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Research on **waterlogging and interventions** in Ricanau Mofo

Scientific study on mitigating water nuisance through socio-technical intervention assessment

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Preface

This study has been performed for the course CEGM3000 Multi-Disciplinary Project, of the Technical University of Delft, the Netherlands. The project team consists of different disciplines, who are representing the faculties of Civil Engineering and Industrial Design Engineering: Environmental Engineering, Hydraulic Engineering, Structural Engineering, Construction Management and Engineering, and Design for Interaction. This collaboration results in a multi-disciplinary perspective on the water nuisance in Ricanau Mofo.

This project's significance lies in identifying interventions that are effective against erosion and water damage, while being locally implementable in the rural areas of Surinam (see Figure 0.1). It can be seen as a pilot project that is scalable to other villages along the Cottica River or in the whole of Surinam.

The research starts off with preliminary, qualitative studies of the community, the region and stakeholders. After that, a quantitative hydrological analysis of the Ricanau Mofo area is performed. From this qualitative and quantitative research, three strategies are identified to intervene in the river bank erosion, the soil erosion and the flood damage in the urban environment. The paper ends by describing the prototype that has been constructed together with the villagers. It is important to note that there are many interventions researched before concluding on the end strategies; these are all described in Appendix C, D and E, together with their challenges, advantages and disadvantages.

Special thanks to STEORR, who made it possible to perform this project. We would also like to thank our supervisors at TU Delft. The project and its final deliverables could not have been realized without the engagement of the villagers, who have helped with the design, regular feedback and the construction of the prototype. Lastly, the team sends a special thanks for the contributions of, MDS, Ministry of Public Works in Surinam, and Anton de Kom College for their knowledge, for donating vegetation and for setting up data measuring instruments.

Figure 0.1: Engagement of the villagers in the project (authors' work)

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Abstract (English)

This research addresses how Ricanau Mofo, a low-lying village in Surinam, can become a more water-adaptive and sustainable village, while it faces land erosion, river bank erosion, changing rainfall patterns and sea level rise. It is urgent to intervene, as these issues are expected to increase in occurrence due to climate change. Constraints and limitations that are important to take into account are cultural preservation, maintaining accessibility to the Cottica River, the limited availability of financial resources and the need for a low-maintenance intervention.

Three strategies are proposed. The first focuses on addressing land erosion. Planting vegetation on critically eroding areas is a short term measure, while the long-term involves constructing footpaths with drainage channels. This not only mitigates soil erosion, but also regulates water and is relatively cost efficient. The second strategy targets the river bank erosion, which includes wooden bulkheads with vegetation and stones for short term implementation. For the long term, a river bank protection system with groynes is designed, to break waves, slow down the stream velocity and in time causes land gain. As the long term plans require external financial aid, a business case is set up and shared with the captain of Ricanau Mofo, STEORR, the District Commissioner and the Ministry of Public Works. The third strategy addresses water damage in the urban environment. Short-term it consists of providing building guidelines of where to build more water adaptive, and how. This is placed on an informational board in the village. The long-term contains a flood early warning system and recommended equipment.

This project's significance lies in identifying interventions that are effective against erosion and water damage while being locally implementable in the rural areas of Surinam. It can be seen as a pilot project that is scalable to other villages along the Cottica River or in the whole of Surinam. However, there are limitations to the project. The most important is the lack of data quantity and data quality. This caused implications for dimensioning the interventions and their financial impact. Another limitation is that the project does not create 'dry feet' for the village; it creates a way of mitigating water damage while living next to the Cottica River. In addition, there is a limitation in the financing of follow-up projects. Therefore, a business case is also being delivered to the Ministry of Public Works, the District Commissioner of Marowijne South-West and the captain of Ricanau Mofo. They can use it to apply for funds from international organisations and include it in future policy plans.

To summarise, Ricanau Mofo can become more water adaptive by regulating how to build and where, by continuing the prototype of the bulkheads by planting more vegetation and, by requesting financial aid for the river bank protection long term. As Figure 0.2 shows, it not only contributes as a report, but also in a tangible form of a prototype and in educational information boards in the local language to enhance the continuity and help the village.

Figure 0.2: Prototype of the river bank erosion intervention (left) with the printed educational boards (right) (authors' work)

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Abstract (Dutch)

Dit onderzoek richt zich op hoe Ricanau Mofo, een laaggelegen, binnenlands dorp in Suriname, zich kan ontwikkelen tot een meer water adaptief en duurzaam dorp, terwijl het te maken heeft met bodemerosie, oevererosie, veranderende neerslagpatronen en de stijging van de zeespiegel. Door klimaatverandering wordt verwacht dat deze uitdagingen naar zullen vergroten. Belangrijke factoren waar rekening mee wordt gehouden zijn de mogelijkheid iets lokaal te kunnen implementeren, het behoud van cultuur, het behoud van toegankelijkheid tot de Cottica-rivier, de beschikbaarheid van beperkte financiële middelen en de noodzaak van de interventie om onderhoudsarm te zijn.

Er worden drie strategieën voorgesteld. De eerste richt zich op het aanpakken van bodemerosie. Het planten van vegetatie op sterk geërodeerde gebieden is een interventie voor op korte termijn, terwijl op de lange termijn de aanleg van voetpaden met drainage systeem wordt voorgesteld. Dit vermindert niet alleen bodemerosie, maar reguleert ook water en is relatief kosteneffectief. De tweede strategie richt zich op de oevererosie, wat op korte termijn houten schotten met vegetatie en stenen inhoud. Op de lange termijn is een vooroeverdam ontworpen met kribben, zodat golven breken, de stroomsnelheid vertraagd wordt en na verloop van tijd land teruggewonnen wordt. De eerste 30 meter van de oever met schotten en vegetatie is samen met het dorp gebouwd als prototype, zodat het na afloop kan worden voortgezet door het dorp zelf. Aangezien de langetermijnplannen externe financiële steun vereisen, wordt een businesscase opgesteld en gedeeld met de kapitein van Ricanau Mofo, STEORR, de districtscommissaris en het ministerie van Openbare Werken. De derde strategie richt zich op waterschade aan de huizen. Op korte termijn omvat dit het verstrekken van bouwrichtlijnen over waar en hoe meer water adaptief te bouwen. Dit wordt geplaatst op een informatiebord in het dorp. Lange termijn omvat een flood early warning systeem.

De relevantie van dit project ligt in het identificeren van interventies die effectief zijn tegen erosie en waterschade, terwijl ze lokaal uitvoerbaar zijn in de binnenlandse gebieden van Suriname. Het kan worden beschouwd als een pilotproject dat schaalbaar is naar andere dorpen langs de Cottica-rivier of in heel Suriname. Er zijn echter beperkingen aan het project. Het belangrijkste is het gebrek aan hoeveelheid en kwaliteit van gegevens. Dit had gevolgen voor de dimensionering van de interventies en hun financiële impact. Een andere beperking is dat het project geen 'droge voeten' biedt voor het dorp; het biedt een manier om waterschade te verminderen terwijl men naast de Cottica-rivier woont. Daarnaast ligt er een limitatie bij de financiering van vervolg projecten. Daarom wordt er ook een business case aangeleverd aan het ministerie van openbare werken, de District Commissaris van Marowijne Zuid-West en de kapitein van Ricanau Mofo. Zij kunnen hiermee bij internationale organisaties fondsen aanvragen en het op nemen in de toekomstige beleidsplannen.

Samengevat kan Ricanau Mofo meer water adaptief worden door de regulering van de bouwpraktijken en -locaties, door voortzetting van het prototype van de keerwanden door meer vegetatie te planten en door financiële steun te vragen om het design van de vooroeverdam en kribben te realiseren. Zoals Figuur 0.3 laat zien, draagt het niet alleen bij als een rapport, maar ook in tastbare vorm van een prototype en educatieve informatieborden in de lokale taal om de continuïteit te bevorderen en het dorp te ondersteunen.

Figure 0.3: Prototype van de oeverprotectie (links) en de informatieborden die geplaatst zijn (rechts) (schrijvers' werk)

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Figure 1.0: Meeting villagers of Ricanau Mofo (authors' work)

1. Introduction

In the context of the Multidisciplinary Project (MDP), students collaborate in teams to investigate issues on behalf of clients, which is the non-profit organisation STEORR in this project. STEORR is an abbreviation of 'Stichting Economische Ontwikkeling in Ricanau, Ricanau Mofo', standing for the economic development of the village Ricanau Mofo (Figure 1.0). MDP teams are composed of students from various disciplines within the Faculty of Civil Engineering and Geosciences, and within this project also from the Faculty of Industrial Design Engineering. The objective is to devise strategic solutions or offer advice. The MDP consists of three phases:

Phase 1: Preliminary investigation. Students embark on a comprehensive situation analysis to define a clear problem statement and objectives. A strategy, the potential contributions from various disciplines, the sequential steps to be followed and the organisation of the project team are stated.

Phase 2: Design and research. During this stage, students implement the strategy devised in Phase 1 and make adjustments as necessary.

Phase 3: In the final phase, students deliver the project outcomes to the client, stakeholders and supervisors in various forms. This encounters a conference in the Ricanau Mofo, a knowledge congress in Paramaribo and a final presentation to showcase the project's findings and conclusions.

The multidisciplinary aspect of the project is defined by the different masters who are represented by the students who collaborated on this project. The represented disciplines are MSc Environmental Engineering, MSc Hydraulic Engineering, MSc Structural Engineering, MSc Construction Management & Engineering and MSc Design for Interaction.

1.1
Project scope

This study focuses on Ricanau Mofo, a small, rural village that is located directly on the Cottica River in northeastern Suriname. It is a low-lying village. Over the last decades, it has increasingly faced flooding. This phenomenon is expected to become more frequent and intense because of climate change (Vandermeeren, 2023).

The project scope is defined by different types of system boundaries, see Figure 1.1. It has geographical, temporal, resource and conceptual boundaries. Geographic boundaries consist of that the project only studies the issues related to water quantity in Ricanau Mofo, Surinam. There are no specific population boundaries, except that it focuses on the entire population of Ricanau Mofo and keeps future prospects of living conditions in mind.

The temporal boundaries are mostly defined based on whether there is data available and for which time periods. The more historical rainfall and precipitation data there is, the more data basis there is for inter- and extrapolation.

This also flows into the resource constraints: the study must be feasible using relatively few tools and resources. The little available rainfall, waterflow, precipitation and depth data of rivers in Surinam can for example cause constraints for this project.

The project period is a conceptual constraint, as there are only ten weeks for the project to be performed in Surinam. In these 10 weeks, it is realistic to create a start and (small) improvement against the water nuisance in the area. Therefore, transferring data and knowledge, and creating shared responsibilities in the (local) community is highly important for the project to be continued.

Figure Figure 1.1: 10-week project scope of the civil consultancy engineering course and its' boundaries

1.2
Problem statement

The problem statement describes the question that needs to be addressed in the current situation in Ricanau Mofo. It represents the water expertise gap that arose from STEORR during preparations and preliminary study and is further elaborated in the literary study. In Chapter 5 the methods used to arrive at the problem statement are descibed.

Figure 1.2: The challanges affecting the floods and damage of area Ricanau Mofo, Surinam

This project focuses on three challenges that affect floods and their damage in the area, see Figure 1.2. Firstly, heavy rainfall triggers land erosion, as the village is situated close to the river, exposing house foundations and tree roots. Secondly, the riverbank is gradually eroding due to both natural processes, as it is situated in the river's outer bend, and shipping traffic that passes through the village approximately twice a month, potentially exacerbating erosion issues. Thirdly, climate change leads to extended periods of heavy rainfall, causing the Cottica River to discharge more water and resulting in rising water levels. Due to Ricanau Mofo's low-lying location, the village experiences flooding, resulting in property damage and the need for temporary evacuation. This is particularly challenging for residents who depend on boarding land as a significant source of income.
When there is heavy rainfall, the water level of the Cottica River can remain high for two weeks (Naipal, 2020). This is due to the drainage of the parallel waterways of the river compared to the Atlantic Ocean. From this, stems the following problem statement:

The need for expansion and development *(why)* ***of Ricanau Mofo*** *(where)* ***in 2023*** *(when)*, ***while the habitants*** *(who)* ***of the village struggle with, Soil erosion, River bank erosion, Increasing rainfall & The rising sea level*** *(what)*
due to the increasing probability of these events occurring *(how)*.

1.3
Research objectives

The Multi Disciplinary Project set up three objectives they aim to achieve in addressing the current situation, as shown in Figure 1.3. From these, the research questions stem in sub chapter 1.4.

Objective 1: Hydrologically mapping the Cottica River, taking tides into account
Achieving comprehensive data oversight by collecting, standardising, and supplementing existing datasets. This effort is aimed at enabling the hydrological mapping of the Cottica River near Ricanau Mofo while identifying and addressing data gaps.

Objective 2: Prioritising and applying feasibility studies to water interventions
This includes analysing which interventions are feasible, taking into account economic, cultural, geographic and political factors.

Objective 3: Addressing the continuity of the project.
This consists of ensuring that the project is taken over by a (local) stakeholder. Mitigating water nuisance requires more than the time frame of this project permits, thus continuance is important. It is also the goal to enthuse a new Multi-Disciplinary Project group of the TU Delft. Lastly. The sub-goals are ensuring the continuity of knowledge by database and creating an overview of relevant contacts.

Figure 1.3: The objectives aim to achieve in the adrressing situation of the project scope.

1.4
Research questions

In order to develop a comprehensive report on how to contribute to a sustainable and water-adaptive Ricanau Mofo in alignment with the Sustainable Development Goals (SDGs) and STEORR's long-term planning, it is crucial to identify and address a series of critical research questions. This chapter outlines the key inquiries that structure the research . First, the research question is stated.

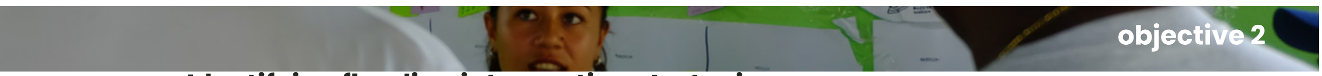
How can the project contribute to a sustainable and water-adaptive Ricanau Mofo, while ensuring its feasibility in the local socio-technical environment?

The research question is then subdivided into three subjects for which sub-questions are identified. These are to understand the hydrologic environment; to identify flooding intervention strategies and to continue the project after this study time period ends.

››

Understanding the hydrological environment

1. What is the rainfall pattern?
   a. What are the annual rainfall averages and extremes in Ricanau Mofo?
   b. Are there any indications of long-term changes or trends in rainfall?
2. What is the flow pattern?
   a. Which data is required to hydrological model the Cottica catchment for practical purposes?
   b. What is the relationship between the water level and discharge at high tide during the dry season?
3. What does a flood in Ricanau Mofo look like?
   a. What are the triggers for flooding events in Ricanau Mofo?
   b. What is the order of magnitude of the discharge in Ricanau Mofo during dry season?



››

Identifying flooding intervention strategies

1. What interventions are there to identify land erosion, river bank erosion and flood damage to the urban environment?
2. Which intervention could be implemented as a pilot within 10 weeks in Suriname?
3. What are the logistical, financial, and environmental constraints to be taken into account when selecting an intervention?

››

Enhancing the continuity of the project

1. Which stakeholders have the interest and resources to continue the project?
2. Which local authority plays key roles in continuity?
3. How can the obtained knowledge of this project be best communicated and passed on to these stakeholders?

Figure 2.0: View from river bank Ricanau Mofo (authors' work)

2. >> Preliminary study

In this chapter, the surroundings of Ricanau Mofo are explored. The focus is on reviewing existing literature to bridge the knowledge gap and provide insights relevant to our research question.

This starts with examining the demographics of the village, in sub-section 2.1, and the region in sub-section 2.2 (see Figure 2.0). After there is more insight into the 'who', it is elaborated which interventions, against the water damage, have already been implemented in Ricanau Mofo in sub-section 2.3. It is outlined on what scale they are implemented and what challenges arise with the effectiveness of the interventions.

Lastly, sub-section 2.4 describes the literature study of interventions implemented in Surinam as a whole. It is shown that there are possibilities in Surinam to mitigate floods and their damage, and the challenges that arise in their implementation.

2.1
The community of Ricanau Mofo

2.1.1 Socio-demographics of Ricanau Mofo
Ricanau Mofo is an agricultural village, with approximately 1000 inhabitants according to STEORR. This number has been growing rapidly, as the COVID-19 crisis caused a huge increase in newborns. However, due to the lack of educational opportunities and lack of employment in the area, many young adults move away from Ricanau Mofo. Demographically, there are many children with respect to young adults and the elderly (VandeMeeren, 2022).

Ricanau Mofo represents a community with a rich cultural heritage. Many of their daily activities are based on agriculture, housekeeping and (cultural) traditions (VanderMeeren, 2022). Every family has their own harvesting ground in the forest, which they reach per foot, per boat or per car. However, their daily lives are vulnerable to the impacts of climate change. For example, the increasing occurrence of floods on the villages' harvesting grounds affects the financial ability of villagers, as this may cause a loss of harvest and thus a loss of income.

'I fear the flooding of my home and my land with harvest the most,' explains a villager in an interview (Goossens, Marsboom, Plaghi, 2022).

2.1.2 Communal places and maintenance
Vegetation, soil and properties existing on personal ground are the responsibility of the closest house or land owner. See Figure 2.1 for an example of a communal space at the river. They decide in which degree the place is taken care of. The communal places are cleaned or repaired when activities are planned. So the maintenance of these communal places is strongly influenced by the amount of activities at the location according to Goosens et al. (2022).

