second choice: Bushnell Core model #119938C

Because of this bad first experience with the brand Bushnell, it was decided to look for a different brand. Surprisingly, after a thorough market search, the only brand for trail cameras that offers the field scan option is the American brand Bushnell. This is why instead of trail cameras, the security camera option was studied. The security camera should be connected to a small computer e.g. a Raspberry Pi to that will be in charge of the scheduled interval recordings. Unfortunately due to a lack of time, expertise and preparation security cameras are not an viable option for this thesis. This brought the search back to square one, a trail camera from Bushnell. This camera will have to be ordered in the Philippines with the shortest delay possible. The best option in these condition was the Bushnell Core Model #119938C. It has a 1080p and 30fps quality and costed 225 euro per camera (incl. delivery and (big) import fees).

While testing the camera at the office of WRC, we came to the realisation that the field scan option of this camera only made pictures and no video recordings. Even though it is written black on white, multiple times in the user manual and the sellers website that it should also make videos in the field scan mode. After contacting the brand Bushnell (again), they confirmed that it was an error and that actually the camera and all the recent Bushnell trail cameras do not have the field scan video recording option anymore. This was a really bad surprise because the field scan video recording option was the main purpose for buying the Bushnell cameras. As an alternative to the field scan, the sensitivity of the motion sensor was put to the maximum. The hypothesis was that with the highest motion sensitivity, floating garbage in the river during rain events will trigger the camera and will still make useful video recordings. This hypothesis was tested multiple time during different rain events and it really did not work. The camera made a lot of recordings of animals (which is what the trail camera are initially designed for) but almost none of the river during precipitations. So in conclusion the Bushnell Core model #119938C (fig 3.7) was a waste of time and it was sent back and the money was reimbursed.

Figure 3.7.: Bushnell Core #119938C

Third choice: Bushnell Nature view HD #119739 During the delivery period the old Bushnell Nature view HD was brought to a local repair shop in the Cebu as back-up plan. Surprisingly the cameras were fixed which was fortunate because the Nature view HD #119739 actually did not work (as described above). This is why, ultimately, the Bushnell Nature view HD was used for the rest of the research project. But now for some unknown reason the camera batteries drained at an extreme rapid pace, in two days the eight AA batteries were completely empty. This is not normal and certainly not ideal but there was no other alternative than to replace the batteries every single time.

3.1.3. Camera locations

The Mahiga creek consists of two sub-creeks that come together in the main creek, as explained in 2.2. The left one is almost always dry. And the right one delivers a (very small) continuous flow of water, approximately 0.011 m^3. Putting a camera in the downstream part, at location 1, is a straightforward decision. The flow there will always be the highest. Also the influence of the upstream sub-rivers on the discharge and water level can be calculated. The second camera, upstream, has to be placed in either the west (sub-creek 1) or east part (sub-creek 2). Sub-creek 1 has, before converging with the sub-creek 2, a sudden height difference of approximately 2 meters as illustrated on figure 3.8. Because of this big height difference there will be no influence from the downstream river on sub-creek 1 (a backwater curve is avoided). This is why, at first, a location for the camera in sub-creek 1

was preferred, it also had a nice constant cross-section. When installing the camera, the following question was asked to different local people: ”How high does the water get here?”, they all answered that the water level could attain a height of about 1 to 1,5 meter in this river part. However, after the camera was installed and a couple of rainfalls with different intensities were recorded, it was observed that sub-creek 1 stayed completely dry. This was a big surprise. After discussing this matter with the local population it was concluded that this sub-creek actually remains completely dry except when there is an intense rain that lasts for the whole day or longer (when there is a typhoon). Even though, typhoons happens regularly here, the chance of experiencing one in the 2.5 month period is quite small. The reason why sub-creek 1 remains dry on the contrary to sub-creek 2, is that the soil is extremely porous and that the sub-catchment for this river part is much smaller. So a camera in location 2 is actually useless most of the time. Luckily this realisation was made quickly and no interesting data was lost (because the camera broke down before). This is why the the second camera was ultimately installed in location 3. The advantage with this location is that much more data can be obtained. The discharge should actually be the same as in location 1, except when there is a flow in the left sub-river, which is almost never the case. This is actually a good way to test the reliability and the consistency of the program OpenRiverCam and the cameras, because the discharge for both locations needs to be the same.
Finding the exact location of the camera depends on many different factors. Firstly, there is the **river characteristics aspect**; are there a lot of disturbances (bends, obstructions, narrowing,...) downstream or upstream of the camera location that could disturb the water velocities. During a flood, how high can the water level usually get and does the water overflow above the river banks. Secondly, there is the **practical aspect**; is the camera safe or can it be stolen or vandalised easily; can the camera catch the whole river cross section or does an extension need to be built; the camera needs to be installed at a certain height, how can this be done efficiently. Another important **practical aspect** is the data collection. The camera needs to be easily attainable to download the data from the SD card of the camera. This means that it is a bad idea to install the camera to a high pole without the ability to access the camera without moving it. Moving the angle of the camera in between rain events can alter the accuracy of the discharge calculations.
For every camera location a bathymetry of the river cross-section has to be made using a total station. It is recommended by OpenRiverCam that a coordinate is measured every 0.30m, also four control points have to be registered. A staff gauge has to be installed (ideally cemented this way it can resist the high discharges of the river) in the camera view.

Figure 3.8.: Mahiga creek camera locations

Installation camera Location 1

Finding the approximate area (depending of the river characteristics aspects) where the first camera was going to be installed went quite easily. A nice constant cross-section was found with vertical banks sides. The cross-section has a constant width of approximately 4 meters and a bank height of 1.8 meters. The water does not overflow even during typhoons. The exact location and installation of the camera (the practical aspect) was much more complicated and resulted from a lot of different trials and errors. The first challenge was with the first camera from section 3.1.2, this camera had a very limited recording angle. However the highest practical height the camera could be installed was approximately 5 meters. With this height not the whole width could be captured (about 80% of the width). The program OpenRiverCam program was still able to function but it did impact the accuracy of the measurements. However, after a week of recording the first camera from section 3.1.2 broke down. After studying the results of the first set-up it was concluded that the quantile uncertainty was too large. This is why it was decided to built a new set-up for the new camera of subsection 3.1.2 which guarantees the possibility of recording the whole cross-section. The new camera set-up is installed using a pole which is hanging above the river (see figure 4.4). The length of the post is determined so that the entire cross-section is captured and it still remains possible to replace the SD card from the camera without moving the camera.

(a) Overview river　　　(b) Set-up

Figure 3.9.: Camera location 1

Next the bathymetry was made using a total station. The river is 3.80 made and is relatively constant. The side banks are almost vertical, a coordinate was measured every 0.30 meters and some additional were made near the banks, so in total 17 coordinates were made. This resulted in the cross-section that can be seen in figure 3.10.

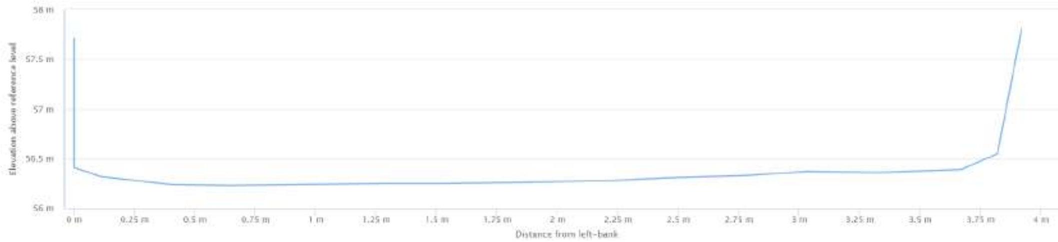


Figure 3.10.: Bathymetry location 1

Installation camera Location 3

As mentioned before, location 2 was not a good idea because the sub-river is always dry (or with a negligible flow) except during typhoons. This is why a new camera place was found in location 3. The river characteristics were good, it has a very constant cross-section. There is a small disturbance 20 meters below but assumed negligible. Because of the gained experience with the installation of the other cameras, the practical aspects were more easily taken care of. A pole with the camera was attached to a house relatively straightforward, as seen on figure 3.11.

(a) Overview river (b) Set-up

Figure 3.11.: Camera location 2

The cross-section of the location 3 is more narrow than the first location, around 2.40 meters wide. The horizontal slope between the banks is also more steep, which means that for low discharges the water only flows in the right part. The side banks again are almost vertical, a coordinate was measured every 0.30 meters and some additional were made near the banks, so in total 11 coordinates were measured. This resulted in the cross-section that can be seen in figure 3.12.

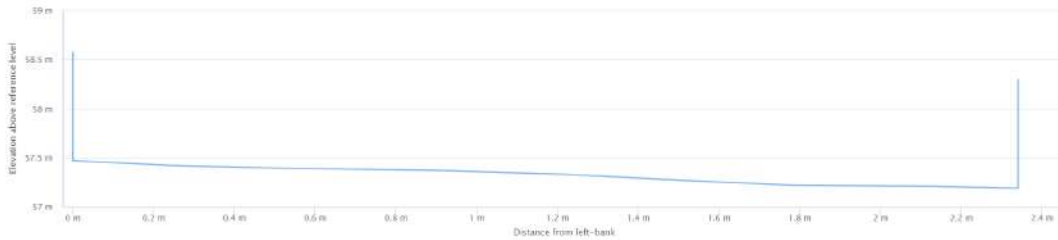


Figure 3.12.: Cross-section location 3

3.2. Methods

3.2.1. OpenRiverCam

OpenRiverCam is a professional software that enables river flow monitoring with cameras. This software is mainly developed by Rainbow Sensing and has been made fully free and open-source. The main feature of the software is that it is able to automatically convert movie shots into surface flow data. By measuring accurately the bathymetry and four reference points using a total station and combining it with the water depth and the calculated surface velocities of OpenRiverCam, the software is able to calculate the river discharge (with a quantile range). Additionally if enough videos (minimal 5) with different water heights are given it is automatically able to establish a rating curve.