Figure 2.1: Ricanau Mofo's communal place at the river bank and some of her villagers.

2.1.3 Connection between social activities and urban environment

Goossens et al. (2022) and Vandermeeren (2022) state a significant connection between social activities and the urban environment. It illustrates the significance of the river bank in terms of spatial importance to meet their needs directly or indirectly. Figure 2.2 shows where current activities which address these needs are taking place. Chapter 2.2 describes this connection and the analysed needs by Vandemeeren in depth.
This illustrates the reason why interventions are implemented in Ricanau Mofo as different boat docks, bathing piers and open locations where chairs can be placed.

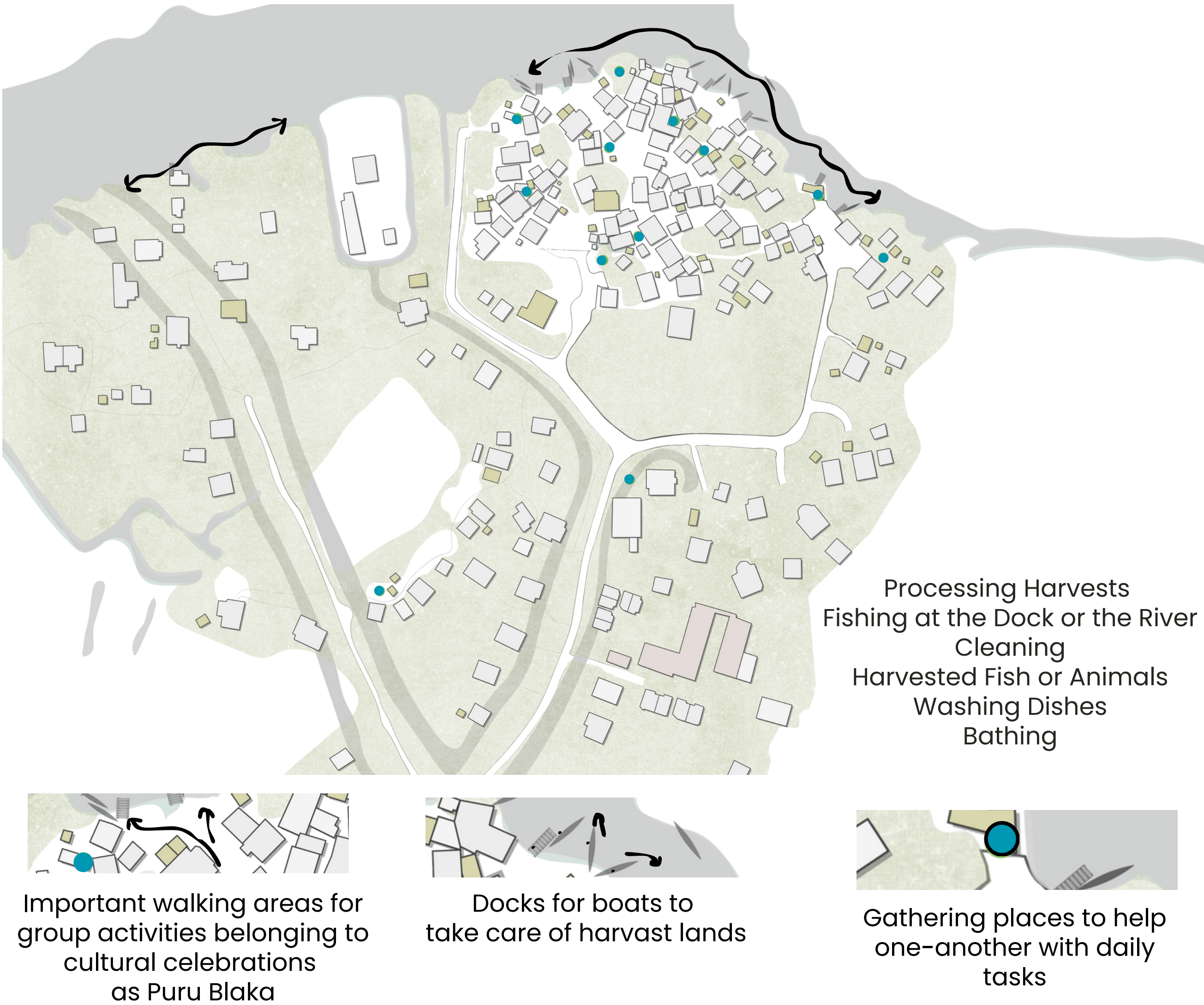


Figure 2.2: Overview of activities meeting analysed needs; mostly centered around the river bank of Ricanau Mofo.

2.2
Geographic features

The design research, conducted by Goossens, Marsboom, and Plaghki (2022), builds upon the information collected from historical, architectural, and landscape analyses. This information is synthesised to develop designs for Ricanau Mofo's future.

Figure 2.3: River bank or Ricanau Mofo and the river bank of similiar river village Wan Hatti: close and (still) distant positioning of housing due to increasing bank erosion.

The study underscores the necessity for residents to adapt their future homes to the challenges posed by the climate in order to sustain their livelihoods in the village. Various forms of elevated housing are explored as potential solutions to mitigate the impact of weather conditions in Ricanau Mofo. However, it is important to note that the study lacks the quantification of the proposed water interventions and explicit designs.

Vandermeeren's study in 2022 explores the impact of climate change on Ricanau Mofo's needs and underscores the importance of preparedness for potential threats. Using a participatory action research approach involving local community input, an integrated risk management plan was developed to enhance community resilience. The study reveals that the community faces higher temperatures and various climate-related hydrological phenomena due to climate change, including increased temperatures, higher peak rainfall, and rising water levels. These phenomena directly or indirectly threaten the community's basic needs, including physiological needs (such as food, water, and temperature regulation) and the need for safety and security (including stability, protection, financial security, and health).

Ricanau Mofo, with approximately 1000 residents, an estimate, remains a relatively isolated community but has been the focus of various initiatives over the past two decades aimed at improving living conditions, such as connecting to the electricity grid, providing access to running water, and constructing a nine-kilometre road linking the village to the nearest town, Moengo (Vandermeeren, 2022).

After the project team inspected other villages during a field trip situated along the Cottica river, Ricanau Mofo appears to be the one experiencing the most flooding. The different river banks are portrayed in Figure 2.3. This is mainly related to the location of the village, which is very low and in the outer bend of the river, and due to the fact that the subsoil is mainly clay, whereas other villages often also have a top layer of sand. The clay layer makes it more difficult for water to infiltrate and the clay soil is prone to erosion.

2.3
Existing interventions against flooding in Ricanau Mofo

As the increasing occurrence of floods influences daily life in Ricanau Mofo, villagers have taken multiple attempts to mitigate the damage.

As explained, villagers are responsible for maintaining their own land, thus the interventions seen are only implemented on people's own ground. For example, the family that lives next to the river bank has placed wooden bulkheads on the river bank to trap sediment and keep the ground from declining after heavy rainfall. Also, it can be seen that some houses are placed on poles and some new houses have elevated floors. see Figure 2.4. For some houses that were already built and experience water nuisance, it can be seen that a small 'wall' from stone has been constructed around the house to keep the water out of the house. Lastly, the addition of gutters on the roof can be seen in some houses to decrease spot erosion.

A more village-wide implementation is the excavation of drainage channels that function as a drainage system. However, maintenance poses a real challenge here as they are overgrown with vegetation and there is no responsible person or organisation to maintain it. Also, this drainage system is not capable whenever there are high water levels in the entire village as they only have a low capacity for regulating water.

Another challenge is the decline of vegetation. As the river bank is an important meeting area, it is kept clean of vegetation as seen in Figure 2.4. However, this vegetation also ensured ground settlement. With its removal, the ground is more exposed to erosion.

In summary: While all of the villagers struggle with water nuisance, most interventions are implemented on the scale of one household, as people are responsible for the perseveration of their own land. The only intervention that is implemented on a village scale is the drainage system, which severely lacks maintenance.

Figure 2.4 : Housing on poles in Ricanau Mofo (left); Bulkheads placed at the river bank by inhabitants (authors' work)

2.4
Existing interventions against flooding in Suriname

Ricanau Mofo is not the only village in Surinam that struggles with floods and their damages. In fact, it is a widely known problem across the country. There have been studies about these phenomena and possible interventions. This sub chapter summarises multiple kinds of research that can contribute to this project.

Figure 2.5: Mangrove plantation created by proffesor Siewath Naipal (autors' work).

Firstly, along the Surinam River, there are multiple villages and cities that face floods. Van den Berg van Saparoea, de Brauw, Nelissen and van der Ent (2007) conducted research on how flood damage here can be mitigated by introducing an effective flood early warning system. The function of such a system would be to alert residents along the Suriname River in case of future floods. This system relies on a hydrological model for predicting water levels, which requires extensive data on water levels and precipitation in the Upper-Suriname area. This research aimed to improve the warning model by utilising this data and conducting additional fieldwork. Van den Berg et. al. concluded that collaboration with stakeholders is also a crucial aspect of implementing the warning system. It is important to apply this knowledge in this project.

Activities in the interior include repairing and replacing the staff gauges installed by this 2007 project team, conducting discharge measurements, and identifying suitable locations for autographic water level recorders. These efforts enable the estimation of flood wave velocities, the determination of water level relationships between villages, and the creation of a monthly-scale rainfall-runoff model.

Augustinus (2004) examines geomorphological and mangrove-related factors contributing to riverbank erosion in the lower reaches of the Suriname River and the Commewijne, particularly in the tidal zone. Figure 2.5 portrays a mangrove plantation. Commewijne's riverbank erosion is significantly influenced by natural geomorphological processes, including outward erosion in river bends and the impact of tides, leading to vulnerable low riverbanks prone to flooding during high tides. Mangrove forests, characterised by their dense network of above-ground roots, branches, and trunks, serve as a vital natural defence. They reduce wave impact, slow down currents, and stabilise the soil with underground roots. Historical riverbank erosion in Commewijne stemmed from plantation development, disturbing natural mangrove growth, especially where docks and structures were erected.

Additionally, agricultural practices, such as drainage, have increased soil compaction and subsidence, exacerbating vulnerability to erosion during flooding. Recent decades have seen a rise in riverbank erosion in Commewijne due to increased human settlement along the rivers. This often involves the clearing of mangrove trees for better views or reduced mosquito and sandfly populations. It is important to take these factors into account when studying the Marowijne River.

Winterwerp et. al (2020) delve into the effectiveness and application of permeable dams over a period of roughly 15 years in regions like Guyana, Indonesia, Suriname, Thailand, and Vietnam. Figure 2.6 shows an example at Weg aan Zee, Surinam. The study aims to consolidate lessons learned, evaluate how these dams function within the physical-biological coastal system, and provide an overview of associated costs. The key philosophy behind permeable dam construction is to rehabilitate mangrove habitats by restoring fine sediment dynamics, aligned with the overarching principle known as "Building with Nature." The main findings highlight the importance of understanding the physical-biological system comprehensively, exercising patience and persistence given the long time frames required for mangrove green belt rehabilitation, and ensuring active stakeholder engagement.

While the paper outlines conditions under which permeable dams may succeed, it underscores that local site-specific factors significantly influence outcomes, making it challenging to provide a one-size-fits-all assessment of success or failure.

These studies show that there are possibilities for Surinam to mitigate floods and their effects. However, the behaviour of water and its damage is not yet quantified for Ricanau Mofo, and the local values and possibilities are not studied, creating knowledge gaps that need to be addressed. It also creates the research gap of which (set of) intervention(s) can be effective to mitigate damage caused by the behaviour of water.

Figure 2.6: Permeable dams constructed near Weg naar Zee, north of Paramaribo, Suriname (photos by E. Van Lavieren, Winterwerp et. al, 2020)

3.

Figure 3.0: Stakeholder analysis (authors' work)

>> Stakeholder analysis

The stakeholder analysis describes which parties have been contacted and have collaborated in a certain way. With the theory of Bryson & Humphrey, the stakeholders are divided into 'Players', Subjects', 'Context setters' and 'The crowd'. Chapter 3.2 explains stakeholders with many resources and high interests. Chapter 3.3 describes stakeholders with little resources but high interest. Chapter 3.4 contains the stakeholders with many resources but low interest and Chapter 3.5 dives into stakeholders with little resources and low interest.
















3.1
Collaborating stakeholders

For collaboration purposes, a stakeholder analysis is performed. All of the stakeholders in this chapter have been contacted during the period of the project, but they did not all play the same part in the project. By researching the stakeholders' objectives and values, it can be mapped how much interest the stakeholder has in the water nuisance in Ricanau Mofo and how much resources, or 'power' they have in changing the situation (see Figure 3.1). It is important to realise that high power could be positive as well as negative for realising the goals of this project.

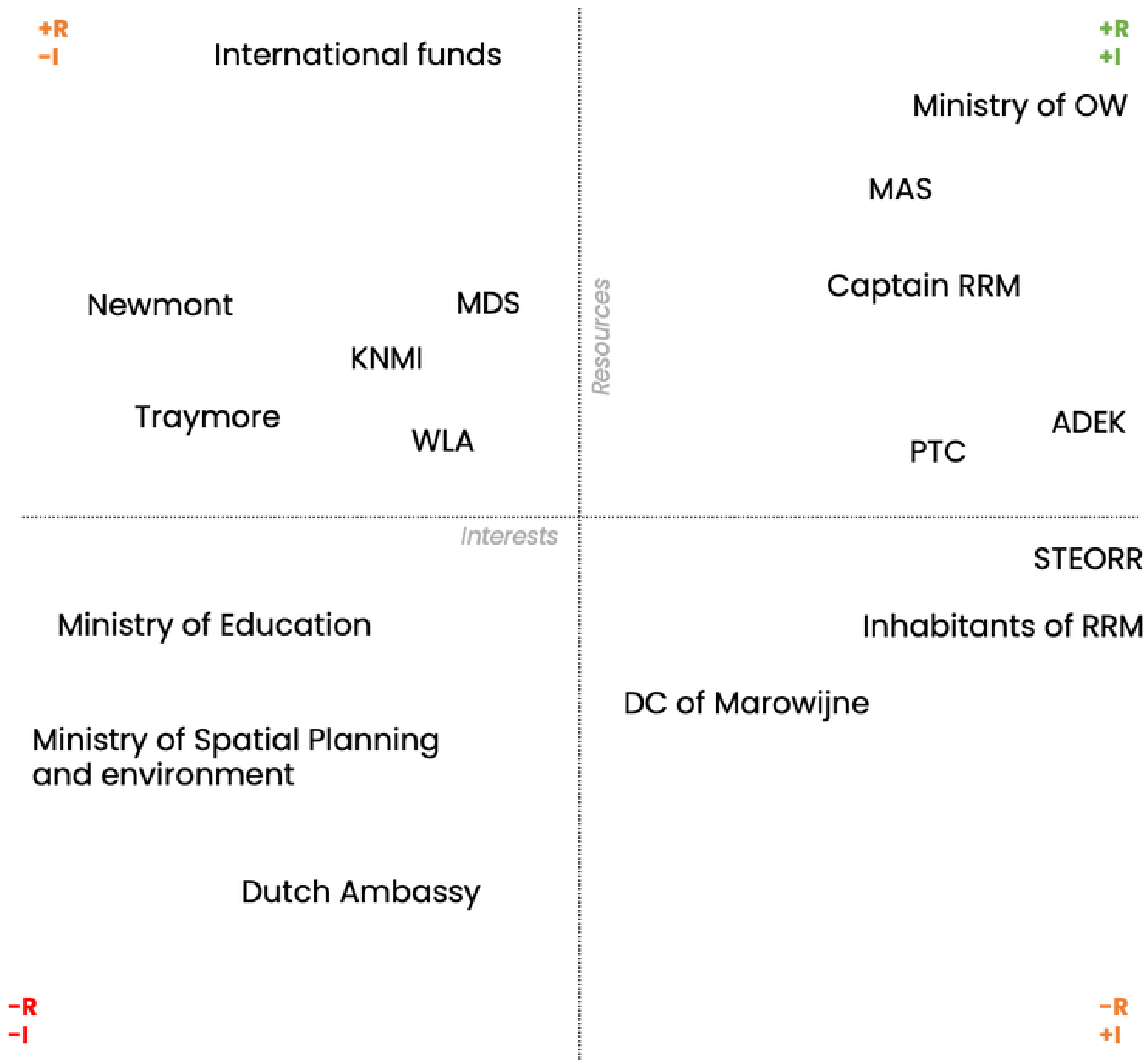


Figure3.1: Overview of resources and interests of the collaborating partners of this project (authors' work)

3.2
‘Players’ - many resources and high interests

These actors are also called the Players according to Bryson & Humphrey (2003). They have many resources to catalyse change in the current situation and have a certain interest in the problem. These are the Ministry of Public Works, the MAS, the Captain of Ricanau Mofo, professor Naipal of the ADEK, and PTC.

These actors are also called the Players according to Bryson & Humphrey (2003). They have many resources to catalyse change in the current situation and have a certain interest in the problem. These are the Ministry of Public Works, the MAS, the Captain of Ricanau Mofo, professor Naipal of the ADEK, and PTC (Figure 3.2).