3.2.2. Slope retention volume

A slope profile has been made of the whole right river part of the catchment using the topographical information of the Mahiga catchment with a 1mx1m accuracy. It can be seen in figure 3.13. The primarily function of a gabion dam is to retain water. This retention is important because of the slow release of water compared to the fast inflow during a intense precipitation which is causing a flash flood. The retention volume is therefore the main object of interest. Once the dam is full, water will simply flow over it and the gabion dams will have almost no further effect on the flow. From the study of the Cebu Belgian Gabion Dam Project it was concluded that gabion dams had very little impact on floods. But this was the case for floods with a large return period. For this research project, flash floods are studied, these have a much smaller return period of around 36.5 days, corresponding with precipitation of 40 mm/day. If gabion dams are installed strategically with a small slope and a wide width, the impact on reducing flash floods will be the greatest. In section 4.3 the retention volume of a gabion dam is calculated based on the slope and width.

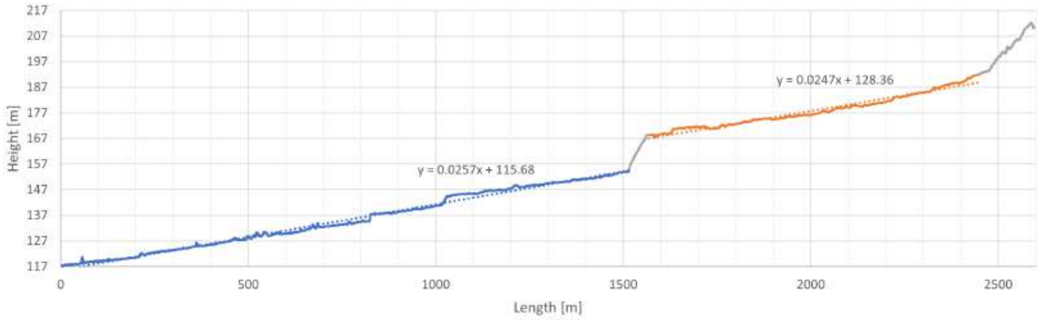


Figure 3.13.: Slope sub-creek 2

3.2.3. HEC-RAS

Previously, in [van der Doelen, 2022] SOBEK3 was used for modelling the effect of gabion dams in attenuating flash floods. However, for continuation of the project it is chosen to continue with HEC-RAS, because the WRC is more familiar with HEC-RAS. The model of M. van der Doelen is still used for understanding the key factors of the gabion dams. HEC-RAS, "Hydrologic Engineering Center's River Analysis System", is a program that can make, among others, flow calculations for a full network of natural and constructed channels. There are two options for calculating the flows: one-dimensional flow calculations and two-dimensional unsteady flow calculations [HEC-RAS, 2022]. The two-dimensional unsteady flow calculations are chosen because the performance is more accurate with hydraulic jumps, over-topping and rough terrains. The results of the calculations are clearly shown with the so called 'RAS MAPPER' function. The input variables of the HEC-RAS model consist of the geometric data, the precipitation/evaporation data, the catchment properties and the boundary conditions.

Geometric data

There is currently a program running in the Philippines, called the UP PHIL-LiDAR program, which produces "flood hazard maps for over 300 river basins in the Philippines reaching virtually a nationwide coverage to respond to the need of stakeholders to increase the level of information available towards disaster mitigation" [Program, 2022]. The University of San Carlos (CenGES) participates in this program and thanks to that, the Water Research Center was permitted to request these files. A digital elevation model (DEM) was obtained with an accuracy of one square meter. Unfortunately, the DEM could not be used immediately because of some minor issues. First of all, bridges were not taken into account. Secondly, there is a small lake/pond in the catchment. This pond does not store any extra water, except the infiltration water from the hill directly adjacent to it. To compensate for this, a big weir is made in HEC-RAS in front of this pond so that no water from the creek can enter the pond and vice versa. Water that would normally flow into the pond is still able to do so.

Precipitation/Evaporation

The measured precipitation from the installed tipping buckets are used as input variables, these are point measurements. In HEC-RAS the input for precipitation is a grid. Thiessen polygons are used to estimate the spatial distribution in the catchment to determine the precipitation grid from the point measurements. This approach is based on defining the area closer to a particular gauge than any other gauges and the assumption that the best estimation of rainfall on that area is represented by the point measurement at the gauge [K.C.Luk and J.E.Ball, 1997]. The main disadvantage for this approach is that with very local precipitation at the point measurements, the total amount of precipitation will be under- or overestimated.

Catchment properties

The main catchments properties that are used in this HEC-RAS model to determine the discharge are:
1. The creek roughness coefficient (Mannings'n value)
2. Imperviousness
3. Infiltration

1. The creek roughness coefficient:
Manning coefficient, is a coefficient for the roughness in the creek, among others determined by the vegetation, debris, the slope of the embankment and the creek bottom. The Mahiga creek is a mountain stream, where there is almost no vegetation in the channel. The embankments are usually steep and at bigger heights there are several trees and other vegetation. According to [n Values, 2006], the minimum, normal and maximum value are respectively 0.040, 0.050, 0.070 for these types of streams. The observed precipitation and discharge data from section 4.1 has a very fast response time (lagtime) of around 20 minutes, which indicates that the roughness coefficient is relatively small.

2. Imperviousness:
This is the percentage of impervious surface area. The Mahiga catchment has little residential area and is mainly a vegetated area. Concrete roads and roofs are the only obstacles in the catchment and therefore the total impervious area is estimated to be around 10 percent.

3. Infiltration:
There are different ways to classify the amount of runoff and infiltration in the catchment. The Deficit and Constant -, SCS Curve Number- and Green and Ampt loss model. The Deficit and Constant loss model has a maximum capacity to retain water. When this capacity is reached, water will start to runoff to the creek. Although much precipitation infiltrates in the Mahiga catchment, this classification method is not used because during flash floods, the precipitation rate exceeds the infiltration rate and the water will immediately runoff to the creek which results in a short lag-time. The Deficit and Constant loss model is not able to deal with infiltration and runoff simultaneously and thus leads to longer lag-times, which is not realistic. The Green and Ampt is possibly the best method to describe the infiltration on longer timescales. It requires four parameters to describe the infiltration. However, for this research with only three measured events on a short timescale these are too many different possibilities to describe the flow. The applied infiltration method in this HEC-RAS

model is the SCS Curve Number which is based on precipitation, soil cover, land use, and antecedent soil moisture. The soil cover and land use are assumed to be similar through the whole catchment, so no difference has been made in land-cover. Other properties such as the Curve Number, the Abstraction Ratio, the Minimum Infiltration rate and the SCS Initial reset time are estimated in 3.2.3.

Boundary/Initial conditions

The initial condition is a steady flow of 0.011 m^3/s assumed through the whole Mahiga creek, this discharge was measured with a velocity meter of the WRC after a period of 6 days without any rainfall. An external boundary condition is necessary for solving the two-dimensional unsteady flow calculations. The boundary condition is a normal depth with a slope of 0.01 at the most downstream part of the Mahiga Creek.

Events

There are three discharge events measured, which will be discussed more extensively in 4.1. These event will be used to calibrate the model. Two events have less calibration value, namely the events on the 24th of August and the 23th of September 2022. Because on the 24th of August only one tipping bucket was installed and for both events, the amount of precipitation was very little. These rainfall events were most certainly very local and it can not be assumed that this precipitation is equally distributed over the whole catchment. The event on the 28th of September has the most precipitation and this precipitation distribution is in all likelihood the most accurate.

There is no flood captured during the time of the project so, a fourth event is 'created'. This flood is based on the frequency analyses from subsection 2.1.1 and the precipitation intensity meter on the roof of the WRC. The return period of the flood is chosen to be around 36 days, which results in a precipitation of 40 millimeters. Preferably, a bigger range of different return periods and therefore different amounts of precipitation would have been chosen, but due to the long running time of HEC-RAS model this was not done. The precipitation is modelled with different intensities, namely 35, 30 and 25 mm/hour. This is also based on analog measurements of the WRC. In chapter 4.4 the 'created' precipitation is described.

Calibration

The calibration of the model was done in several steps. The model was started in the unsteady-flow mode with the initial condition of 0.011 m^3/s and with a computation interval of 0.5 seconds. During the calibration, the accuracy of the DEM was changed from one square meter to 20 square meter so that the calculation was stable and the run-time shorter. The computation interval remained 0.5 seconds. When calibrating on the three events, several aspects are taken into account such as discharges, accumulated volumes and rating curves.

4. Results and discussion

4.1. OpenRiverCam results

4.1.1. Rainfall on the night of the 24th to 25th of August

The first rainfall is measured with the old cameras (from subsection 3.1.2.1) and happened on the night of the 24th to 25th of August. Unfortunately at that moment only rain gauge 1 was installed. The rain event started at 23h08 and ended at 00h04, so it lasted for 56 minutes and a total of 16.4 mm rain was recorded. This results in an intensity of 17.57 mm/h. The cameras were still in their first set-up. So camera 2 was still in location 2 (where no water is flowing except during typhoons) and camera 1 did not yet have the rod-extension and the optimised set-up. So, camera 1 did not catch the whole river width, but only about 3.2m out of the 4m. OpenRiverCam was still able to compute the discharge because the reference point were still in the frame. However, as a consequence, is the quantile uncertainty is (much) bigger. The camera recorded videos lasting 10 seconds and were made every 5 minutes. The discharge analysis starts when the rain started at 23h10 and ended when the river is at its initial river discharge at 01h35, so in total 30 videos have been analysed by OpenRiverCam. In figure 4.1 below, the hydrograph of this rain event can be observed. Note that there are two different y-axis. The quantile uncertainty is quite large. The lagtime between the first rain peak and the first discharge peak is 45 minutes and between the second rain peak and second discharge peak is 40 minutes.

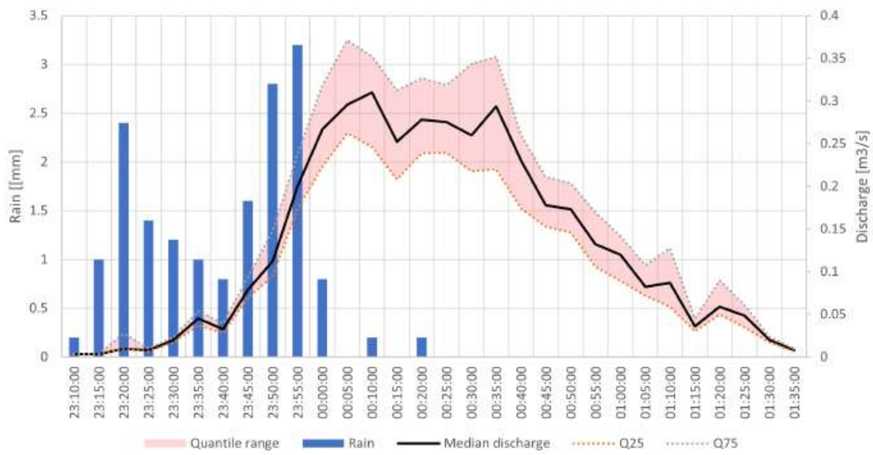


Figure 4.1.: Hydrograph rain event on the 24-08-2022

4.1.2. Rainfall on 23rd of September

Because the camera (from subsection 3.1.2.1 broke down on the 30th of August, and the new cameras (subsection 3.1.2.2 arrived on the 12th of September there were no recordings made in the intervening period. The new cameras were installed in the afternoon of the 14th of August. A much better and improved set-up was made using an extension rod (see figure 4.4). Because the reference points were different there was also a new, more accurate bathymetry made. Unfortunately, due to very bad luck, the first rainfall event after the installation happened 9 days later in the afternoon of the 23rd of September. It was a relatively small rainfall with a duration of around 25 minutes and total of precipitation of 11 mm with an intensity of around 30 mm/h. During the rain event, discharge measurement using a current meter were made as well. This way the accuracy of the calculations of the OpenRiverCam program could be checked. According to tipping bucket 1, the rain started at 14h40 time. At 15h03, it was observed with own eyes that the water depth and the river discharge still were very low, respectively 0.07 m and 0.06 m^3/s. But very suddenly, at 15h08, the river discharge increased almost instantaneously. All the garbage and debris from upstream arrived in a sudden moment at 15h09 and a peak flow was observed. At 15h11, the current measurements started. It was the first rain event in more than a week, so there was a lot of garbage in the water. This garbage often got stuck in the current meter which caused that the measurements took more time than usual. The current measurements ended at 15h25, at this moment the discharge was already much lower. This means that the discharge during the time of the flow measurements was not constant. Ideally it would have been better to make the measurement in a constant discharge but the rainfall was too short for this. The discharge calculations using the current meter can be found in appendix A.5.

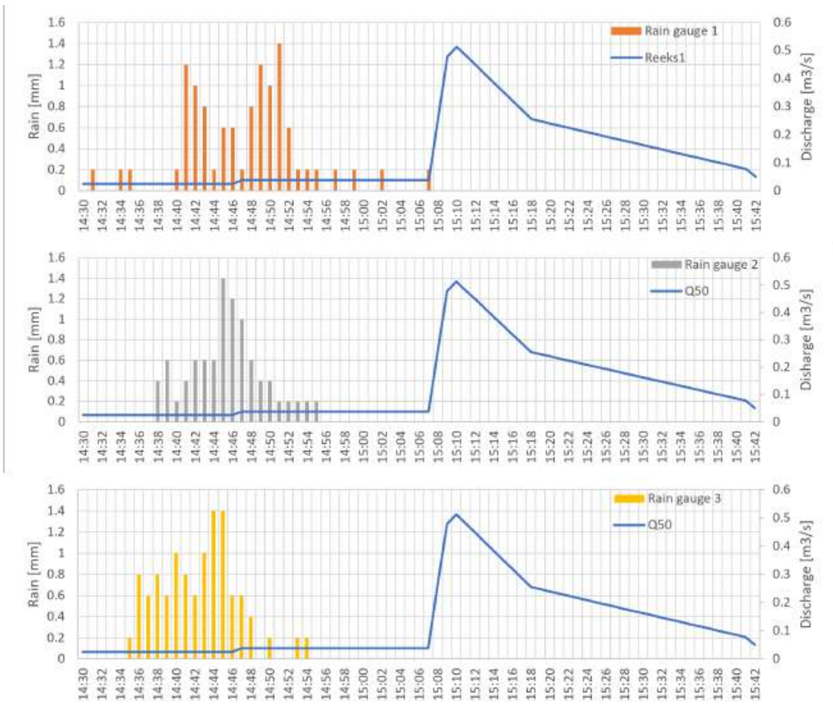


Figure 4.2.: Hydrograph rain event on the 23-08-2022

During the rain event of the 23rd of September, six videos were made by camera 1. The peak discharge was recorded at 15h09 and is equal to 0.542 m^3/s. The next video recording was made at 15h29 and is equal to 0.170 m^3/s. The calculated discharge using the current meter in location 1 was made between 15h11 and 15h25 and is equal to 0.255 m^3/s. This discharge lies right in between the discharges calculated by OpenRiverCam and thus indicates that they are coherent and most probably correct. The difference in discharge calculated by OpenRiverCam in a time span of 20 minutes (between 15h09 and 15h29) is more than thrice. This difference is very large but it is consistent with the observed flows on-site during the rainfall event. The hydrograph can be observed in figure 4.2. The average lag time between the three rain gauges and the peak discharge is 22 minutes. It was visually very clear that the flow velocities were much higher at 15h09 compared to 15h29. This big and fast difference also gives a good indication of the catchment characteristics related to a flash flood. Thanks to the improved set-up, the quantile range for this rain event calculated by OpenRiverCam compared to the 24th of August was much lower. This why in the hydrograph of figure 4.2 and 4.3 only the median discharge is illustrated.

4.1.3. Rainfall on 28th of September

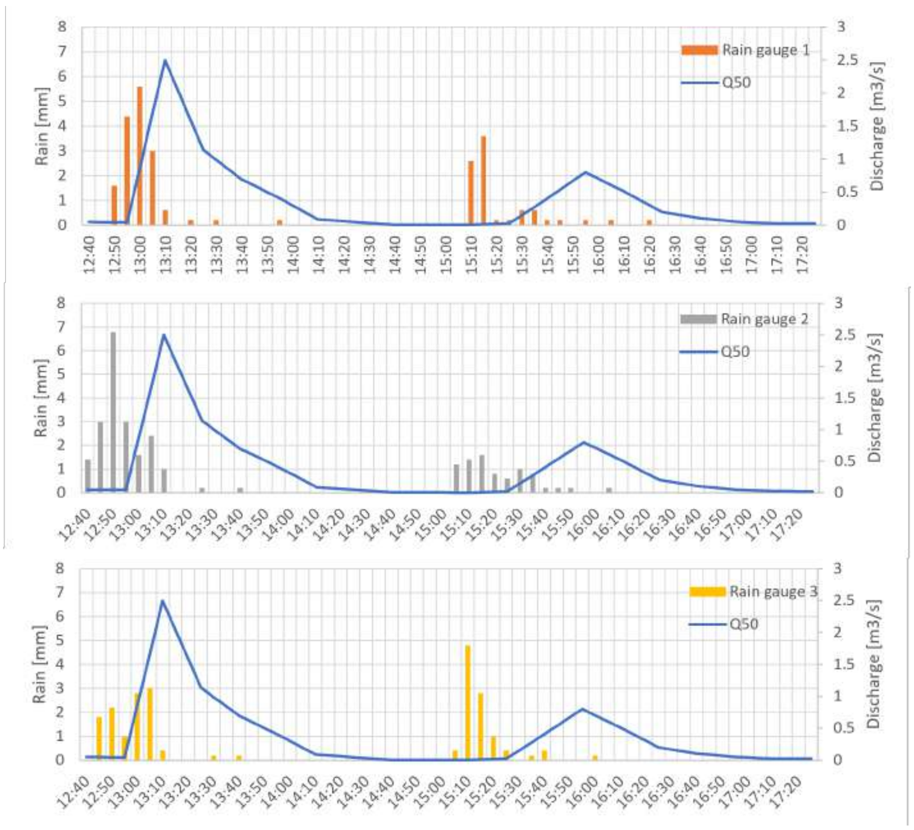
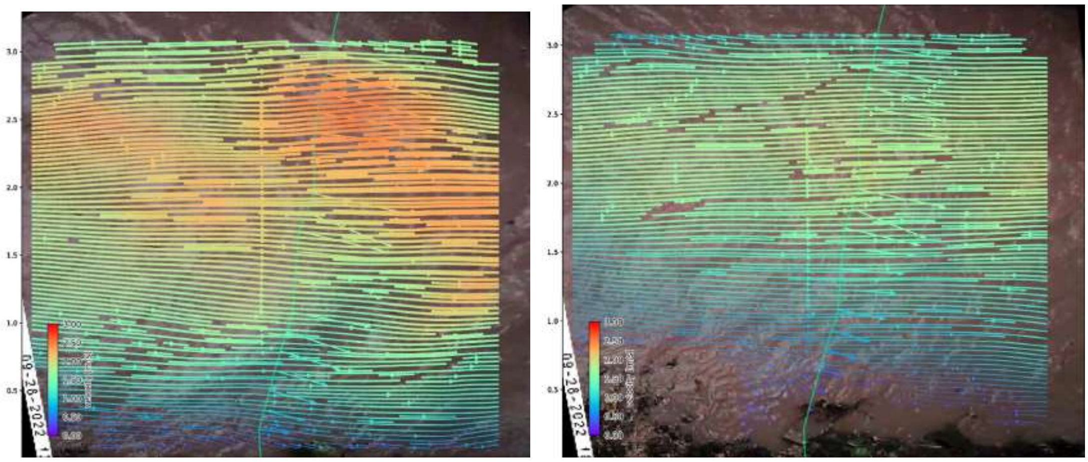