The Ministry of Openbare Werken (Public Works) is responsible for developing, building and maintaining public works for a liveable, clean and beautiful Surinam (Ministerie van Openbare Werken, 2023a). The interesting subdirectories are the sub-directory of Wet & Dry Civil Technical Works; the sub-directory of Public Green & Waste; and the sub-directory of Research & Innovation. These initiate, implement and maintain projects that share common ground with water management.

The Maritieme Autoriteit Suriname (MAS) is involved in various activities, including measuring rivers, marking navigational channels, and ensuring safe navigation. They are also responsible for registering and inspecting vessels, providing advice on the construction of waterworks, and piloting ships according to the Law of Maritime Authority in Surinam (Wijdenbosch, 1998). They also collect data on several rivers in Suriname, for example, depth measurements, which is interesting for this project (Maritime Authority Suriname, 2022). Thereby, MAS could provide information about ships, maximum lengths and depths, tidal reports, and charts with water depths for the entire Suriname.

The village is governed by Captain Mésack, who can be seen as the ‘mayor’ of Ricanau Mofo. The captain governs and directs each decision that concerns his village. The captain must report to the District Commissioner (DC) (Goossens, Marsboom & Mathieu, 2022).

Professor Naipal is a hydrologist, working as a professor at the Anton de Kom (AdeK) University of Surinam. The university accommodates multiple bachelor studies, including an Infrastructure and Civil Engineering bachelor (Anton de Kom Universiteit, 2018). His personal goal is to recover and reinforce original, nature-based coastal protection in Surinam (United Nations Surinam, 2020). He initiates and implements multiple projects to contribute to this goal, one of which is called ‘Weg naar Zee’, for which he grows and plants mangroves (Anton de Kom Universiteit, n.d.).

PTC is the Polytechnical College in Surinam; it is a university of Applied Science. Its mission is to provide applied scientific education with professional and market-oriented perspectives, efficiently contributing to the competence of the student (PTC, n.d.).

Figure 3.2: Walk through Ricanau Mofo with captain Mésak, meetings and conference with MAS and Ministry of Public Works multiple directories and Professor Naipal visiting Ricanau Mofo for hydrological (authors’ work). PTC group picture at the entrance (PTC website, 2023)

3.3
‘Subjects’ - little resources but high interest

Actors with little resources to address the water nuisance in Ricanau Mofo, but high interest in improving the situation. Bryson and Humphrey (2003) distinguish this group as the subjects. This is interesting as they might not have many resources, but could become key stakeholders in the ultimate realisation. These are the district commissinar of Marowijne and the inhabitants of Ricanau Mofo (Figure 3.3).

For this project, the inhabitants of Ricanau Mofo have high interest but little resources. They lack the financial capacity for great skill interventions but are at the same time the key players for implementing an intervention. The same goes for the District Commissioner of Marowijne (DC), who is also financially limited and has foremost knowledge in other areas but could still be an important stakeholder to collaborate with. The captain of Ricanau Mofo reports to the DC.

The power of the inhabitants lies in the preservation of the village’s communal spaces. The community utilises these areas to facilitate social activities, including a football field, two recreation centres, a church, and shelter structures for ceremonial purposes (Figure 3.4). What sets this village apart is the presence of two chicken farms, two grocery stores, a nursery, and an agricultural greenhouse. Some of these facilities are supported by organisations like STEORR or international funding bodies (Goossens, Marsboom, Plaghi, 2022).
For the upkeep of the village's shared spaces, the captain enlists a team of adult males for repairs. The team requests a daily wage for their services (Mésak, 2023).

Figure 3.3: Meeting the District Commissioner and collaboration with villagers of Ricanau Mofo (authors’ work)

Figure 3.4: Overview of common properties in Ricanau Mofo (Goossens, Marsboom, Plaghi, 2022)

3.4
'Context setters' - many resources but low interest

These actors are interesting as they have many resources, but they have low interest in the project. Bryson and Humphrey (2003) identify them as the Context Setters. Or at least, at first. When the problem is framed in a certain way or with certain collaborations, the interests of these actors can be encouraged. This applies to international funds, the MDS, KNMI, Newmont, Traymore and the WLA (Figure 3.5).

According to the field inspection, Surinam (partly) relies on international funds for their (mega-)projects. Therefore, international funds have high power. However, they do not necessarily have a high interest when not stimulated.

The daily tasks of the Meteorological Dienst of Surinam (part of the Ministry of OW) incorporate accumulating climate data and posting daily weather forecasts on the Facebook page of the Ministry of Public Works (Meteorologische dienst Suriname start dagelijkse weersverwachtingen, 2023). They carry power as they have non-public data about precipitation, but might not share high interests.

The KNMI is also a context setter. It is a Dutch company that accumulates weather, climate and seismological data and functions as a knowledge centre (KNMI, n.d.). It has been collaborating with the MDS for almost 25 years. In August of 2023, the KNMI was given the opportunity by the Dutch Ministry of Foreign Affairs to enhance this collaboration with (more) financial resources (KNMI versterkt samenwerking met Suriname, 2023). However, it is not likely for the KNMI to foster a high interest in the project.

Located approximately 60 kilometres south of Moengo, Newmont is mining open-pit gold. Ownership of the mine is structured as a limited partnership, with Newmont Suriname holding a commanding 75% interest, and serving as the managing partner. The estimated mine life spans 12 to 14 years. Annually, this operation yields around 393,000 attributable ounces of gold, contributing significantly to both the global gold supply and the local and national economies. For now, most of the material transport goes by road (Newmont Corporation, 2023). The other part goes by boat via the port of Moengo, which is owned by Traymore. Twice a month a ship sets sail to navigate through the Cottica river and reaches the Atlantic Ocean.

Traymore is a company responsible for the operation and management of the Moengo port. While they serve multiple clients, their largest and most significant client is Newmont. Traymore requires certification to collaborate with Newmont. The primary role of Traymore N.V. (2022) includes managing the exportation of goods, facilitating shipments to and from Moengo, and connecting the region with the global market. Traymore is under the ownership of Mr Profijt.

The WLA (Waterloopkundige Dienst) performs measurements on a national level about changes in the water level of Surinam. It is a sub directory of the sub directory Research and Innovation of the Ministry of Public Works (Overheid van de Republiek Suriname, n.d). It has power by the data it accumulated but does not directly overlap with the research objectives.

Figure 3.5: Meeting the Meteo, KNMI, Traymore and WLA. Newmont is direclty contacted via Traymore (authors' work)

3.5
'The crowd' - little resources and low interest

These actors are identified as the crowd according to Bryson and Humphrey (2003). They have low power and interests in the problem statement, but do have certain similarities with the project. These are the Ministry of Education of Surinam, the Ministry of Spatial Planning and Environment and the Dutch Embassy in Paramaribo (Figure 3.6).

For example, the Ministry of Education coordinates, leads and regulates the educational system of Surinam (Overheid van de Republiek Suriname, n.d.-b). Education has an indirect effect on water nuisance and its mitigation, through the spreading of knowledge. The Ministry of Spatial Planning and Environment is set up with the goal of improving the living conditions in Surinam as a whole. It aims to create a country in which future generations can still enjoy a 'Switi Sranang', a country that incorporates nature in its spatial planning (Overheid van de Republiek Suriname, n.d.-c).

The Dutch Embassy is the last stakeholder in this project with limited influence in the sociot-echnical environment of Ricanau Mofo. It represents the Dutch government in Surinam and helps its citizens abroad where possible (Ministerie van Buitenlandse Zaken, n.d.).

Figure 3.6: Meetings with Ministry of Education coordinator, ROM and Dutch Embassy (authors' work)

Figure 4.0: Installing measurement instruments (authors' work)

4. >> Quantitative hydrological study

This chapter describes the quantitative hydrological analysis of the Ricanau Mofo area, located on the Cottica River (Figure 4.0). This is an important step for understanding the watercourses in the area and for quantifying future solutions. This understanding can also lead to improved flood alerts.

This chapter relates to the first research objective named in 1.3. It is aimed at enabling the hydrological mapping of the Cottica River near Ricanau Mofo while identifying and addressing data gaps.

Chapter 4.1 describes the study area. Chapter 4.2 describes the data needed to map the area hydrologically. Then, Chapter 4.3 discusses what data is already available. Chapter 4.5 describes how additional research was implemented to gather data, with Chapter 4.4 providing a list of materials used for the study. Chapter 4.6 contains the results. Chapter 4.7 discusses the results and concludes on the research questions posed in 1.4.

4.1
Study site

4.1.1 Geographical information

Ricanau Mofo is a small village situated along the Cottica River in northeastern Suriname (see Figure 4.1), with an estimated population of around 1,000 residents. The village is located on the outer bend of the meandering river, which eventually flows into the sea near Paramaribo, where it experiences the influence of tides, which is discussed further in 4.1.3. The river generally has a gentle gradient and stretches approximately 150 kilometres from Paramaribo to Moengo, with a substantial portion of it running parallel to Suriname's coastline. The average drop of the river bed is estimated with a linear interpolation of the elevation of the river based on SRTM data (resolution 30x30m). The slope of the river bed as illustrated in Figure 4.2 holds 1 metre every 2000 km. The catchment of the Cottica near Ricanau Mofo is illustrated in Figure 4.3.

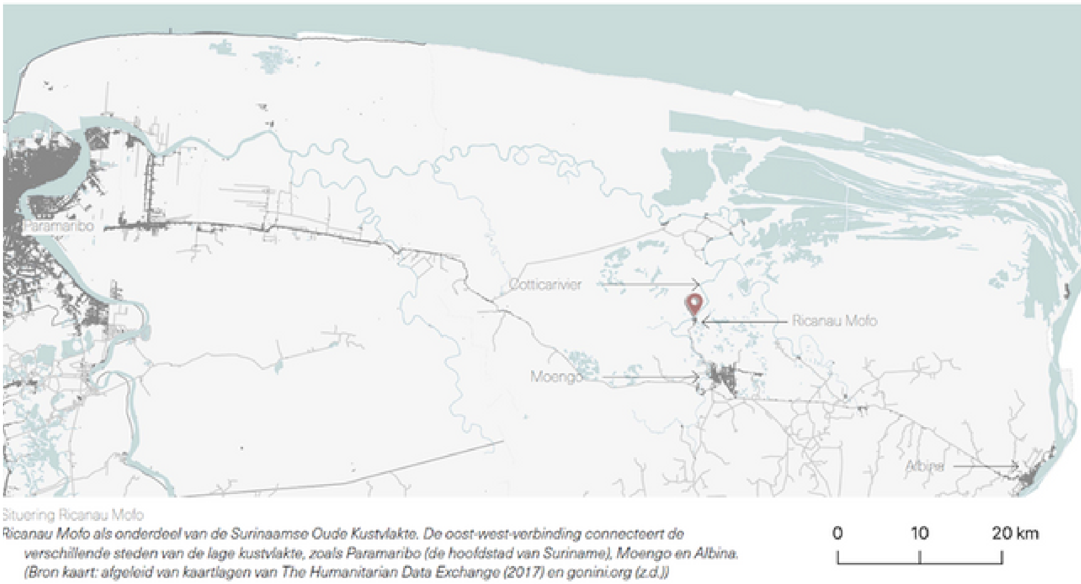


Figure 4.1: Location of Ricanau Mofo in Suriname (Vandermeeren, 2023).

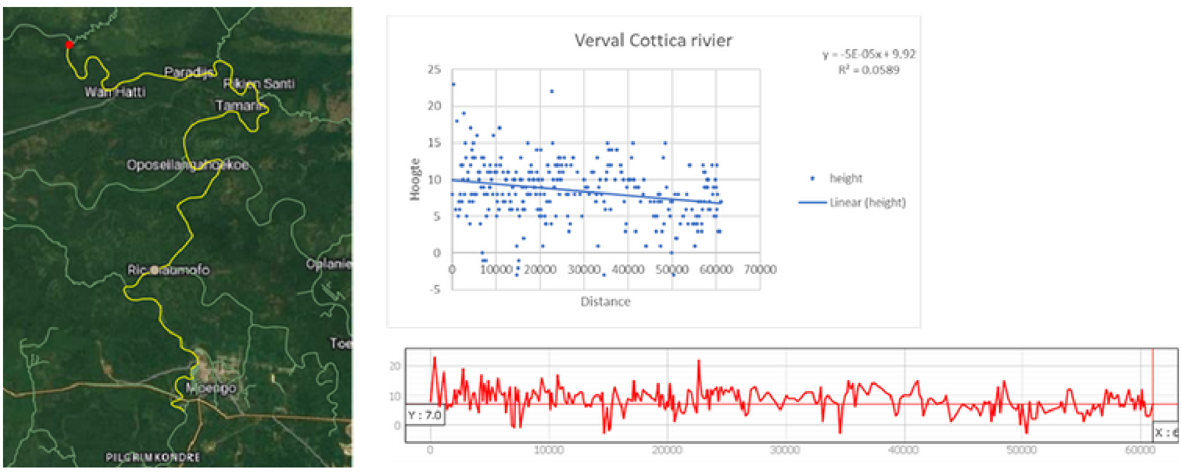


Figure 4.2: Decay of the Cottica river segment (shown left) based on 30x30m SRTM over 60 km.

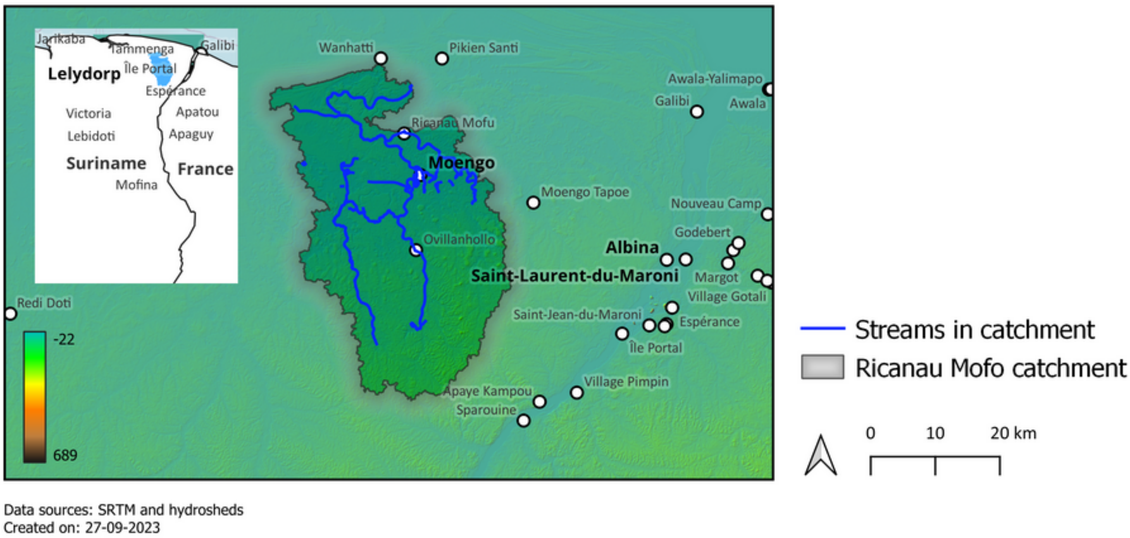


Figure 4.3: Catchments of the Cottica river (authors' work)

4.2 Climate system, change & waterlogging

Ricanau Mofo experiences a tropical climate characterised by high humidity and abundant rainfall levels. These climatic conditions contribute to the lush vegetation that is typical of the region. The average monthly temperature in Marowijne ranges from 24 to 31 degrees Celsius (World Bank Climate Change Knowledge Portal.). The hottest months are usually September and October, while the coolest months are January and February. Rainfall occurs throughout the year, with an average annual precipitation of around 3,000 millimetres World Bank Climate Change Knowledge Portal.). Like the rest of Suriname, Ricanau Mofo also experiences two rainy seasons and two dry seasons, with slightly reduced rainfall during the dry periods. In Figure 4.4 the monthly mean-temperature and precipitation can be found.

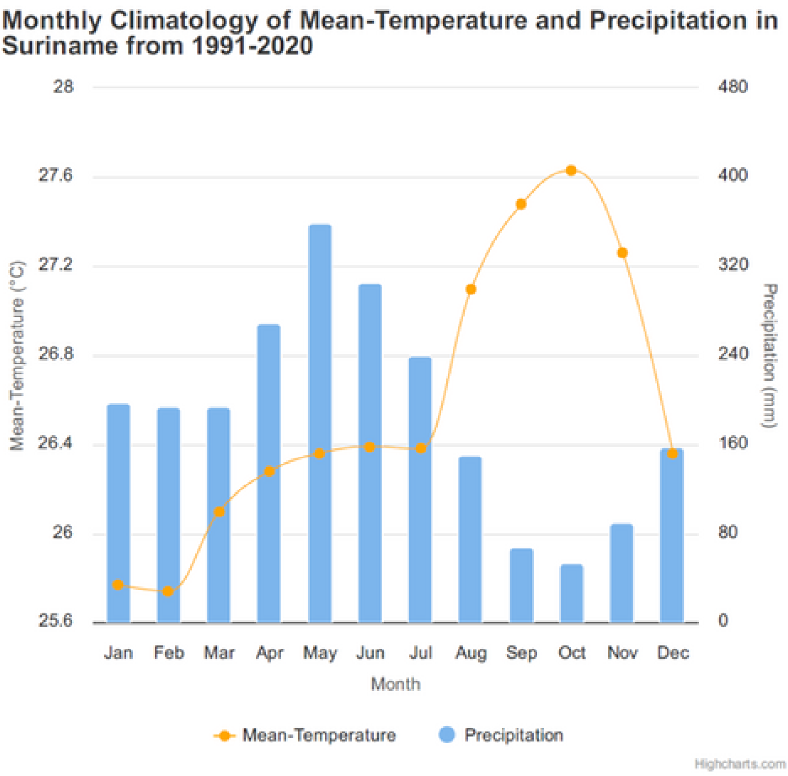


Figure 4.4: Monthly climatology of mean-temperature and precipitation in Suriname 1991-2020 (World Bank Climate Change Knowledge Portal.).