Figure 4.3.: Hydrograph rain event on the 28-09-2022

The next rain event, after the one of the 23rd of September, happened on the 25th of September. Unfortunately no recordings were made by the new cameras because of the missing field scan option. So, was decided to install the old cameras from subsection 3.1.2.1 again. The following rain event happened on the 28th of September. The intensity and distribution varied between the three different rain gauges. According to rain gauge 2 the rain event started at 12h41 and ended at 13h10, so it lasted for 30 minutes and the average total rain recorded between the three rain gauges is 15 mm. This results in an intensity of 30 mm/h. Two hours later at 15h07 a second rain event started, with an intensity for rain gauge 1 of 37mm/h and for rain gauge 2 of 14.8 mm/h. To save the the camera's battery, the time interval between two recordings had been set to 15 minutes. So, between 12h40 and 17h30, 20 videos were made, which were analysed by OpenRiverCam. The hydrograph can be observed in figure 4.3. For the first rain event, the lag time varies between 10 minutes and 20 minutes. The lag time of the second rain event varies between 45 and 50 minutes. The peak discharge can arrive extremely suddenly (as it was visually observed on the rain of the 23rd of September). It is therefore important to note that because of the larger time interval of 15 minutes between each recording, it is possible that the peak discharge happened minutes before the recording and thus the real peak was bigger and more sudden.



(a) Velocity grid first peak

(b) Velocity grid second peak

Figure 4.4.: OpenRiverCam computation on 28th of September

4.1.4. Rating curve

In total 54 discharge calculations have been made. With these information a rating curve was iterated. This relation can be used to predict discharges at an occurring water level and to calibrate the model. The rating curve for location 1 in the Mahiga catchment is described by the following relation:

$Q = c(h+a)^n = 17.7949 * h^2.48575$

with: c and n = rating curve constants derived from the observations
a = water level corresponding to zero discharge

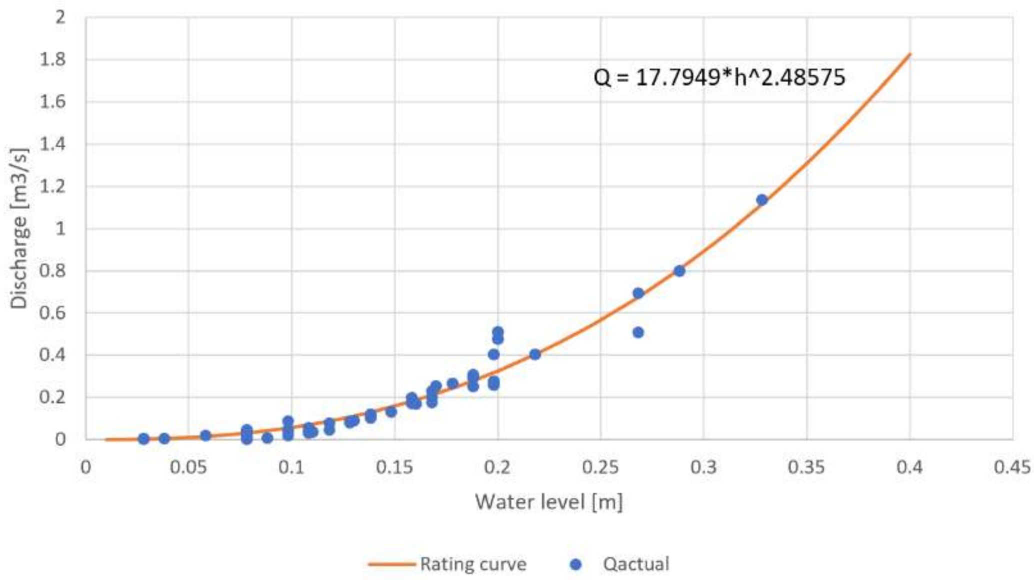


Figure 4.5.: Rating curve

4.2. Overview data

Table 4.1 an overview is made of all the different information that was determined from the data of tipping buckets and the cameras. For each rain event there are 3 different data inputs depending of the rain gauge. To keep a clear overview, an interval is given between the smallest and largest value of the three different rain gauges. The specific information of each tipping bucket for each event can be found in the appendix figure (A.5).
The lag time is calculated as the time interval between the center of gravity of the input variable and the center of gravity of the output variable. The concentration time is an estimation of the maximum time a water particle needs to travel from the most upstream point to the outlet of a catchment. From the hydrograph, it is the time between the end of the precipitation and the inflection point from the discharge curve [van der Ent, 2021]. The total discharge is calculated from the area under the discharge curve. Then the total rain is calculated as the sum of the recorded precipitation of each tipping bucket times its respective area. The first tipping bucket covers an area of 500.000m^2, the second tipping bucket an area of 1.900.000m^2 and the third tipping bucket an area of 1.000.000^2. Note that unfortunately for the rain event on the 24th of August only tipping bucket 1 was installed. For this event, total rain has been calculated as the precipitation of tipping bucket 1 times the total area of the catchment. This assumption can be made because it was a relatively big precipitation event.

A lot of different discussions points rise from table 4.1. The first point is that the four rain events each have a really different profile (in terms of amount, duration and total discharge). There are not two similar rain events recorded which is not ideal for calibration and testing of the accuracy of the calculations. A second important point is that before the rain event on the 23rd of September, there was not a single rain event for 9 consecutive days. The temperature was high which caused a lot of evaporation and the soil being quite dry. During the rain

Rain event	24-08	23-09	28-09 #1	28-09 #2
Precipitation [mm]	16.4	9.2-11.4	11.0-19.0	7.4-9.8
Duration [minutes]	56	19-31	22-33	34-36
Intensity [mm/h]	17.57	22.1-35.4	27.5-40.9	13.1-16.3
Lag time [minutes]	40	20-25	10-20	40-50
Concentration time [minutes]	75	27-30	45-50	65-70
Total discharge volume [m^3]	1166	526	4475	1926
Total rain [m^3]	57120	35160	56740	30560
Ratio [%]	2.04	1.55	7.89	6.30

Table 4.1.: Overview data

the soil infiltration therefore was much higher. This explains why the total river discharge and the ratio are much lower compared to the other events. Thirdly, as explained before the three events each have, unfortunately, a different discharge calculation interval because of the camera complications. For the rain event of the 28th of September, the interval was 15 minutes. This is quite large, especially in this catchment where the peaks arrive extremely fast and suddenly and also decrease at a strong pace. With an interval of 15 minutes, it it possible that the peak was larger and happened a couple of minutes before the actual camera recording. Fourthly, it is assumed that the rain was homogeneous over each tipping bucket area. This is most probably not correct, especially for rains with a lower precipitation.

4.3. Slope retention volume

The sub-creek 2 has a total length of approximately 2500 meters with a height difference of 80 meters between downstream and upstream part. As can be seen in figure 3.13, the river can be divided with two main slopes that can be approximated with a mean slope of 0.0257 over a length of 1500 meters and 0.0247 over a length of 880 meters. Assuming a height of 2 meters for the gabion dams (the same height was used for the Cebu Belgian Gabion Dam Project) and a constant river width of 4 meters, a simple calculation can be made to determine to total volume retention due to the gabion dams.
With a slope of 0.0257 and a gabion height of 2 meters, a retention basin can be made over length of approximately 74m (2m/0.0257 = 77.82 meters) with a total retention volume of 75m*2m*4m*0.5 = 300m^3. This means that that if a gabion dam is installed every 80 meters, a maximal of 18 gabion dams can be installed in the downstream part of the river. These dams will a retain a maximal of 5400m^3 (=18*300m^3). With a slope of 0.0247 and a gabion height of 2m, a new retention basin can be made over length of approximately 77 meters (2m/0.0247 = 80.97 meters) with a total retention volume of 77m*2m*4m*0.5 = 308 m^3. This means that that if a gabion dam is installed every 82 meters, a maximal of 10 gabion dams can be installed in the upstream part of the river. These dams will retain a maximum of 3080 m^3 (=18*300 m^3).
So using this simplified calculation method and building the maximal amount of 28 gabion dams over the Mahiga river, a maximum volume of 8480 m^3 water could be retained. As a comparison, the maximal total discharge recorded was on the 28th of September and equaled 4475 m^3, adding the second part precipitation of that day (although most water of the first part would have flown through the gabion dams) is 6401 m^3. These events did not

lead to a flash flood but the volumes still give an indication on the water that can be retained using the gabion dams.

4.3.1. Five gabion dams

In HEC-RAS only 5 gabion dams will be modeled. The exact location of the dams were mainly chosen in function of the slope. With a smaller slope, a bigger retention volume can be obtained. This is why, the slopes are smaller than the average slope used above. Also, the width of the river is a bit bigger upstream and it has been assumed to be 4.5m. An overview of the capacity of each dam is given in table 4.2. The total accumulated volume is approximately 2400 m^3.