4.3 Tidal river

In the context of tidal rivers, an interdisciplinary fusion between physical oceanography and hydrology is evident. Tidal phenomena, typically manifesting predominantly along coastal regions, extend their influence inland, thus affecting water levels in rivers. This phenomenon is particularly occurring in low-lying deltaic areas, where the topographic elevation in relation to sea level remains below 10 metres (Hoitink & Jay, 2016). In Figures 4.5 and 4.6 it can be seen that a large part of water levels in the rivers of Suriname are likely to be influenced by the tides. Notably, in the case of the Cottica River, a pronounced impact of tides on the river's water levels has been observed. During low tide, the river's flow is seaward, while during high tide, it reverses direction, flowing landward. Adjacent to the village, there is a relatively deep creek, ranging from 4 to 6 metres in depth (based on self-measurements). During low tide, water from the creek flows into the river, whereas during high tide, water from the river flows into the creek. The tide also significantly affects the river's water level, with an average increase of 1.8 metres during low tide compared to high tide (MAS, 2020).

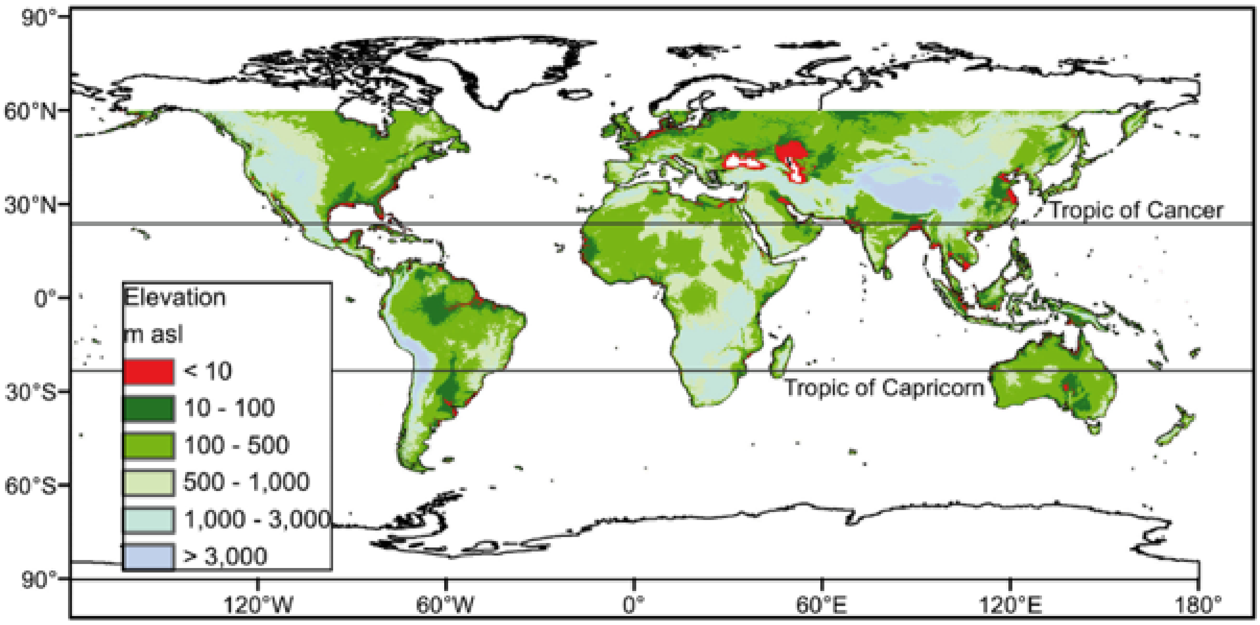


Figure 4.5: World map of elevation from the Shuttle Radar Topographic Mission (SRTM; data source: CGIAR-CSI), adopted from Hidayat (2013). In regions with elevations less than 10 m, inland rivers are likely to be affected by tidal influences (Hoitink & Jay, 2016).

In regions where direct discharge measurements are unavailable, it is customary to employ a stage-discharge curve to establish the correlation between water levels and the river's discharge. This approach enables the indirect monitoring of the river's discharge (Soulis, 2021). However, in the case of the Cottica River, the presence of tidal influences introduces complexity in establishing a direct relationship between stage and discharge. Tidal forces affect the river's stage by causing fluctuations with high and low tides, as well as impacting discharge by altering the flow direction and varying flow velocity. Nonetheless, it may be feasible to discern a connection between high and low tide water levels and the river's discharge, potentially through extensive data analysis or hydrodynamic modelling (G. Prinsen, personal communication, October 16, 2023).

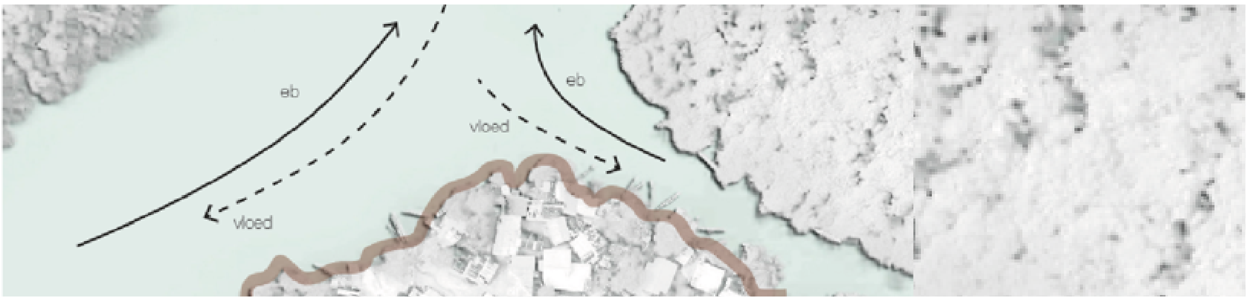


Figure 4.6: High tide (vloed) and low tide (eb) flows in RIcanau Mofo (Vandermeeren, 2023)

4.2
Required data

To predict and understand the hydraulics of the river, data collection is required (Figure 4.7). This is essential for dimensioning the interventions and coming up with prediction models. Two main components are key to understanding the area of the river in a hydrological way. The first category is the meteorological data. Suriname is a relatively low-lying country in which there are few differences in altitude. The rivers are mainly filled with rainwater, and so is the Cottica River. For understanding the hydrological behaviour of the river, data on precipitation and evaporation are therefore also essential to understanding how the hydrological system responds. In addition, it is of importance to analyse the data about future climate projections, and sea level rise to evaluate its effect on the area. To map the behaviour of the river itself, river discharge is important. By talking about the amount of water discharged, future interventions can be sized accordingly.

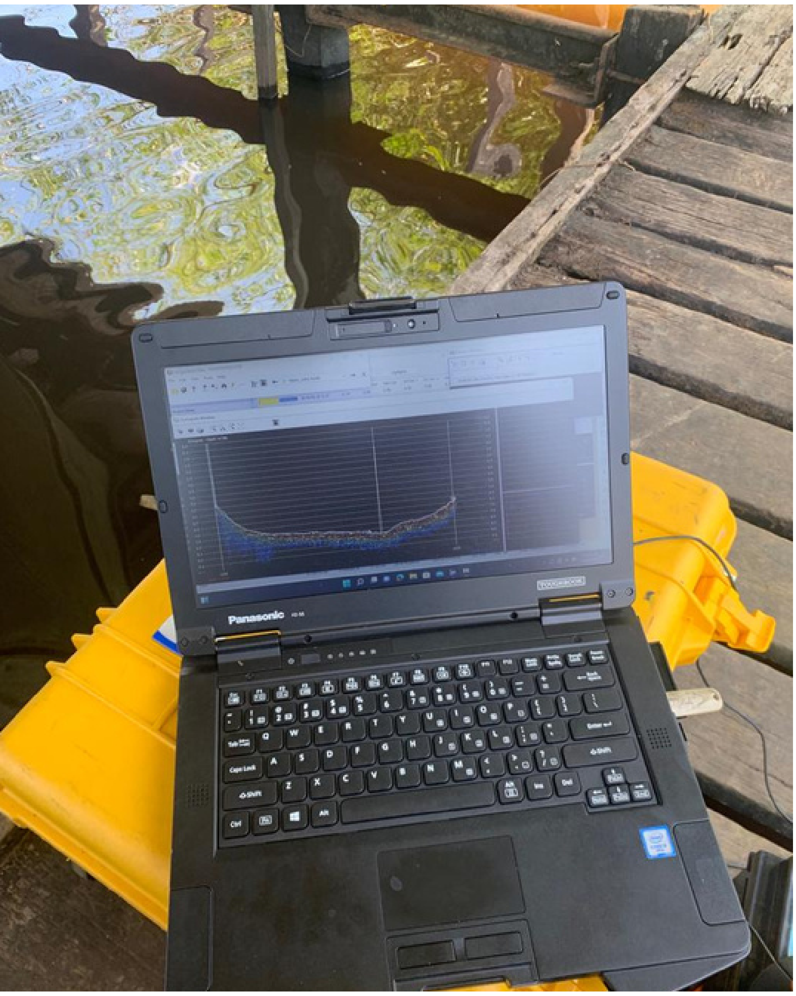


Figure 4.7: Visual representation of measurements of the bed profile (left) and water level measurements at Traymore, Moengo both by Martitieme Authoriteit Suriname

4.3
Data collection

The precipitation data of the stations of Zorg & Hoop, Zanderij and Nickerie are obtained through the KNMI and cover a timespan of April 1961 to May 2023. The data of the station of Moengo is obtained through the Meteorologische Dienst Suriname (MDS) and covers a timespan from June 2022 onward. The second component contains data about the river itself. In order to analyse how much water flows through the river the discharge needs to be obtained.

After identifying this data gap it was decided to collect the flow velocity profile of the river together with the wet bathymetry, which together results in the discharge of the river. In this research, the wet bathymetry is obtained as described in 4.5.1. in collaboration with MAS. The flow velocity profile is collected as described in 4.5.2 with Prof. Naipal for the Anton de Kom University in Suriname. In order to correct the tidal behaviour of the river it is needed to measure the water level. This data was obtained through MAS which collected the data in the nearby port Traymore, further upstream in Moengo. No historical data about the discharge of the river was available during this research.

Since the availability of data was very scarce the quantitative analysis mainly focussed on the collection of data for future research. No hydrological model was constructed, due to the lack of data. However, a **GitHub repository** was set up with all the collected data and information about the river and catchment. In Figure 4.8 an overview of the collected data can be seen.

Locations of weather stations and measurements are shown in Figure 4.9 and in Tabe 1.0 an overview of the available data in the repository is given.

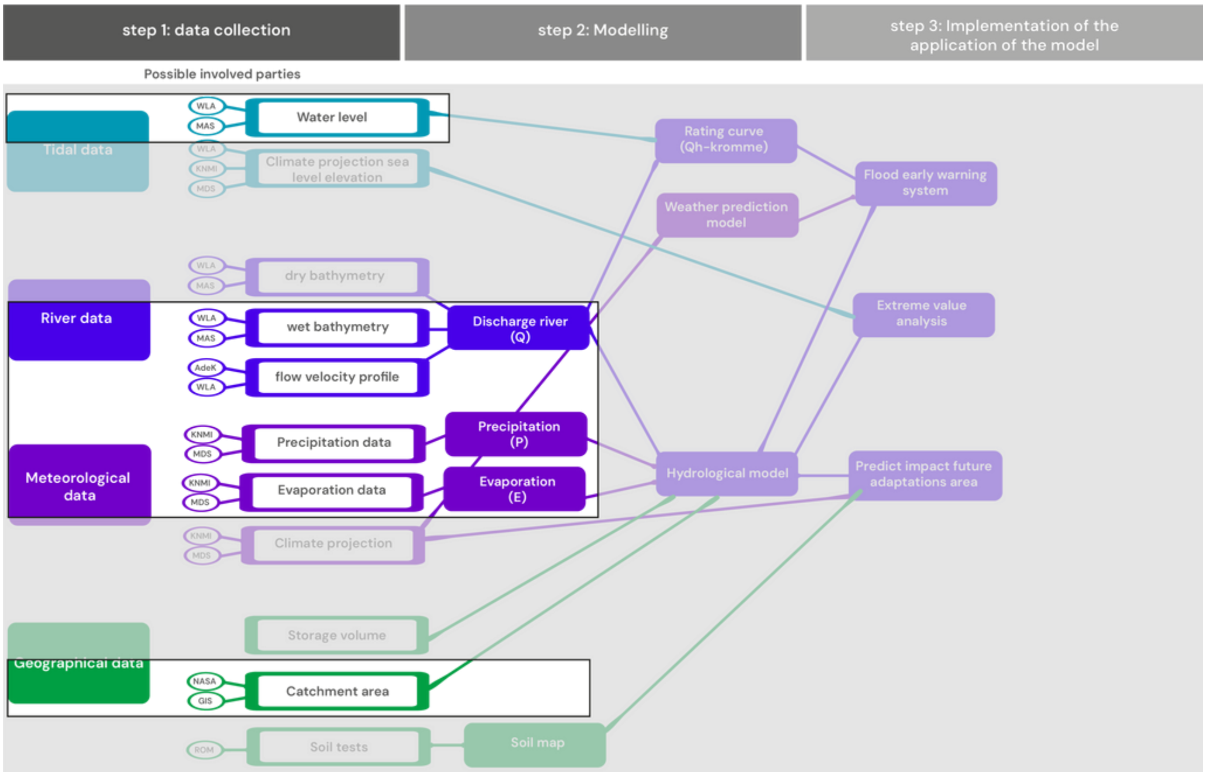


Figure 4.8: Overview of the steps to be taken before implementing data driven solutions, including possible involved parties. The boxes indicate the focus area of the current study (authors' work)

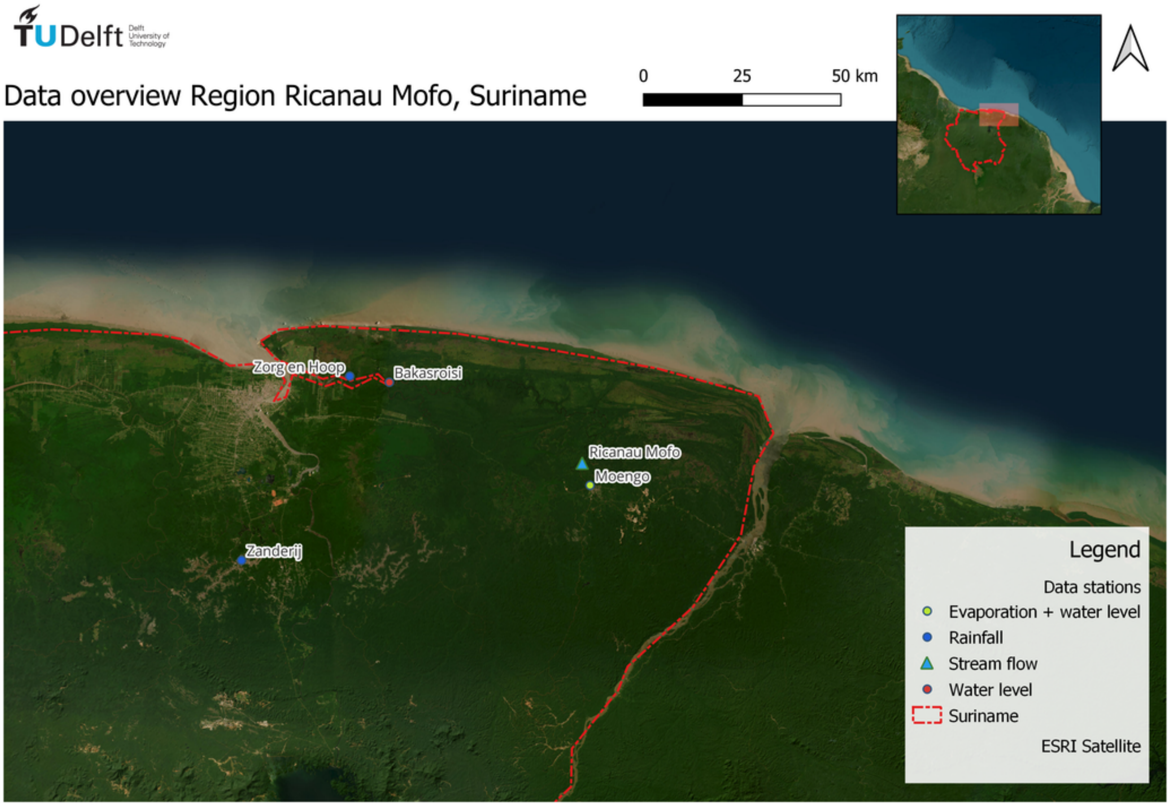


Figure 4.9: Map with important wheather stations for Ricanau Mofo and locations of measurements perfomed in this research (authors' work)

Table 1.0: Overview of data made available in the repository

Location	**Source**	**Data**	**Start dataset**	**End dataset**	**Measurement period**	**Comment**
Moengo	MDS	Evaporation	06-06-2022	31-08-2023	10 minutes	Evaporation calculated from measured Relative Humidity, Air temperature, Solar radiation and Wind speed
Moengo	MDS	Precipitation	06-06-2022	31-08-2023	10 minutes	Not yet available. Can be requested at MDS
Ricanau Mofo	AdeK, TU Delft	Flow velocity	10-10-2023	29-10-2023	5 minutes	Measurements performed during MDP
Ricanau Mofo	MAS, TU Delft	River bed profile	29-09-2023	29-09-2023	-	Measurements performed during MDP
Nickerie	KNMI	Precipitation	01-04-1960	31-05-2023	Daily	Not used for this research
Zanderij	KNMI	Precipitation	01-04-1960	31-05-2023	Daily	-
Zorg en Hoop	KNMI	Precipitation	01-04-1960	31-05-2023	Daily	-
Moengo	MAS	Water level	03-11-2023	26-09-2023	10 minutes	-
Bakasroisi	MAS	Water level	26-07-2019	26-09-2023	10 minutes	-

4.4
Materials

Additional measurements took place to fill missing data gaps as described in chapter 4.5. In this chapter a list of materials, with which the measurements were done for the Cottica River at Ricanau Mofo (see Figure 4.10), is provided.

- Measuring equipment wet bathymetry
    - Single beam echo sounder
    - GNSS GPS
    - Korjaal / boat
    - Battery
    - Sound velocity measurer SWiFT SVP Valsport
    - Toshiba Pocketbook Panasonic FZ-55
    - CEESCOPE CEE LINK-R
    - Water level gauge
    - Timer
    - Clock
    - hypack
- Measuring equipment flow velocity
    - Side Looking Doppler (SLD) OTT
    - OTT SLD EAsyUse
- Software
    - QGIS 2.28
    - Python 3

Figure 4.10: The Cottica river is hyrdologically mapped with the above descibed materials (authors' work)

4.5
Methods

In this chapter the methods to obtain missing data are described. The measurements took place in collaboration with local authority MAS and Professor Naipal of Anton de Kom University.

4.5.1 Wet bathymetry
In the pursuit of gathering bathymetric data pertaining to the Cottica River in proximity to Ricanau Mofo, a collaborative effort was established with the Maritime Authority of Suriname (MAS). A local resident loaned a traditional vessel known as a 'korjaal' to facilitate the data collection process. The equipment utilised for the survey comprised a single-beam echo sounder, which was affixed to the boat via a custom-built apparatus and subsequently immersed in the water. Additionally, a Global Navigation Satellite System (GNSS) GPS device was positioned atop the echo sounder to ensure a precise correlation between depth measurements and GPS coordinates as could be seen in Figure 4.11. Both the GPS and the single-beam echo sounder were interfaced with a CEESCOPE unit, facilitating real-time data acquisition and transmission to a Toshiba Pocketbook.

Upon transmission to the laptop, the recorded measurements were imported into the computer program Hypack for subsequent analysis and processing. To power the CEESCOPE, a dedicated battery source was employed. This configuration allowed the boat's captain to plot perpendicular lines to the direction of the river's flow, thus enabling the systematic collection of cross-sectional data. Along the straight segments of the river, cross-sectional measurements were taken at intervals of 25 meters. Within the river's meandering sections, cross-sectional data was acquired at 50-meter intervals. For the purpose of tidal correction, the timestamps of each measurement were meticulously documented.

The single-beam echo sounder operated with two distinct frequencies: a 33 Hz frequency for discerning the river's hard bottom and a 200 Hz frequency for identifying the soft bottom. Sound velocity measurements were incorporated to correct the raw data for sound travel time, accounting for variations in water particle density. Given the tidal nature of the Cottica River, all collected data was standardised to the lowest water level. This was achieved by periodic readings, taken at ten-minute intervals, of the water level from a dedicated water level gauge, facilitating the identification of both high and low water levels.

Figure 4.11: Measuring set-up for measuring wet bathymetry (authors' work)

4.5.2 Flow velocity profile

The river's flow velocity profile is assessed through the utilisation of a Side Looking Doppler (SLD). Notably, the SLD operates at a fixed angle of 5 degrees, as visually depicted in Figure 4.12. Configuration settings for deployment are managed within the accompanying software program, OTT SLD Easy Use. The SLD conducts measurements at 300-second intervals and employs a 600 kHz frequency for this purpose. The measurement grid is oriented perpendicular to the river's flow direction. Each measurement cell covers a designated size of 10 meters, implying that the SLD records flow velocity readings at intervals of 10 meters, commencing from 3 meters away from the SLD due to a 3-meter blanking distance. The data output represents the average flow velocity over 300-second intervals.

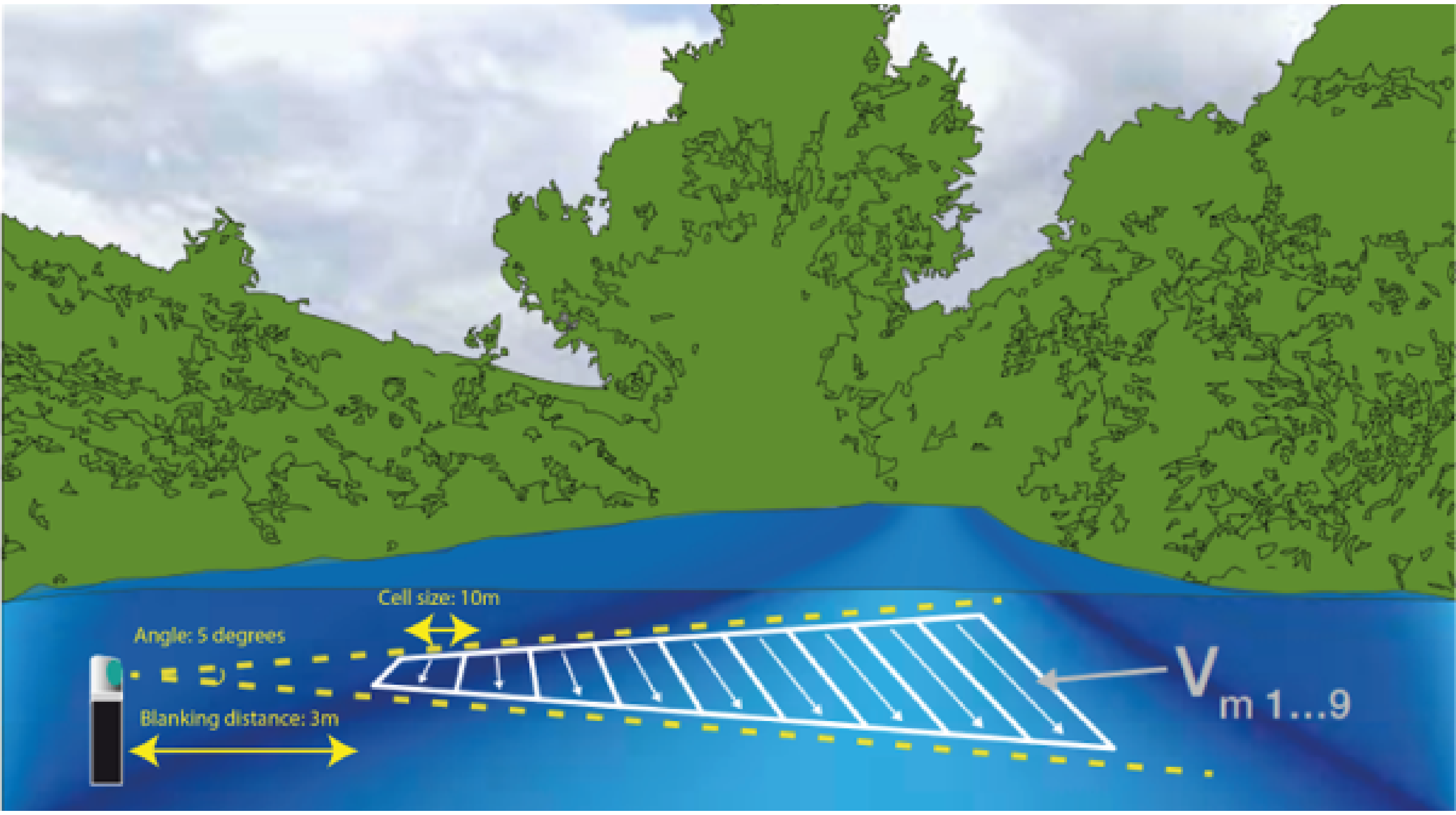


Figure 4.12: Deployment of the SLD

Figure 4.13: Location of the installation of the SLD.

Due to the tidal influence on the Cottica River, it is crucial to ensure that the Side Looking Doppler (SLD) is installed during low water levels to maintain its continuous submersion beneath the water surface. To enable ongoing measurements, it is essential to position the SLD close to the riverbed. That is why ultimately, the choice was made to place the SLD upside down resulting in a positive flow velocity in the land inwards direction and a negative flow velocity in the land outward direction. The optimal location for SLD attachment is just before the river's bend, where the flow lines of the river run parallel to one another. This specific location is visually represented in Figure 4.13 on the map.

The SLD is affixed directly to an iron bar, which is, in turn, securely fastened to a wooden plank. A protective sleeve is employed to safeguard the SLD. The plank and sleeve have been estimated to be buried at a depth of approximately 20cm into the ground, with additional anchoring to the scaffold post accomplished through the use of ropes and nails. The SLD is positioned at a depth of 1.3m distance measured from the water level during low tide. To accommodate the tidal variations, measurements are conducted during both low and high spring tides. The initial measurement occurred during low spring tide on October 7, 2023, and the final measurement was planned to take place on October 29, 2023, coinciding with high spring tide. However, due to a defect in the battery only until October 18 2023 was measured. The installation of the SLD can be seen in Figure 4.14.

The SLD not only measures the flow velocity of the river, but the water level as well. It uses a pressure sensor for this purpose. In combination with the earlier measured wet bathymetry, a rating curve of the high water level during the dry season can be set up. However, the water level measurements failed to be conducted, which made it hard to correct for the tides and to set up a rating curve.

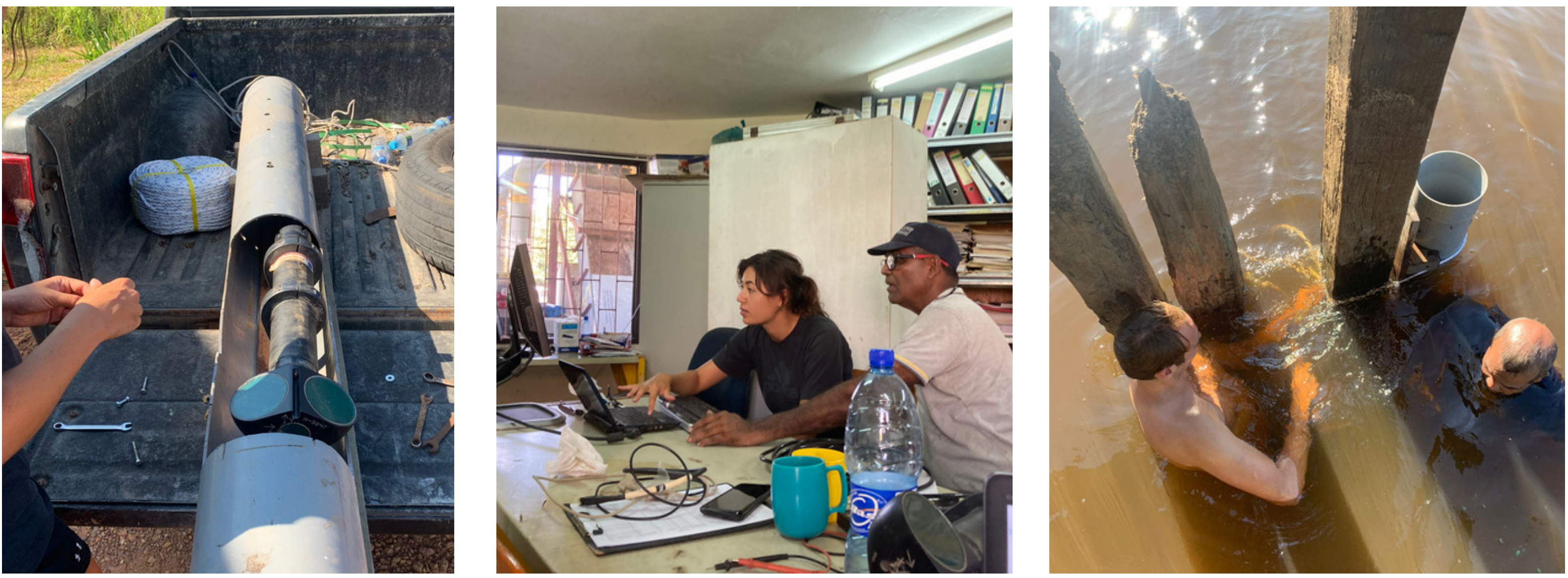


Figure 4.14: Installation of the SLD onto the jetty and data extraction with prof. Naipal (autors' work)

4.6 Results

In this section the results of the obtained measurements and data are analysed and presented. All data analyses can be found in the repository.

Analyzing the flow rate graph (see Figure 4.15), a few notable observations can be made. Firstly, the peak corresponding to land inward flow shows a notably steeper incline compared to the peak associated with land outward flow. This difference may be explained by the fact that during low tide, water primarily moves land outward along the river's natural flow direction, resulting in greater pull or flow intensity in that direction.

However, it's worth highlighting that the peak flow velocities in the land inward direction are higher than those in the land outward direction. A possible explanation could be that the water level is lower during the peak belonging to the inland flow direction than during the peak belonging to the landward flow direction. This is plausible because it is expected that when low tide turns into high tide and flow direction reverses the flow becomes nearly 0, which correlates to high and low water. The land inward peak occurs after low water, while the land outward peak occurs after high water. However, local measurements of the water level failed, so this data cannot be analysed. Additionally, the graph illustrates that near the riverbank, tidal effects lead to comparatively less variation in flow velocities when contrasted with the middle of the river. It can also be seen that near the river bank in cells eight and nine, regardless of the tide, the direction of flow almost always lands outwards.

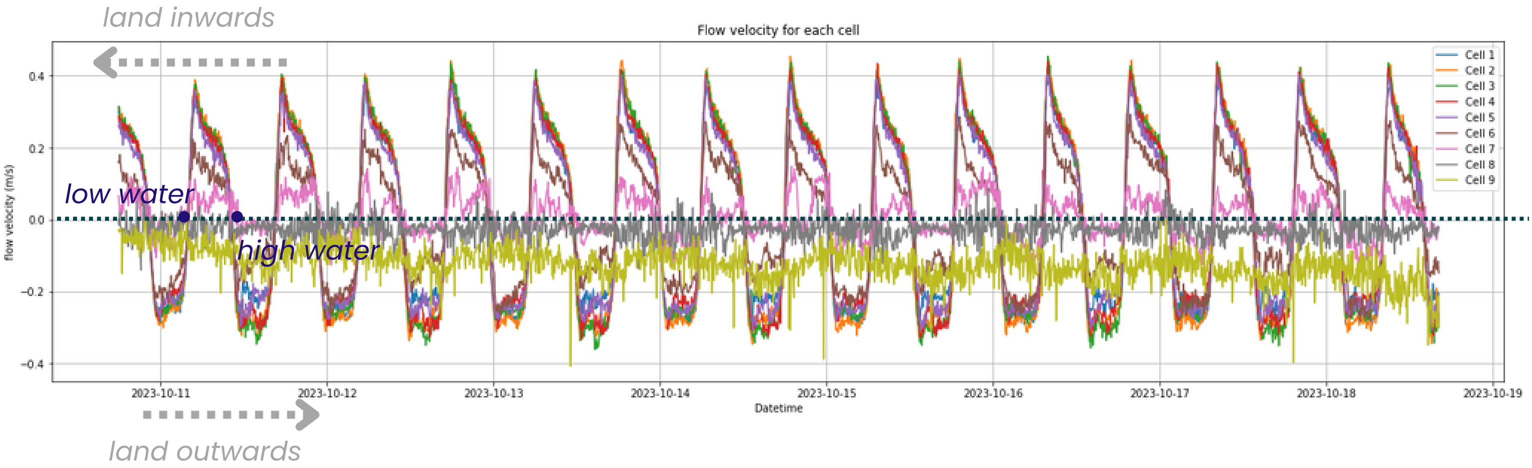


Figure 4.15: The flow velocity over the time for each cell measured with an SLD.