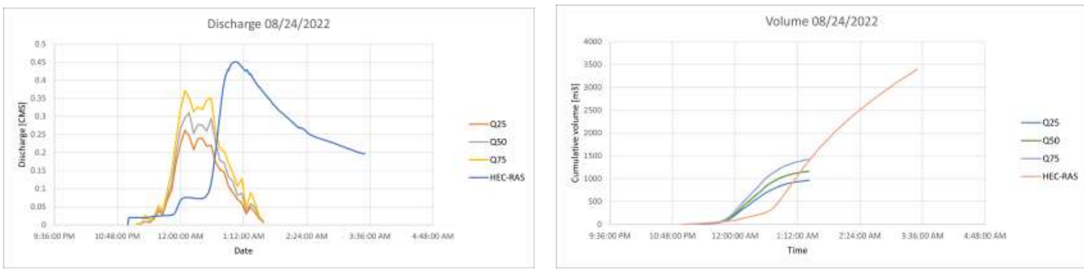
Gabion	Location [m]	Slope	Volume accumulation [m^3]
Gabion 1	840	0.0178	505.6
Gabion 2	1156	0.0199	452.3
Gabion 3	1300	0.0167	538.9
Gabion 4	1895	0.0188	478.7
Gabion 4	2098	0.0218	412.8
Total			2388.4

Table 4.2.: Slope retention method for 5 Gabion dams

4.4. HEC-RAS

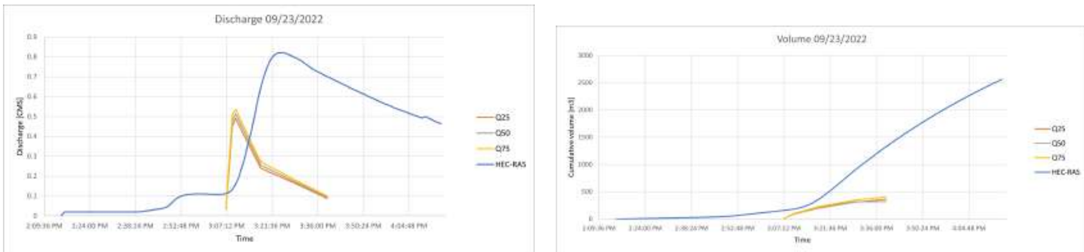
4.4.1. Calibration results

The three measured events are used for calibrating the model. For every event the discharge, accumulated volume and the rating curve are compared. The exact same location is used in HEC-RAS as from the data obtained by camera 1 from the OpenRiverCam. Table 4.1 showed that the ratio volume measured precipitation and volume measured discharge was low for the events at the 24th of August and the 23th of September which is probably due to the local precipitation and the high infiltration. The measured discharge on the 28th of September is therefore more important for calibrating. The results are shown below in figures 4.6, 4.7 and 4.8. They are obtained with a creek roughness coefficient of 0.04, an impervious percentage of 10 percent, an infiltration rate of 21 mm/hour and a reset time of 0.9 hours. Especially the infiltration rate seems surprisingly high, but can be explained by the rough porous terrain and the dry periods before the events took place. The results show as well when the peak has passed the discharges remain higher. This could not be solved by changing the model parameters (reset time did not have a big influence). An advise will be to do the calibration with more measured events and with real flash flood data. The rating curve is very dependent on the creek width and thus the location. Due to the higher resolution of the DEM file is the rating from OpenRiverCam and HEC-RAS on the same location not similar, nevertheless it is still attached in appendix A.9.



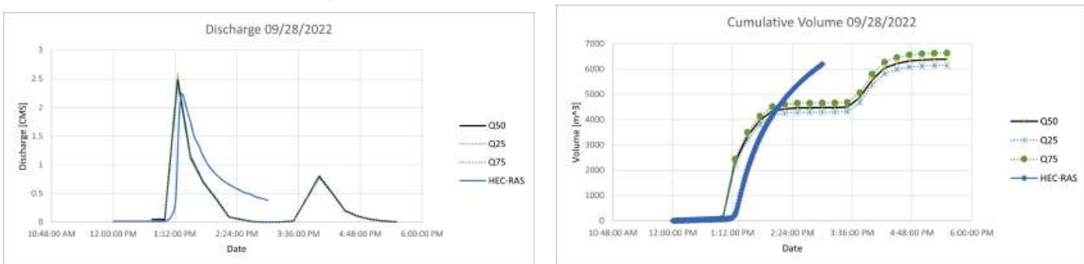
(a) Discharge (b) Volume accumulation

Figure 4.6.: Calibration results 08-24-2022



(a) Discharge (b) Volume accumulation

Figure 4.7.: Calibration results 09-23-2022

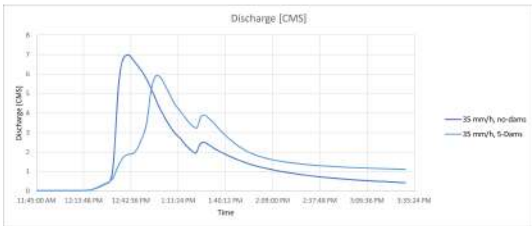


(a) Discharge (b) Volume accumulation

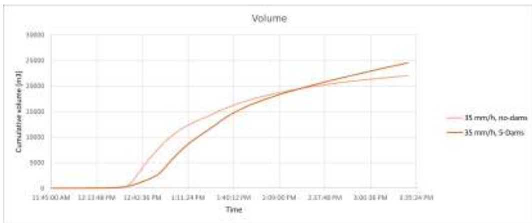
Figure 4.8.: Calibration results 09-28-2022

4.4.2. Gabion dam results

Gabion dams have been installed in the calibrated model to get a better understanding of the influence on the discharge. When at least 5 gabion dams are installed and maintained properly, the accumulated volume will be around 3000 m^3 according to the HEC-RAS model. The peak flow from figure 4.9 shows that with intensities higher than 35 mm/h and with a duration of at least 1 hour, the attenuation is getting less effective, so more gabion dams should be build when this occurs often. In general, more gabion dams should be applied than modelled, because in this model the retention volume is its maximum, whereas in reality this volume is partly filled with sediments. What stands out is that the discharge is delayed for all three intensities. This has an advantage, the peak flows of both sub-creeks will not arrive simultaneously in the main creek, because the gabion dams are only placed in sub-creek 2. If the delay is not enough, objects such as trees and big rocks that block the flow can be removed to reduce the friction in sub-creek 1, so that the peak flow will arrive earlier in this sub-creek. And flow will be more evenly distributed after the convergences.

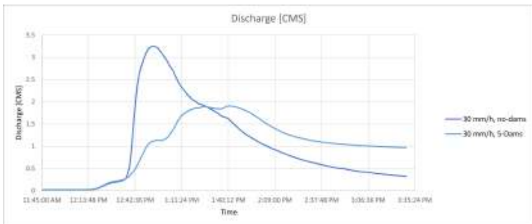


(a) Discharge

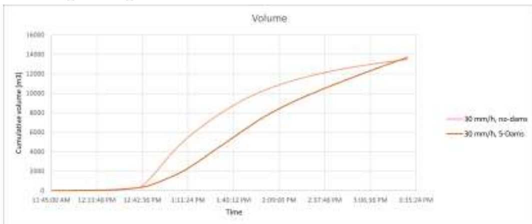


(b) Volume accumulation

Figure 4.9.: 35 mm/hour precipitation

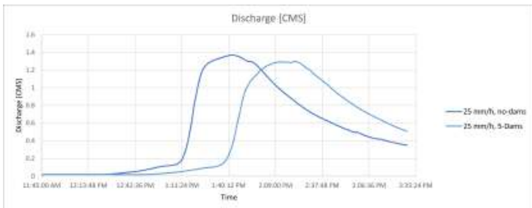


(a) Discharge

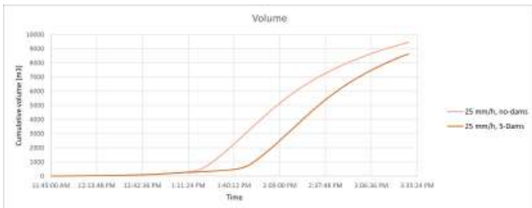


(b) Volume accumulation

Figure 4.10.: 30 mm/hour precipitation



(a) Discharge



(b) Volume accumulation

Figure 4.11.: 25 mm/hour precipitation

5. Conclusion

During the eight weeks where the three tipping buckets were installed, 21 precipitation events were recorded. The maximal intensity recorded during that time was: 96 mm/hour (five minute maximum). Unfortunately no flash floods were recorded but using a frequency analysis it was concluded that flash floods occurred in the Mahiga catchment with a precipitation amount of 40mm per day and a return period of 36.5 days. During the eight week project two flash floods happened (none of which were recorded), this corresponds nicely with the return period. The trail cameras recorded in total three different precipitation event. Using OpenRiverCam, the discharge and a rating curve could be calculated. However it is not recommended to use trail cameras, security cameras are a much more reliable option. This answers the first sub-research question: *How can the discharge be determined of the river using trail cameras?*
The second sub-research question is: *How does the Mahiga catchment react to different kinds of precipitation intensities?*. This question is more difficult to answer because making conclusions about the catchment characteristics with only three hydrographs is complicated. Furthermore, during these events it could not be excluded that this precipitation was homogeneously distributed which makes the question even harder to answer. It was observed that, when there is no rain for extended period of time, it influences the infiltration rate and river discharge. According to table 4.1 only ratios between 1.5% till 6.30% seem to runoff, which is influenced by the precipitation distribution, but is still a huge amount of precipitation that infiltrates. Also, the hydrographs show that the lag time is very short. So, although the infiltration rate is high, the precipitation rate must be even higher, which is why it results in these short lag times.

With the results from OpenRiverCam and the tipping bucket data, a model of the Mahiga catchment is made and calibrated in HEC-RAS. This model is used to answer the main research question of this thesis: *"Do gabion dams have an impact in attenuating flash floods in the Mahiga catchment?"*. In the model five gabion dams have been built to see the response on precipitation events with three different intensities, namely 35, 30 and 25 mm/hour with each having a total final amount of 40 mm. These intensities are based on an earlier flood event, analog data and the frequency analysis. The gabion dams are 2 meters high and have their full retention volume available (no sediments trapped). The results show that the gabion dams do have an impact in attenuating flash floods. The peak-flow declines for all three intensities. With intensities higher than 35 mm/h or with a longer precipitation duration, more gabion dams should be build. Also, the discharge is delayed for all three intensities. So, the peak flows of the two sub-creeks will not arrive simultaneously in the main creek, because the gabion dams are only placed in one of the sub-creeks. Additionally the difference in peak can even be more delayed if the obstructions in sub-creek 1 are removed. It must be stated that the HEC-RAS model is calibrated on very little hydrographs which makes it very hard to estimate the accuracy. However, a simplification of the attenuation effects can also be determined with a simple calculation using the slope retention method.

The results show that HEC-RAS overestimates the retention volume with around 20% compared to the slope retention, which is partly due to the implementation of the gabion dams on the most effective locations in HEC-RAS. However, based on the frequency of removing sediments, more gabion dams should be build to compensate for the retention volume decrease.

6. Recommendations

In this chapter some critical comments and recommendations are given to the research. These can be useful for the continuity of this project or for more optimized use of OpenRiverCam.

- Firstly we very highly recommend of never using trail cameras with OpenRiverCam. Trail cameras with a field scan option only exist with older cameras from the brand Bushnell and they are not reliable, the battery length is too short and the video quality is not very good. We do recommend the use of security cameras with a Raspberry Pi that can control the camera. Preferably using the electricity grid or a car battery as power source.
- Secondly, a recommendation for OpenRiverCam, because using a staff gauge and video recording to know the water depth is not very accurate due to e.g. lower recording quality during the night. A more, accurate and reliable option would be too use pressure level sensors. This would greatly improve the accuracy of the discharge calculations because the water level has a very big influence.
- Thirdly, straightforward but nevertheless very important, is the uniformity of the measurements. It is very important to have a constant interval and camera set-up to make valid conclusions about the river characteristics.
- The Onset HOBO tipping bucket has larger measurement errors with very high precipitation intensities (120 mm/h) which should be paid attention to.
- The characteristics of a flash flood are still a bit vague, because there was no precipitation measured that lead to a flash flood. A flash flood intensity used in this research is from an analog measurement device, which is then used for the HEC-RAS model of the Mahiga catchment, but spatial variation between the three tipping buckets could not be included.
- Calibrate the HEC-RAS model on more events, real flash floods and bigger rain events. All the gabion dams results made with HEC-RAS are very dependent on the calibration and the accuracy of the model is unknown.
- Model the gabion dam more realistic and if possible add sediment. One of the main problems of gabion dams is clogging and sediment settling. Water cannot flow through the dam anymore or only with high discharges and the amount of water that can be retained by the dam decreases. [Water-Resources-Center, 1994] says that the gabion dam is full of sediment after 1 year, which emphasizes the importance of maintenance.
- In the Belgian dam project [Water-Resources-Center, 1994] a plan has been made for digging out the sediments. An advise would be to look at this report and do more research how the sediments can be removed more effectively with the little money available.

- Try different gabion dam types, this has also to do with the sediment. For example by adding a gate in the gabion dam that lets small discharges through so that it does not have to go trough the gabion dam.
- Expenses are excluded from this report. It is recommended to search for other solutions for the flash floods reduction and make a cost comparison, both on the short and long term. When making an investment in the gabion dams, keep in mind that they will not solve the floods with longer return periods such as typhoons or big storms with more total precipitation.

Bibliography

A.Hauet, T.Morlot, and L.Daubagnan (2018). Velocity profile and depth-averaged to surface velocity in natural streams: A review over a large sample of rivers. *Journal füEDP Sciences*, 40.

HEC-RAS (2022). Hec-ras user's manual. *The U.S. Army Corps of Engineers' River Analysis System*.

I.Harris, T.J.Osborn, and et al. (2020). CRU TS monthly high-resolution gridded multivariate climate dataset. *Scientific Data*, 7.

K.C.Luk and J.E.Ball (1997). Modelling the instantaneous spatial variability of rainfall. *International Congress on Modelling and Simulation.*, pages 71–76.

n Values, M. (2006). Manning's n values. *Corvallis Forestry Research Community*.

Program, U. D. (2022). Phil-lidar 1 project. Technical report, Philippines Department of Science and Technology (DOST).

van der Doelen, M. (2022). Flash flood attenuation, attenuating flash floods using gabion dams in cebu city, philippines. *Bachelor thesis*.

van der Ent, R. (2021). Extreme precipitation, flood risk change. *Assignment 3*.

Water-Resources-Center (1994). *The Cebu Belgian Gabion Dam Project*. Service Laique de la cooperation au developpement, University of San Carlos, Cebu City, Philippines.