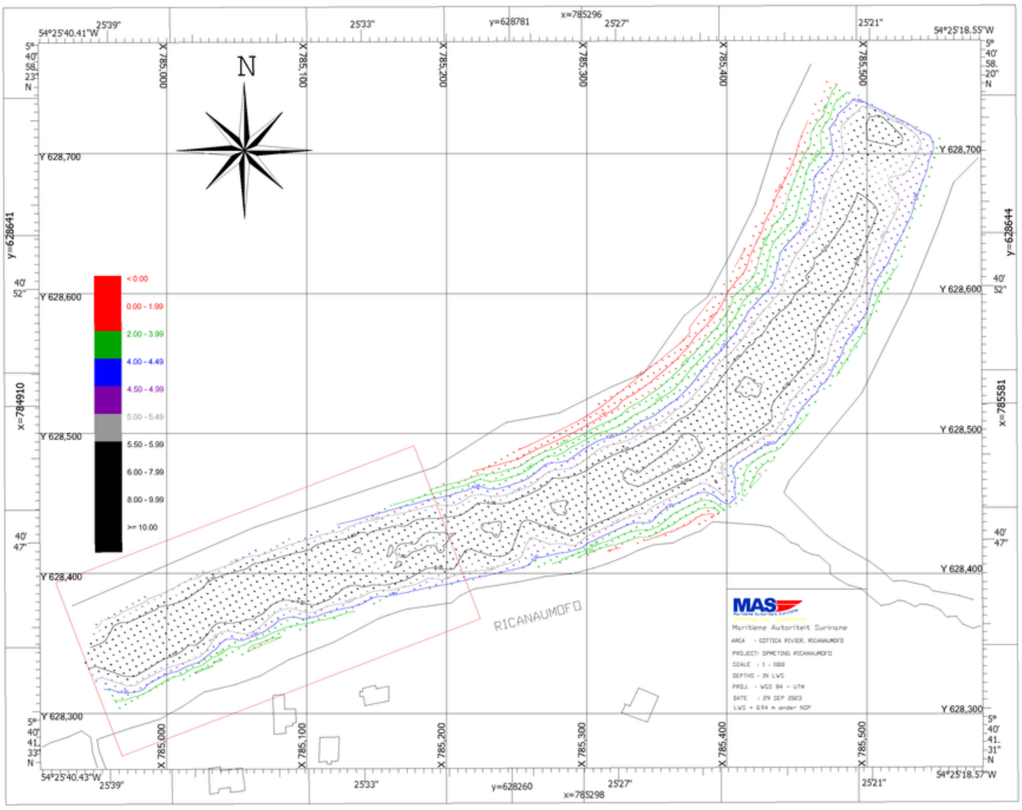


Figure 4.16: River bed profile of Cottica river at Ricanau Mofo measured with a single beam echo sounder.

Measurements of the river's depth could only be taken within a range of approximately 5 meters from the riverbank since the boat was unable to reach the far end. The depths of the river can be up to 10 meters below LWS as shown in Figure 4.16. To utilize these measurements for converting flow velocities to discharges, a profile at the SLD measurement site is essential. The average depth in Figure 4.17 is computed within 5 meters of the SLD location. In areas where the boat couldn't reach, extrapolation was performed with a slope of 1/3, estimated based on visual observation. The flow area per cell was calculated based on the average water height in Moengo because the water level sensors in the SLD were not working properly. The cross-sectional area was divided in the 9 cells according to the cells measured with the SLD. as could be seen in Figure 4.17. Multiplying the cross-sectional area times the flow velocity for each cell and summing it results in the discharge. Since the water level measurements failed it was impossible to make the cross-sectional area dependent on time and tide. That's why an average cross-section is obtained. Using the maximum flow direction land inwards the discharge results in 179.1 m3/s. Looking at the maximum flow direction land outward the maximum discharge was calculated to be 141.5 m3/s. Note that this is just an estimation to get a feeling for the order of magnitude, since the cross-sectional area doesn't take into account the changing water level, especially since it is highly unlikely that the discharge in land inward direction is higher than the discharge in land outward direction.

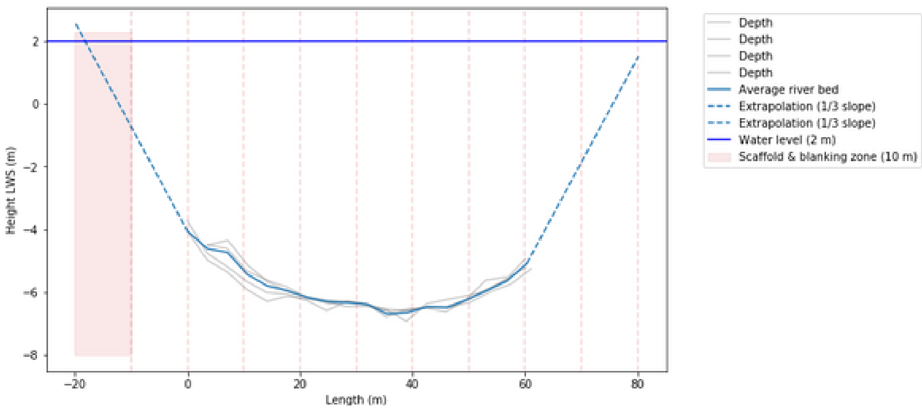


Figure 4.17: Cross section of the Cottica where velocity measurements were performed (right)

4.7 Discussion & Conclusion

In this section, there is elaborated on the discussion points arising from the results paragraph and conclusions are drawn.

The fact that the Cottica River is a tidal river makes analysing it a lot more complex. The flow is calculated by doing the cross-sectional area times the flow velocity, both of which depend on the tide. As can be seen in the results, the direction of flow in the river slows down, speeds up and is reversed under the influence of the tide. In addition, it is known that the water level also rises and falls due to the tide, which affects the cross-section. As the measurements of water level failed, a good overview of the distribution of discharge over time could not be made. Therefore, an attempt was made to determine the discharge at the time of maximum flow velocity land inward and land outward using an average cross-section. This assumes that the tide and water level do not affect the cross-section, which is actually a given that cannot be ignored. Therefore, the flows calculated at the time of maximum flow velocity are not necessarily the actual maximum flow. For future research, it is crucial to measure flow velocity simultaneously with the water level so that the cross-section can be correlated with the tide.

The bottom profile near the river banks was difficult to map because the boat could not get closer to the bank. Extrapolating the data in this area is very difficult and can lead to wrong results and conclusions.

The average water level upstream in Moengo was taken to calculate the cross-section, assuming that the water level 8 km upstream in Moengo is the same as the water level at Ricanau Mofo. Given the river's little gradient, it seems plausible, but the assumption has not been checked.

In addition, only the rainfall data of Zorg & Hoop and Zanderij were available, which was considered too far away from the research area to be included in the report. However MDS possesses recent data from a weather station in Moengo 8km upstream from Ricanau Mofo, but this was not accessible for this research. To use such data for future research it is advised to share the data according to the FAIR principles (**F**indability, **A**ccessibility, **I**nteroperability, and **R**euse of digital assets) (GO FAIR initiative, 2022).

Coming back at the objectives of this research as described in 1.4 some questions remain unanswered. Due to the lack of data, nothing could be said about the correlation between rainfall events and the discharge of the river and thus trigger events for flooding. Because of failed measurements no relationship between the water level and discharge is established. The first step in the direction of practical purposes for for example a flood early warning system is to collect and share reliable data about rainfall, evaporation, discharges of the river and the water level.

Figure 5.0: Collaboration on strategies (authors’ work)

5. >> Qualitative study

This chapter describes the methods used for intervention identification and analysis (see Figure 5.0). The qualitative data collection techniques employed include multiple interviews, observations, validating sessions, four conferences, and prototype development for a co-creational approach. The resulting strategies for addressing land erosion, water erosion and flood damage to the urban environment are stated in Chapter 6.

5.1
Methods used for context and intervention analysis

The qualitative data methods used are interviews, observations, workshops, case studies, conferences as generative sessions, function analysis and prototype development. All in order to construct a broad understanding of the context (Sanders&Stappers, 2012).

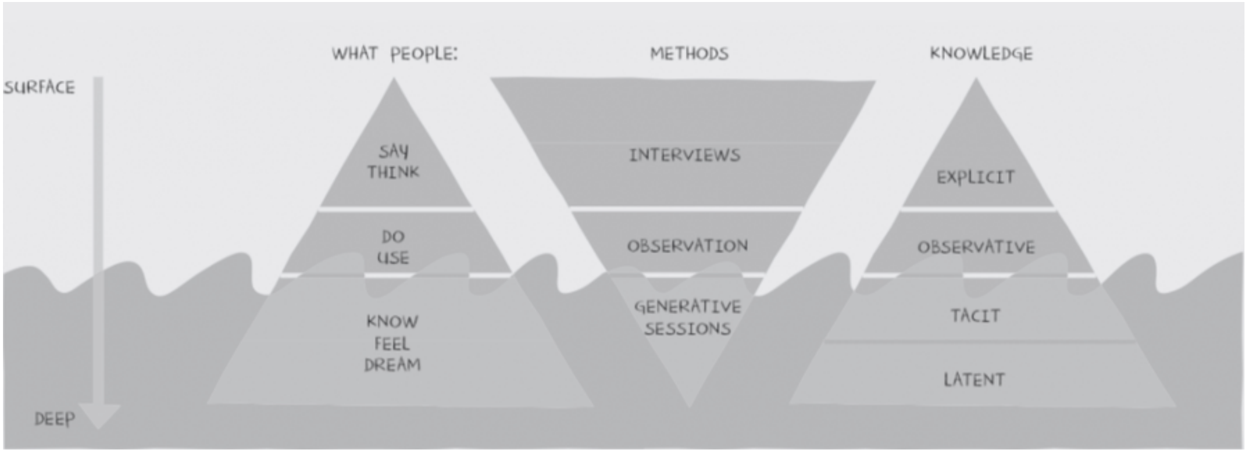


Figure 5.1: By employing various methods, this research doesn't just uncover surface information but also incorporates the tacit and latent knowledge of stakeholders (Sanders & Stappers, 2012).

Several interviews and observations are conducted to map stakeholders' values, interests, needs and current challenges (see Figure 5.1). These aspects were already researched for the end-users of the intervention (villagers of Ricanau Mofo) by VanderMeeren in 2022 (see Chapter 2). Other stakeholders will be analysed in what interests, powers and problems they encounter. The goal of these interviews and observations is to:

- Identify current problems from multiple perspectives, as this is a multi-perspective issue. This will enable more effective collaboration and consensus building;
- Identify how the continuity of the project can be assured. This is crucial as a feeling of responsibility must be created after this specific project comes to an end.
- Validation of stakeholder needs;
- Project feasibility assessment; interviews with local parties can help map the local availability of materials and knowledge, both of which the internet here lacks information.

A list of performed interviews can be found in Appendix B and some moments are captured in Figure 5.2. It includes the interviewee, the organisation or group they represent, the goal of the specific interview and the time and date.

Figure 5.2: Interviews with villagers to identify their values and participative boat rides to explore the environment (authors' work)

Throughout the project, four conferences were organised. The first one was in the Netherlands, in which the goal of this project was formulated. The Dutch consultancy Nelen & Schuurmans shared knowledge about a weather platform they conceptually designed for the area, but for which financial resources were missing. The KNMI was also present, who explained that they collaborate with the MDS for primarily ozone measurements and lastly, the Surinam Ambassador was present, who explained that Surinam does not need 'another report on the pile', but values a tangible prototype.

With this head start, the second conference was organised in Ricanau Mofo; the opening conference. With this, the inhabitants were informed about the reason the study took place and how. Also, a few inhabitants agreed to regularly validate the design and cocreate a design. These feedback work sessions took place at least once a week throughout the project.

The last conferences were the final conferences: one in Ricanau Mofo and one in Paramaribo. The conference in Ricanau Mofo is to present the end product, transfer knowledge needed for continuity and explain what steps are to be undertaken after the group leaves. Here, Captain Mésack and the district commissioner play an important role and are also present. The concluding conference is in Paramaribo, to update the central stakeholders about the end result and how this could be a pilot for other villages down the Cottica River and other areas in Surinam that face floods.

Figure 5.3: Field inspection with Ministry of Public Works. MDS, WLA and STEORR (authors' work)

After the research stage, the insights were combined and checked with the WWWWH method (an acronym for Who, What, Where, When, Why and How) of the Delft Design Guide. This method entails obtaining a thorough understanding of the challenges, its stakeholders, as well as facts and the values involved. It serves as a checklist to generate important questions to be asked when analysing a design problem. A helpful start, especially when facing a wicked problem; open (fuzzy or no boundaries), networked (has many elements that relate to each other), complex (it is constantly changing) and dynamic (many dependencies between stakeholders present)(Dorst, 2021). The iterative problem/situation statement is described in Chapter 2.

During the design phase, there are multiple feedback sessions with key inhabitants and other stakeholders for a co-creational approach (Delft Design Guide, 2013). These work sessions have the goal of contributing knowledge and different perspectives to create a more feasible project (see Figure 5.3). Another type of work session that is performed is a field inspection with the Ministry of Public Works (sub directorate of Wet & Dry Civil Technical Works; sub directorate Public Green & Waste; sub directorate Research & Innovation); Meteorologische Dienst and the Waterloopkundige Afdeling (WLA). The goal was to talk through possibilities of what the government could add to the project.

As local case studies, is it educational to visit other villages along the Cottica river. The goal is to see if there are any other villages that face floods, which (nature-based) solutions the villages have implemented already and talk about whether they are effective or not.

Interventions are identified using a core method in the Delft Design Guide: the Function Analysis. This aims to break down complex systems into their fundamental functions. This systematic approach helps designers identify essential functions and their relationships, paving the way for innovative problem-solving and efficient design solutions. The three main functions that need to be addressed in this project, with their sub-functions, are:

1. Mitigating river bank erosion;
    a. Strengthening the river bank;
    b. Maintaining accessibility to the Cottica River and creek;
    c. Slowing down the stream close to the river bank;
    d. Breaking waves.

2. Mitigating land erosion;
    a. Conducting drainage after precipitation;
    b. Providing strength to the soil;
    c. Mitigating subsidence of the soil.

3. Mitigating flood damage to the urban environment.
    a. Mitigating the occurrence of floods;
    b. In case there still are floods, mitigating damage;
    c. Controlling the water level.

Lastly, it is aimed to develop a tangible prototype, which is the last method used to address water nuisance in Ricanau Mofo (see Figure 5.4). The goals of developing a prototype are:

- Providing the local villagers of Ricanau Mofo with a straightforward and practical model. This enables them to reproduce the construction, ensuring that follow-up constructions can be implemented by the community itself without requiring extensive external expertise. It thus plays a part in the continuity of the project;
- It subsequently stimulates possible investors to see the possibilities of a small-scale implementation of the intervention, such as the Surinam Ministry of Public Works or Newmont. This can aid in overcoming the financial restrictions of Ricanau Mofo;
- The creation of a prototype has the possibility of increasing the understanding of certain problems, as it is a direct visual aid. It thus makes it accessible and comprehensible to the local population;
- Lastly, a prototype enables the essential part of assessing, validating and iterating the design as a pilot project. A tangible design provides data.

Figure 5.4: Explaining the prototype and preparation together with the villagers (authors' work)

Figure 6.0: River bank protection strategies (authors' work)

6.

>> Solution proposal for short- and long-term

In this section, the possible intervention plans are stated to address each of the three predefined functions in Chapter 5: addressing river bank erosion, addressing land erosion and addressing water damage to the urban environment (Figure 6.0). The plans each consist of the short and long-term possibilities, thus phasing, USPs and key stakeholders. The project plan for all three design solutions includes material procurement, preliminary design sketches, site preparation, construction timelines, and maintenance strategies for short-term and long-term goals.

The interventions that form the most efficient and feasible strategies are based on a multi-criteria analysis, as seen in Appendix C, D and E. In these appendices, all the analysed interventions can be seen, with the reasoning why or why not they are incorporated in the final design, based on quantitative factors, interviews and work sessions with the villagers (see Appendix F).

6.1 Strategy to address river bank erosion

In summary, this strategy combines structural measures with natural solutions to address soil erosion, tidal waves, and ship-generated waves. It protects the riverbank and enhances its ecological and aesthetic appeal. Figure 6.1 describes the interventions and their timeline. Figure 6.2 portrays the adressed river bank erosion.

Figure 6.1: Short and long term interventions for river bank erosion (authors' work)

Figure 6.2: River bank erosion in Ricanau Mofo (authors' work)

6.1.1 Short term strategy

In the short term design, river bank terraces are implemented that function as planter boxes, enhancing vegetation growth and providing erosion protection (see Figure 6.3). Firstly, these tiered terraces are separated by bulkheads made from locally provided timber. They create an environment conducive to diverse plant species, bolstering riverbank stability.

This brings us to the second component, which involves vegetation (coconut palms, mangroves, morisi and podosiri trees) along the riverbank. Their extensive root systems act as natural stabilisers, with additional positive side effects of food production, souvenirs and children's toys that increase community support. In addition to trees and mangroves between the layers of terraces, and carefully selected grass species (on the land) are also suitable for Suriname's climate and soil conditions. Using cocos protection on the river bank would be an effective addition, but is has not been implemented, yet, due to the fact that it is not available (on a large scale) in Surinam yet.

The last component is the addition of stone aggregates consisting of various diameters. Stone aggregates are placed on the river bank to increase the stability of the top layer. This will give the freshly planted vegetation a perfect situation to settle into the ground until it is able to stand on its own. It will help protect small plants against the tidal waves of the river by breaking the waves. Thereby, this layer acts as a shield against the impact of raindrops, which can dislodge soil particles and cause erosion.