A. Appendix

A.1. Local rain

Figure A.1.: Local rain

A.2. Tipping Bucket data

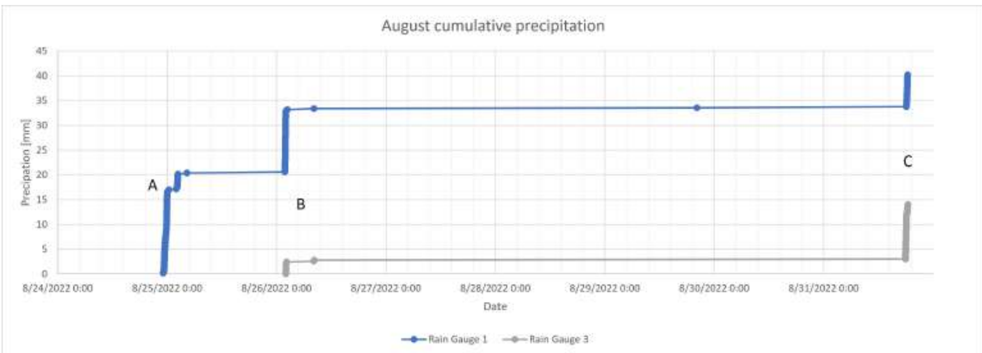


Figure A.2.: Overview cumulative precipitation August

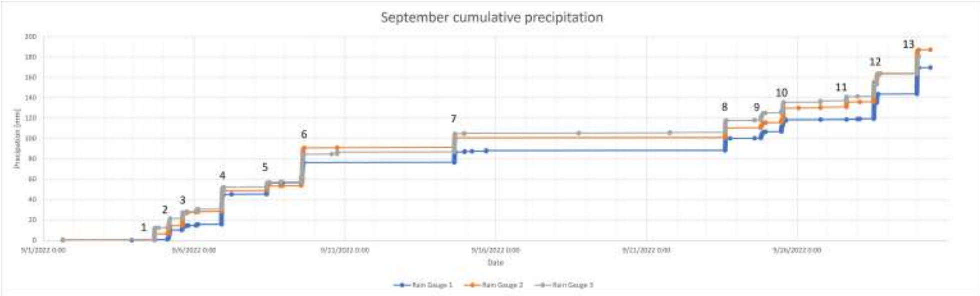


Figure A.3.: Overview cumulative precipitation September

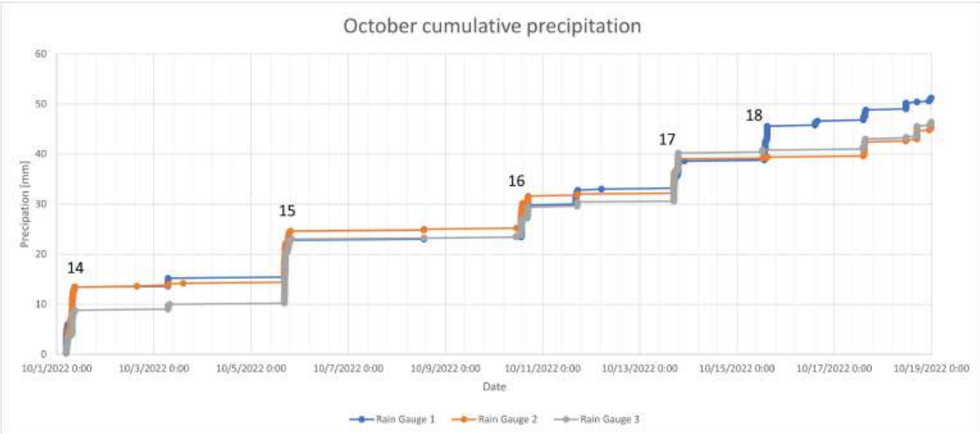


Figure A.4.: Overview cumulative precipitation October

	Begin Time	Precipitation [mm]			Time [minutes]			Intensity 5 min [mm/h]			Intensity 10 min [mm/h]			Intensity 30 min [mm/h]			Intensity 60 min [mm/h]		
Event:	[Date + time]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
A	8/24/2022 23:08	16.4	[-]	[-]	56	[-]	[-]	52.8	[-]	[-]	38.4	[-]	[-]	21.6	[-]	[-]	16.6	[-]	[-]
B	8/26/2022 1:48	12.2	[-]	2.8	13	[-]	10	96.0	[-]	26.4	67.2	[-]	15.6	25.2	[-]	5.2	12.8	[-]	2.6
C	8/31/2022 17:54	6.4	[-]	10.8	19	[-]	30	38.4	[-]	48.0	30.0	[-]	44.4	13.2	[-]	21.6	6.6	[-]	11.2
1	9/4/2022 16:25	0.4	5.6	11.0	3	12	12	4.8	52.8	93.6	2.4	32.4	64.8	1.2	11.6	22.8	0.6	5.8	11.4
2	9/5/2022 2:54	8.2	7.2	8.2	38	35	40	33.6	64.8	33.6	18.0	49.2	26.4	6.8	23.6	12.0	6.0	12.2	6.0
3	9/5/2022 14:46	3.2	11.6	5.6	16	18	18												
4	9/6/2022 21:45	27.6	19.6	20.0	47	42	42	76.8	67.2	72.0	72.0	54.0	56.4	48.4	34.8	36.8	28.2	19.8	20.6
5	9/8/2022 9:42	10.4	4.2	4.6	38	27	8	40.8	21.6	16.8	27.6	18.0	13.2	17.6	8.8	6.8	10.6	4.4	4.6
6	9/9/2022 13:14	19.4	35.4	25.8	100	108	60	64.8	52.8	88.8	45.6	46.8	66.0	26.8	37.2	41.6	18.4	26.0	25.8
7	9/14/2022 15:01	9.8	9.4	17.4	21	37	34	64.8	33.6	67.2	44.4	28.8	60.0	20.4	18.0	34.4	10.4	9.8	17.8
8	9/23/2022 14:30	11.4	9.2	11.2	31	17	19	60.0	60.0	62.4	48.0	44.4	55.2	22.8	18.8	23.2	11.8	9.6	11.6
9	9/24/2022 18:55	5.4	3.8	6.2	52	33	118	12.0	9.6	24.0	10.8	7.2	14.4	6.0	4.4	7.2	3.8	2.8	4.4
10	9/25/2022 11:16	10.2	14.0	10.0	84	99	96	36.0	50.4	50.4	25.2	48.0	33.6	10.0	22.8	15.6	5.8	12.4	8.4
11	9/28/2022 12:41	15.0	19.0	11.0	22	33	24	67.2	86.4	64.8	62.4	62.4	45.6	30.8	37.6	22.4	15.6	19.4	11.6
12	9/28/2022 15:07	8.0	7.4	9.8	36	34	36												
13	9/29/2022 23:08	25.0	22.2	16.0	49	54	47	81.6	72.0	43.2	72.0	58.8	38.4	45.6	41.6	29.6	25.2	22.6	16.4
14	10/1/2022 4:41	12.8	13.2	8.0	51	251	205	57.6	40.8	36.0	31.2	21.6	19.2	12.0	10.0	8.4	7.0	5.4	4.4
15	10/5/2022 16:14	7.0	9.8	12.2	150	145	140	21.6	52.8	33.0	14.4	30.0	30.0	7.6	14.0	18.8	5.0	7.8	10.2
16	10/10/2022 13:08	4.8	4.8	3.0	41	64	30	28.8	24.0	14.4	19.2	14.4	10.8	8.0	8.0	6.0	5.0	4.8	3.4
17	10/13/2022 16:47	5.2	6.6	9.4	126	128	126	16.8	38.4	50.4	13.2	22.8	25.2	5.6	8.4	11.2	3.0	4.4	4.2
18	10/15/2022 13:25	6.9	0.4	0.6	92	143	2	33.0	2.4	7.2	10.8	1.2	3.6	6.0	0.4	1.2	5.0	0.2	0.6

Figure A.5.: Overview Measured Precipitation

A.3. Approximate discharge

Because of the camera delays and the need for data, during big rainfalls, approximate velocity measurement were made using floating objects. These velocity were then multiplied with a factor of 0.8, to approximate the velocity of the whole cross-section instead of the of the surface velocity. This was then multiplied with the volume to get a discharge.

$$Q = A * L/t * f \tag{A.1}$$

Where:

Q = the discharge [m^3/s]
A = cross-section of the river [m^2]
L = length from point A to point B [m]
t = time it took for the object to flow from point A to point B
f = coefficient to compensate from surface velocity to mean velocity in the river, a normal value for this is 0.85. According to A.Hauet et al. [2018], 0.8 is a better value to use for small natural streams.

A.3.1. precipitation 05/09/2022

The precipitation on the fifth of September consists of two events. The surface velocity is only measured for the second event. It is assumed that the rainfall on the first event has no influence. However it is possible that the lag time is shorter than normal due to this earlier event. The precipitation on the second event started at 14:27 and ended 36.

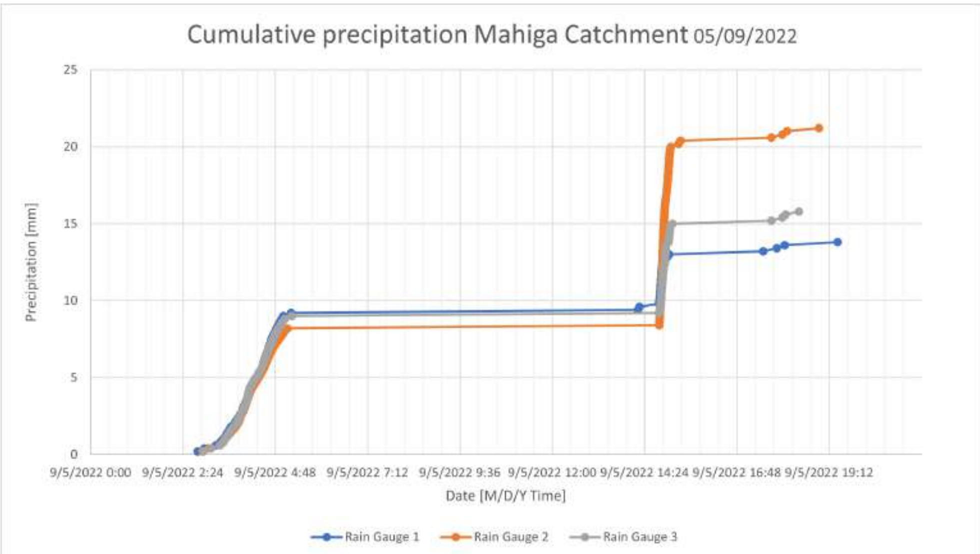


Figure A.6.: Precipitation 05/09/2022

The velocity measurement were made at 3:39 PM. Seven different time measurements were made: 7.68s, 6.81s, 7.31s, 6.65s, 6.51s, 6.11s, 7.55s. This gives an average of 6.95s. The measured length is 17.10. The area of the water has a trapezoidal shape of around 1.0 square meter.

$$Q = (A * L/t) * f = 1.0 * 17.10/6.95 * 0.8 = 1.97m^3/s \tag{A.2}$$

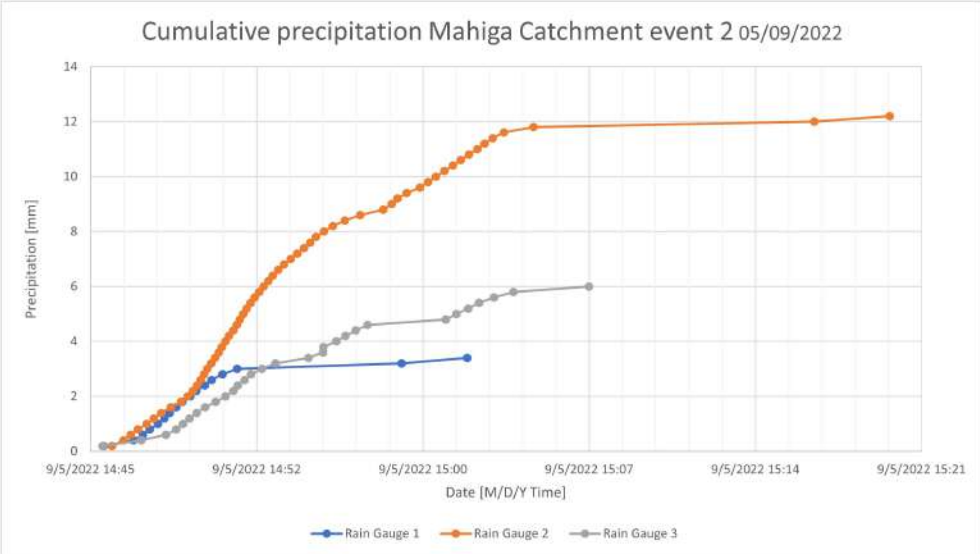


Figure A.7.: Precipitation 05/09/2022, event 2

A.3.2. precipitation 9/9/2022

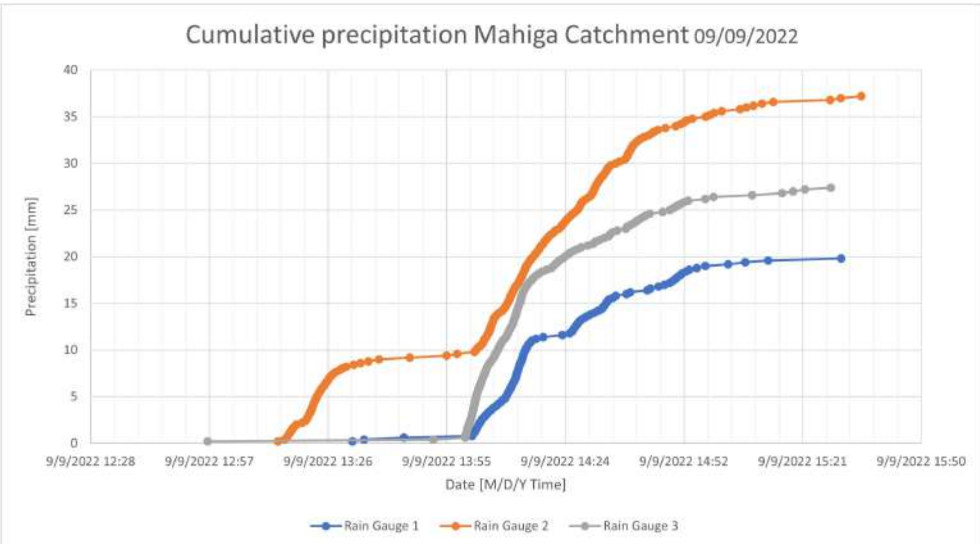


Figure A.8.: Precipitation 09/09/2022

On the 9/9/2022 there was a big rain event in Cebu, which causes two houses to flush away in a different catchment close to the Mahiga catchment. Unfortunately for this research, the cameras were not working at this moment. However, an employee of the WRC, Sir Jing Jing, went to the Mahiga Creek and made a video on 4:10 PM. The precipitation on this day shown in started at around 2:00 PM and ended around 3:20, with a small precipitation event beforehand at the location of tipping bucket 2.

The surface velocity is measured using the time it took for several objects to flow over a distance of 13.12 meter. Together with the depth and the earlier determined bathymetry of the creek, the cross-section is established. The different time measurements were: 10.08, 10.10 seconds.

$$\mathcal{Q} = (A * L/t) * f = 0.63 * 13.12/10.09 * 0.8 = 0.65 m^3/s \tag{A.3}$$

Sir Jing Jing went also to the creek of location 2. Here he made the following time measurements: 6.38 and 6.43 seconds over a length of 5.80 meter. The cross-section of the creek has a trapezoidal shape with an estimated area of 0.40 square meter.

$$\mathcal{Q} = (A * L/t) * f = 0.28 * 5.80/6.41 * 0.8 = 0.17 m^3/s \tag{A.4}$$

A.4. Rating Curves

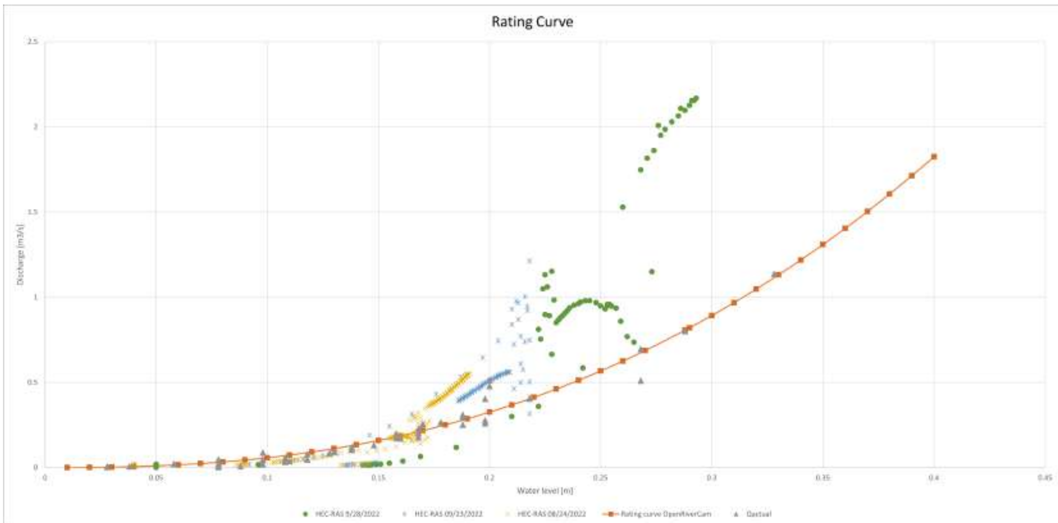
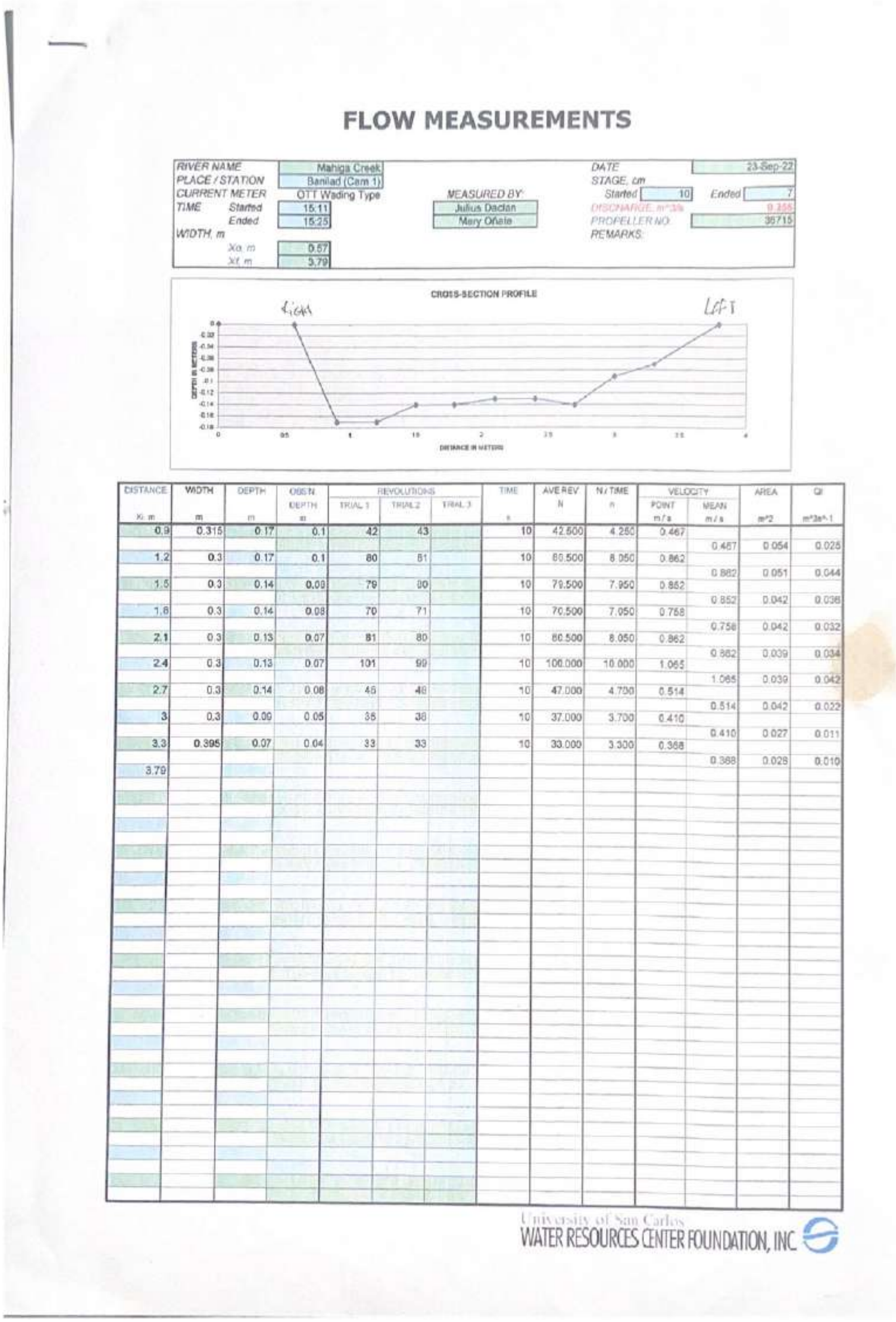


Figure A.9.: Compared rating curves

A.5. Discharge measurements on the 23/09/2022



FLOW MEASUREMENTS

RIVER NAME	Mahiga Creek	DATE	23-Sep-22
PLACE / STATION	Banilad (Cam 1)	STAGE, cm	Started 10, Ended 7
CURRENT METER	OTT Wading Type	MEASURED BY: Julius Daclan, Mary Oñate	
TIME Started	15:11	DISCHARGE, m^3/s	0.258
TIME Ended	15:25	PROPELLER NO.	35715
WIDTH, m		REMARKS:	
Xo, m	0.57		
Xf, m	3.79		

CROSS-SECTION PROFILE

Right

Left

DEPTH IN METERS

DISTANCE IN METERS

DISTANCE Xi m	WIDTH m	DEPTH m	OBS'N DEPTH m	REVOLUTIONS TRIAL 1	TRIAL 2	TRIAL 3	TIME s	AVE REV N	N / TIME n	VELOCITY POINT m/s	MEAN m/s	AREA m^2	Qi m^3s^-1
0.9	0.315	0.17	0.1	42	43		10	42.500	4.250	0.467			
											0.467	0.054	0.025
1.2	0.3	0.17	0.1	80	81		10	80.500	8.050	0.862			
											0.862	0.051	0.044
1.5	0.3	0.14	0.09	79	80		10	79.500	7.950	0.852			
											0.852	0.042	0.036
1.8	0.3	0.14	0.08	70	71		10	70.500	7.050	0.758			
											0.758	0.042	0.032
2.1	0.3	0.13	0.07	81	80		10	80.500	8.050	0.862			
											0.862	0.039	0.034
2.4	0.3	0.13	0.07	101	99		10	100.000	10.000	1.065			
											1.065	0.039	0.042
2.7	0.3	0.14	0.08	46	48		10	47.000	4.700	0.514			
											0.514	0.042	0.022
3	0.3	0.09	0.05	36	38		10	37.000	3.700	0.410			
											0.410	0.027	0.011
3.3	0.395	0.07	0.04	33	33		10	33.000	3.300	0.368			
											0.368	0.028	0.010
3.79													

University of San Carlos
WATER RESOURCES CENTER FOUNDATION, INC

Figure A.10.: Discharge measurements made by the current meter on the 23/09/2022