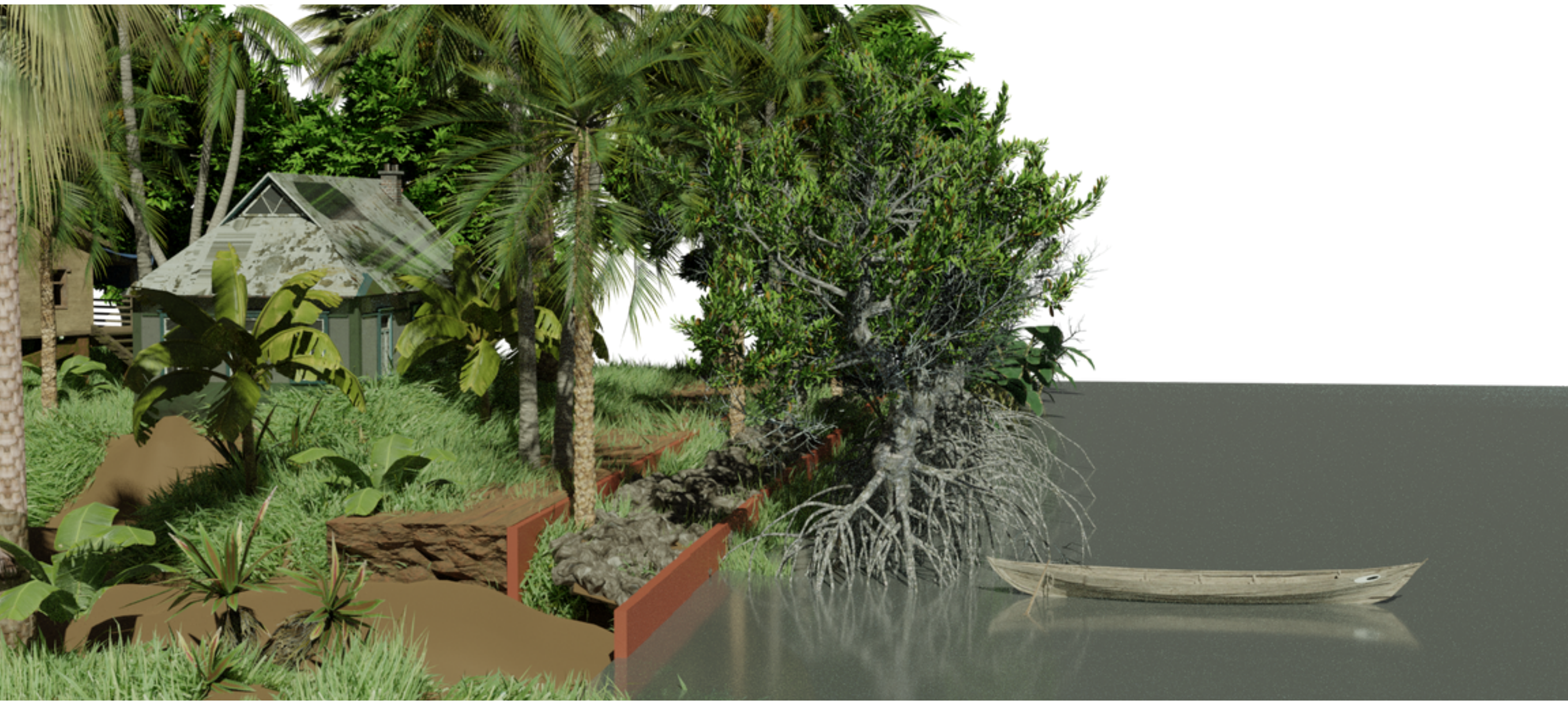


Figure 6.3: Render of tiered terraces, with vegetation and aggregates in between (authors' work)

Figure 6.4 shows the areas in which soil erosion is most prominent and urgent to address. The focus on these high-priority areas is critical, likely due to factors such as low ground, a steep slope or the absence of vegetative cover. Along the bank, the implementation of the short term solution will be performed, see Figure 6.5.

Figure 6.4: Areas in which land and bank erosion is most prominent and urgent to address

Besides the previously stated functionalities, this strategy is also feasible due to its financial picture. The costs associated with this strategy are relatively low, ensuring that it remains an economically viable solution. Importantly, the implementation of this plan does not necessitate the use of heavy machinery, making it accessible and feasible for community involvement. This financial accessibility allows local communities to actively engage in the protection of their environment, stimulating a sense of ownership and responsibility.

Figure 6.5: Top view of the short term bank erosion protection

The choice of long-lasting wallaba timber minimises maintenance costs in the erosion control strategy. Wallaba timber's exceptional durability, with a lifespan of at least 40 years, reduces the need for frequent replacements and upkeep expenses.
Moreover, employing locally sourced materials, including wallaba timber, lowers transportation costs. This eliminates the need for expensive long-distance shipping, promoting financial efficiency.

Additionally, Suriname's abundant vegetation, thriving due to favourable environmental conditions, allows for easy local sourcing, reducing expenses and effort associated with plant acquisition and transportation (see Figure 6.6). These factors collectively enhance the financial feasibility of the strategy, making it both cost-effective and sustainable.

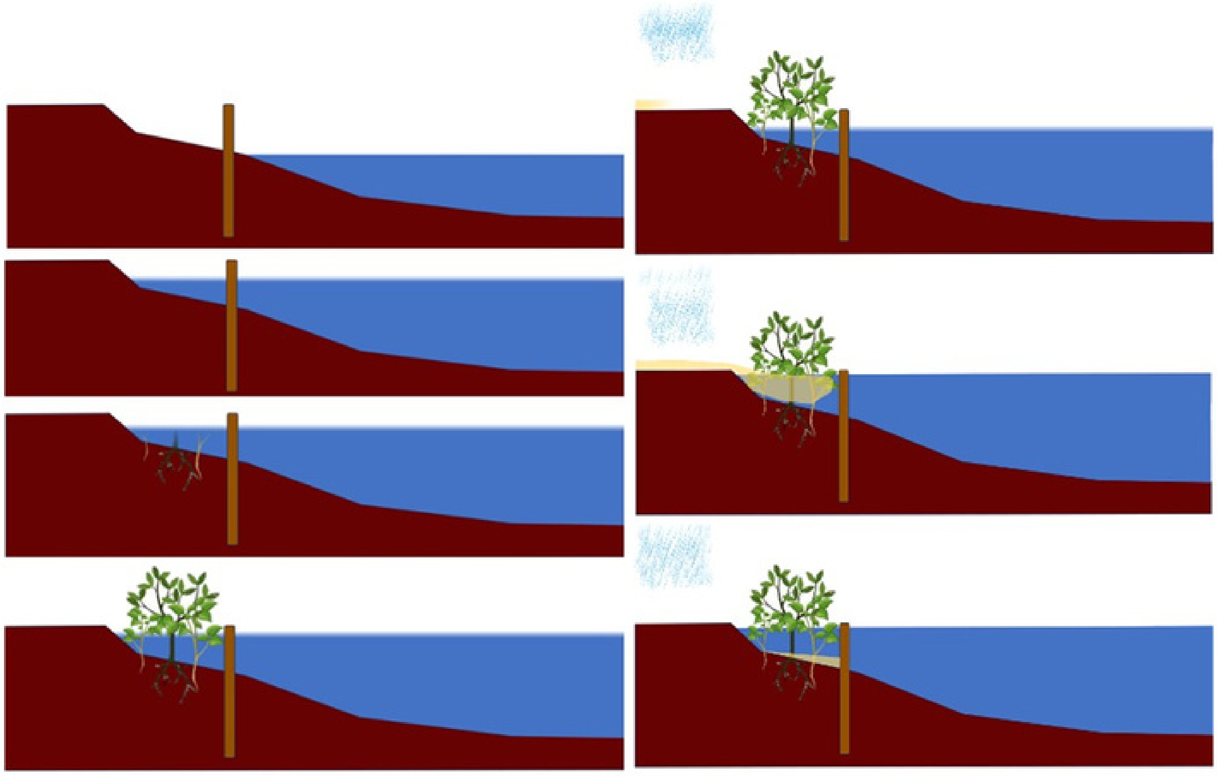


Figure 6.6: Illustration of the functioning of the bank protection system; Water is able to enter the enclosed area between the timber bulkheads and the original bank, creating a calm area for vegetation to grow (left column). Sediment transported by the rain from land to the bank is captured by the vegetation and bulkhead. Creating land reclamation over a long time (right column).

6.1.2 Long term strategy

The long term bank erosion mitigation plan for the Ricanau Mofo area comprises two key elements. Firstly, the number of terraces could be extended even more into the river. This will again reduce wave energy, facilitate sediment capture, and provide space for another row of mangroves, which is the ultimate goal.

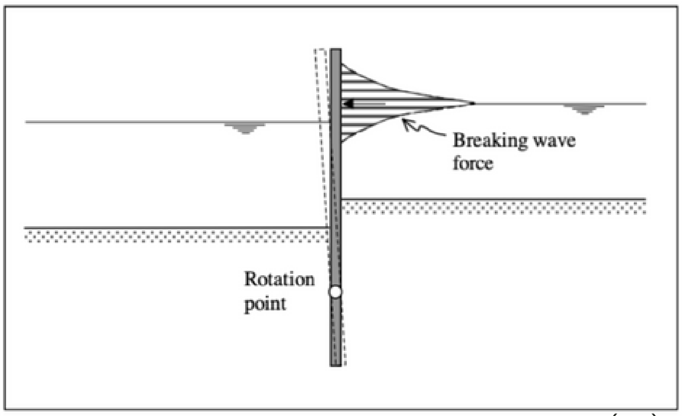
To ensure the system's resilience against natural forces, it's imperative to consider environmental factors during construction. Notably, the tidal range in the area, as measured at approximately 1.8 meters by MAS, significantly influences the design. Consequently, it has been determined that any above-ground structures should be elevated at a minimum of 2.1 meters.

Additionally, calculations have been conducted to ascertain that the wave height is approximately 0.2 meters, see repository (Schiereck, 2019). This information guides the design's necessity for robustness in withstanding wave impacts effectively.
The horizontal boards, an integral component of the system, play a pivotal role in resisting potential collisions, especially from small boats. To ensure their structural integrity, the thickness of these boards is meticulously calculated, taking into account factors such as deflection, loading, support conditions, the inherent strength of Wallaba wood, and the board dimensions.
The thickness of these horizontal boards, determined by the collision force exerted by small boats, will be set at 2.5 meters in length. The calculation of board thickness will meticulously consider factors like deflection, loading, support conditions, Wallaba wood's strength, and board dimensions.
The selection of the appropriate wood type for construction is critical to ensuring the long-term durability and effectiveness of the bank protection system. We are currently exploring various wood options, including Groenhart, Brownhart, bolletrie, Manbarklak, and Wallaba, carefully evaluating their individual strengths and suitability for our project's specific requirements.

It's worth noting that during discussions with the Ministry of Public Works and villagers experienced in working with wood for decades, the strength classifications for two potential wood types have been identified:

- Groenhart: Classified as D50/D70.
- Wallaba: Classified as D35. (Appendix I involves all mechanical properties of Wallaba)

It has been stated by MAS (2020) that the average ship length of passing ships is 120 meters. It is likely that these ships may become grounded due to their depth before reaching the bank protection. Therefore, to determine the primary force acting on this construction, we must consider the impact of smaller, typical Surinam boats that may encounter similar conditions. These forces can be seen as the governing forces for structural analysis. Appendix I shows that this governing force is 4.032, acting on the top of the construction pile. The forces from the ground, acting on both sides (see Figure 6.7) of the construction system, are disregarded since they weigh up against each other.



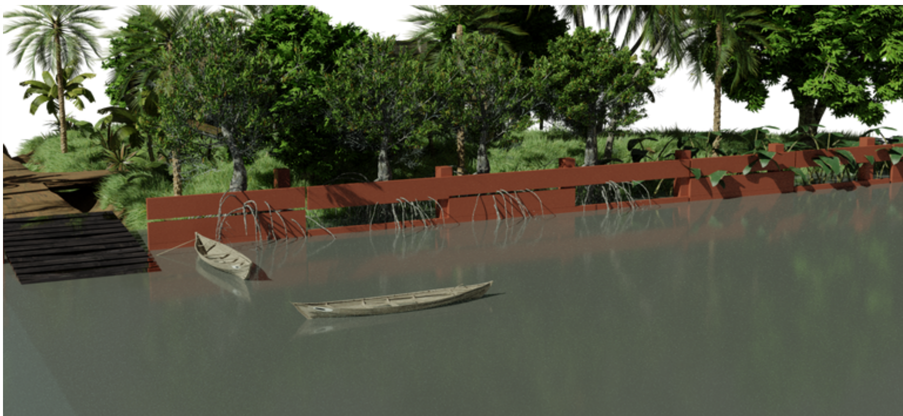


Figure 6.7: Structural behaviour of the piles (left) and visual representation of the river bank protection (right)

A Matrix Frame is employed for the purpose of simulating the behaviour of a foundation pile, as depicted in Figure 6.8. In this illustration, alongside the model, there are visual representations of the moment distribution and shear force distribution for the upper 2 meters of the pile. It's important to emphasise that the displayed moment values in the model are not reflective of reality due to the limitations of the underlying clay soil. Consequently, the calculated moment values are scaled down to 25% of what is visually represented in Figure 6.8. This adjustment offers a preliminary estimate but should not be construed as an accurate numerical value.

To account for the unique properties of the clay soil, engineers rely on a parameter called the Kd value. In this context, the Kd value quantifies the soil's ability to resist moments. The estimated Kd value for the clay soil under consideration is 5000 kN/m for the lower section of the ground and 1000 kN/m for the upper section. This distinction reflects the varying resistance to moments at different depths within the clay soil.

To obtain an accurate assessment of the foundation pile's moment resistance, a more in-depth structural analysis is necessary. However, this analysis is contingent upon obtaining specific soil characteristics, as the clay's ability to bear moment loads is directly linked to its properties. Hence, a comprehensive evaluation of the soil's characteristics is a prerequisite to determine the precise moment resistance of the foundation pile.

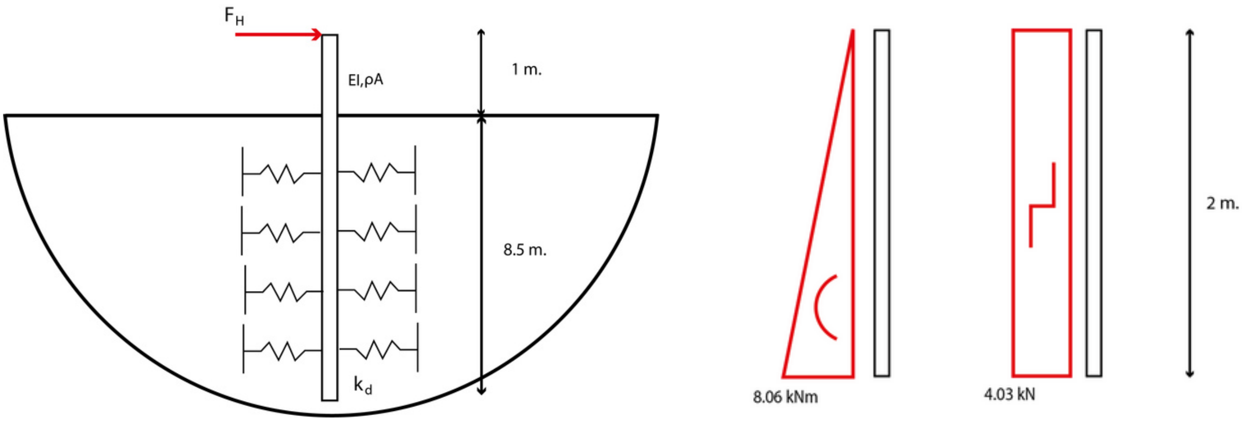


Figure 6.8: Loads and stresses and bending moment on the piles of the river bank protection

In Appendix I, an evaluation of unity checks has been conducted for the foundation pile. These checks encompass three critical aspects: pressure perpendicular to the fibre direction, bending moment, and shear force. It is worth noting that all unity checks yield results in Table 2. This signifies that the construction of the foundation pile is appropriately dimensioned to effectively withstand the forces exerted by a potentially collapsing boat. In other words, the pile's structural design is robust, ensuring it can adequately support and resist external forces and maintain the safety and stability of the structure in the event of such an eventuality.

Table 2: Unity checks on the foundation pile

Perpendicular to fibre direction	**Bending moment**	**Shear force**
0,05	0,61	0,25

In the long term, it would be recommended to extend the sheet pile wall along the complete bank, as shown in Figure 6.9. The openings represent jetties from which the people can enter the water for washing, fishing and recreational facilities. In the future, when the land reclamation is sufficient a new line of bank protection (further placed from the original bank) can be added to gain even more land. This should be done in consultation with MAS and maybe other ministries.

Figure 6.9: Expansion of the bank protection on the long term

6.1.2.1 Groynes

Secondly, groynes could be an effective addition to the bulkheads and terraces. Groynes are used to deflect currents and stimulate sedimentation. Typically, they are placed perpendicular to the river flow.
Permeable groynes may be used on beaches, but are widely perceived to function best in locations where there is a current but minimal waves, particularly rivers like the Cottica.
The spacing between the piles and the level of the piles above the bed or beach will depend on the intended influence of the groyne, but whilst the spacing is often approximately equal to the diameter of the pile, no established relationships are available for design purposes (Redirect Notice, n.d.).

The design can be divided into two options; the submerged and the un-submerged groynes. The design of the groynes itself can be seen in Figures 4.10 and 4.11.
The length of the poles depends on the choice of submerged or unsubmerged. Because the tidal range is significant in the Cottica River the groynes will be un-submerged during low tide and submerged during high tides. For that reason, a length of 9 meters is chosen. With 9 meters the poles will reach a sand layer which will lead to a stronger construction.

The dimensions of the poles are suggested to be 10x10 cm, this is because it is a familiar dimension in the area. The area between the poles is assumed to be the same as the diameter of a single pole.

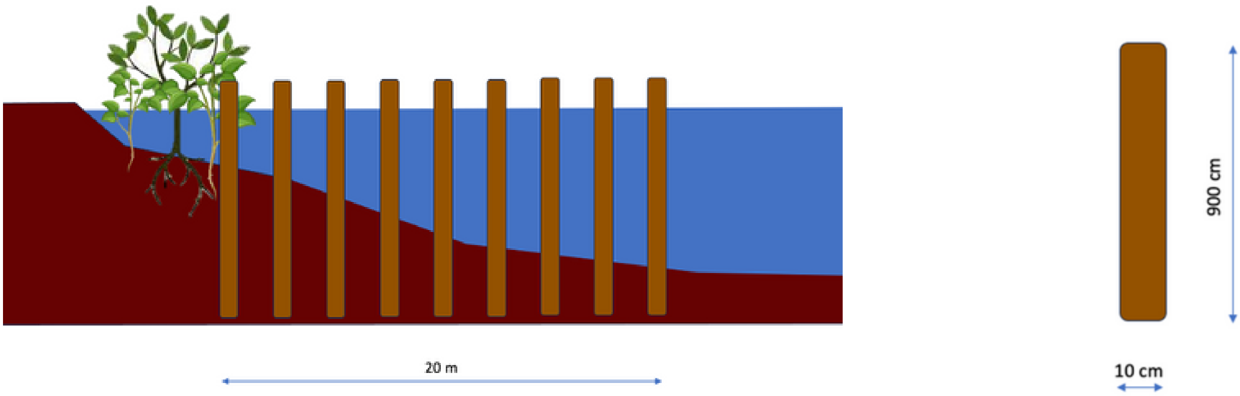


Figure 4.10: Illustration of the dimensions of the groynes

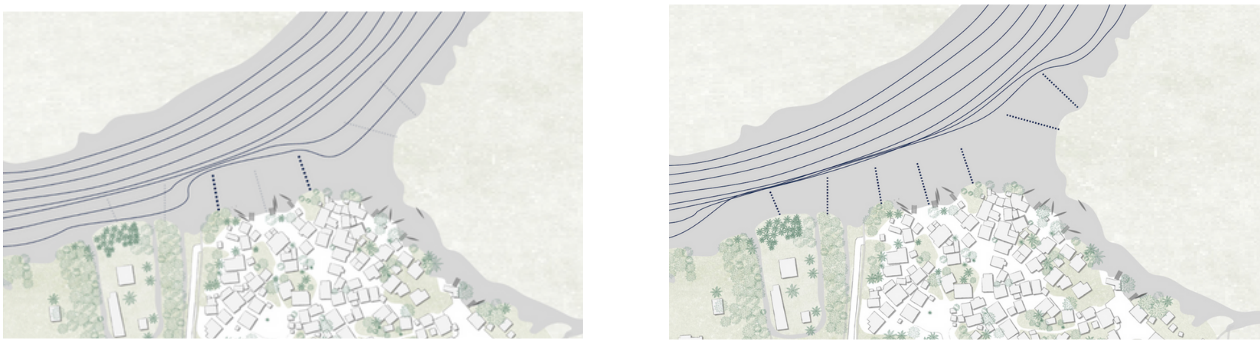


Figure 4.11: Effect of groynes on the streamlines in the river

6.1.3 Stakeholder and Maintenance Plan

The short term plan can be constructed and maintained on a local level. The first few metres of the river bank protection along the most eroded areas of Ricanau Mofo are realised in a prototype version in the time period of this project. This is explained in Chapter 7. With this tangible example, it is more feasible for inhabitants to recreate the structure of the timber with the vegetation. The ground where this is placed is owned by a few families, creating the responsibility for caring for all the vegetation on this part of their land. They are the owners of the fruits of the vegetation, creating another motivation for maintaining the vegetation. To help with this maintenance, some of the vegetation planted in this project is 'given' to the kids, who may place their name on the plant and are educated on how to care for it. Tips on vegetational growth are also stated in the information board on land erosion, seen in Figure 4.12 and Figure 4.13.

For constructing and maintaining the long-term strategy of groynes and river bank protection, a more central stakeholder is needed. Therefore, a business case of the river bank protection is set up and given to the captain of the village, but also to the Ministry of Public Works itself and to the District Commissioner. Whoever initiates the project is also responsible for maintaining or setting up the most efficient maintenance procedure, as it depends on who takes the lead. The Ministry of Public Works stated in an interview (Shatish Baghwandin, personal contact, 13 October 2023). that the ministry itself also had financial limitations, but with a full business case that they can send to international funds, it might be realised that they could rely on international funds.

6.1.4 Risks and limitations

The short and long term strategies are set up to create a feasible and efficient way of realising the goals. These goals were strengthening the river bank, while maintaining accessibility to the Cottica River and Ricanau Creek, slowing down the stream close to the river bank and breaking waves.

The vegetation and terraces strengthen the bank but do not prevent bank erosion. It even creates the risk that in the areas where it is not implemented, the erosion might increase until it is constructed there as well. Therefore, it is important to create a continuity support base. Another risk that arises is that the holes in the river bank protection are placed too high, in which case the sediment will not (optimally) be trapped in the structure. There is also the risk that extreme weather events interfere with the growth of the vegetation in the early stages, as they are prone to damage by extreme environments. Even though the terraces, vegetation, groynes and river bank protection mitigate river bank erosion, it has a negative impact on the accessibility to the Cottica River and the Creek. The groynes do slow down the stream close to the river bank but have the limitation that they cannot be placed too far into the water where they interfere with the fairway. The risk also arises that even though there is a design and business case for the river bank protection and groynes, central stakeholders lack the capacity to continue the project.

The risk arises that the inhabitants rely on the structure to prevent high water levels in the village. It is important to mitigate this risk by communication and visualisation. Therefore, the information board is an important key to creating awareness of which functions these constructions fulfils, and which do not.

THE FOLLOWING PAGE PRESENTS THE INFORMATION BOARD THAT IS PLACED IN THE VILLAGE, TO ENSURE THE KNOWLEDGE IS LOCALLY AVAILABLE AND THAT THE STRATEGY CAN BE IMPLEMENTED.

Figure 4.12: Educational board on river bank erosion (authors' work).

Figure 4.13: Educational board on river bank erosion placed in context (authors' work).

6.2
Strategy to address soil erosion

This strategy combines structural measures with natural solutions to address soil erosion. It protects and strengthens the soil, and regulates water after heavy precipitation. Figure 6.14 describes the interventions and their timeline. Figure 6.15 portrays the addressed river bank erosion.

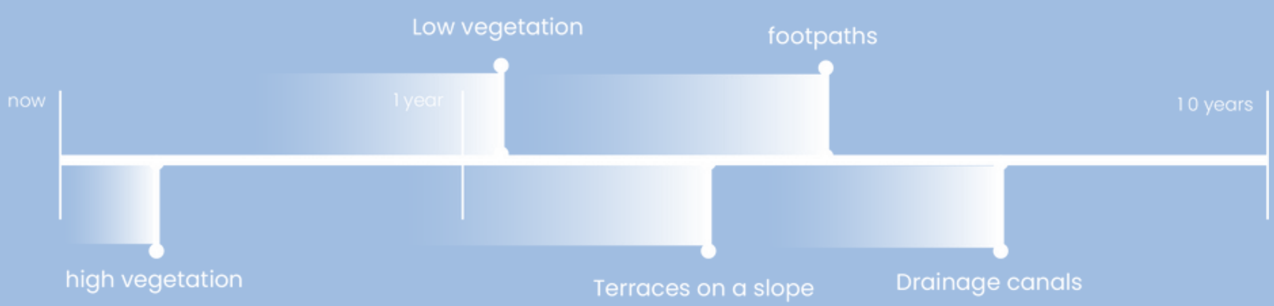


Figure 6.1:4 Short and long term interventions for soil erosion (authors' work)

Figure 6.14: Soil erosion in Ricanau Mofo (authors' work)

6.2.1 Short term strategy

(Re-)planting vegetation is introduced to prevent soil erosion. With an added utility value, the motivation for maintenance and economic support increases.

The vegetation selection has a robust root system and serves as a natural stabiliser while also offering practical benefits such as food production and creating souvenirs and children's toys, which resonates with the community tradition of taking considerate care of family fruit trees (VanderMeeren, 2022). See Figure 6.16 for the selected phase 1 vegetation for Ricanau Mofo.

When selecting vegetation, consider the following factors:

- Soil chemical warfare: Observe light requirements and allocate double the space for slower-growing species.
- Shade tolerance: Determine whether a species is a pioneer or climax type, with pioneers needing more light and climax species better suited for shade (they may require protection).
- Suitable for the freshwater conditions of the Cottica River.
- Tolerance to foot traffic
- Salinity is 0 at the Cottica River.
- Pollination is not a hindrance.
- Moisture content is 100% year-round.

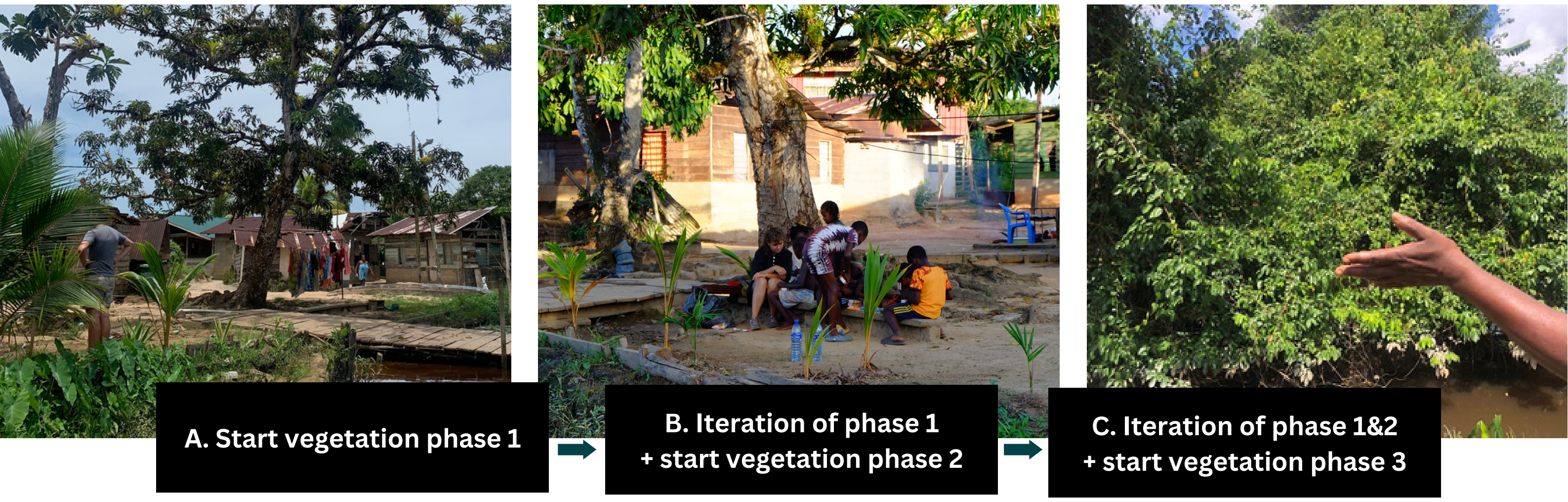


Figure 6.16: Side view of the river bank where diverse vegetation is still present in Ricanau Mofo. Phase 3 will look like this.

Chapter 6.5 shows the design of prioritised areas for vegetation. At the river bank in the village centre coconut palms, morisi palms, podosiri palms and mangrove trees are placed. Land inwards the same vegetation and mango trees are suggested to be planted to protect probable future bank lines. See Figure 6.16 for suggested vegetation selection.

Figure 6.17: The selection of vegetation for soil erosion at the river of Ricanau Mofo for phase 1: from left to right: manja trees, cocos palms, podosiri palms and morisi palms combined with creepers, grass and herbs.

The vegetation design includes the growth of the plants over decenia leading to a spatial recommendation of six different plants per squared meter by forest expert Maarten Ariëns (Foreest, 2023). For positioning the trees diameter of the crown of adult trees is taken into account (see Figure 6.19).

- Morisi trees have a crown diameter of 5-6m
- Cocos palms have a crown diameter of 5-6m
- Podisiri palms have a crown diameter of 4-6m
- Mango trees have a crown diameter of 8-10m

The Young phase ends when shade appears on the ground. The Pole stage can then begin, allowing for the introduction of shade-tolerant vegetation such as shrubs, small trees, grasses, and herbs.

Figure 6.19: The step by step guide with the journey of coconut, podossiri or morisi seeds to grown palms.

In order to support plant growth and introduce new plants to grow, the following is crucial:

- Place them higher for increased oxygen in the soil. Don't plant too deep; place them cold on the ground and then cover them with soil, removing any tire tracks.
- Transfer fungi from another tree to the new plant to make it more resilient and promote better growth with the infusion of extra energy. Also called entering the soil.
- Utilize fallen fruit seeds. Accelerate root growth by placing them in plastic bags for three weeks in a sunny location. Once roots emerge, transfer them to a glass of water, allowing the first leaves to develop, and preparing them for planting in the soil. A maintenance guide is shared with the primary school and villagers of Ricanua Mofo to share steps of self-growing palm trees (see Figure 6.20).

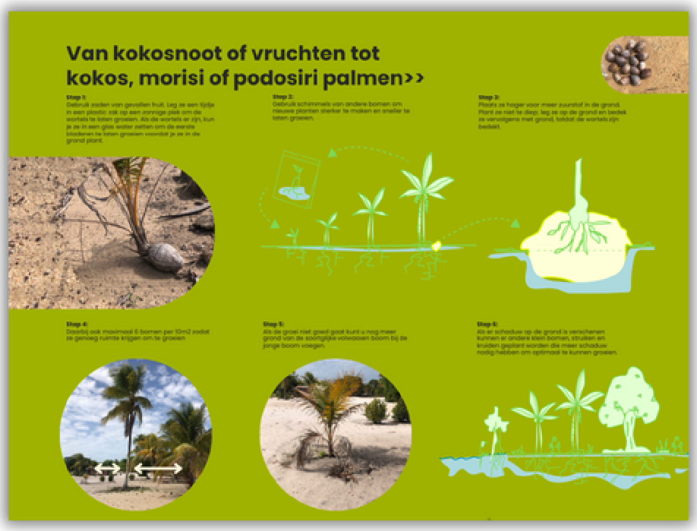


Figure 6.20: The step by step guide with the journey of coconut, podossiri or morisi seeds to grown palms.

6.2.2 Long term strategy
Footpaths concentrate pedestrian traffic along specific routes, which can help reduce soil compaction (see Figure 6.21). Compacted soil is less prone to erosion because it's more stable and less susceptible to being washed away by rain or runoff. When designed with care, it can avoid damaging or disrupting vegetation cover. Healthy vegetation, particularly grasses and other ground cover, stabilises the soil with its root systems, preventing erosion.

The inclusion of drainage features can divert water away from the path. By managing water flow and preventing it from running directly over the soil, footpaths reduce the erosive force of flowing water. In order to maintain the footpaths for a longer amount of time the top layer is decided to consist of gravel.

Gravel is relatively low-maintenance compared to other locally used materials, like bauxite. It doesn't deteriorate as quickly as organic materials (e.g., wood chips), and it doesn't require regular replacement. It provides a stable and durable surface that can help prevent erosion on the paths, especially in areas with heavy rainfall or runoff, this is of importance. The gravel acts as a protective layer, reducing soil exposure to the erosive forces of water.

Besides, gravel is permeable, allowing water to infiltrate and drain through the path. This feature helps manage water runoff, reducing the likelihood of surface erosion and minimising puddles or muddy conditions on the path. Gravel is often chosen for footpaths in natural or outdoor settings due to its accessibility. It's easy to walk on, even for individuals with mobility challenges, and provides a stable surface in various weather conditions.

Figure 6.21: Possibilities for creating footpaths (not validated) with a small scale design of the path with vegetation and a drainage system on both sides (authors' work)

6.2.3 Stakeholder and Maintenance Plan

Both the short-term and the long-term implementation require maintenance and maintenance costs. The locally implementable vegetation is maintained by the community itself. This is assured as the ground in the village is divided amongst families, creating the responsibility for caring for all the vegetation on their land. They are the owners of the fruits of the vegetation, creating another motivation for maintaining the vegetation. To help this maintenance, a few tips are stated in the information board shown in Figures 6.22 and 6.23.

As there are few financial resources for the maintenance of the footpaths and drainage systems, it is important to incorporate a more central stakeholder. The captain of Ricanau Mofo proposed to contact the Ministry of Public Works to initiate and maintain its construction. In addition, when short and clear internship assignments are formulated by STEORR, PTC has indicated it may be able to take up these small projects as graduation projects (Hellings, personal contact, 12 October 2023).

6.2.4 Risks and limitations

This strategy fulfils parts of the predefined functions for land erosion. The first goal was to conduct drainage after precipitation, which is realised to a certain amount by implementing drainage systems besides the footpaths. However, it can only drain water up to a certain amount of precipitation. When the precipitation leads to higher water levels than the drainage system can carry away, the drainage system will fail the goal. The second goal was to provide strength to the soil, which is done by planting vegetation and creating footpaths. However, the use of where to walk also depends on cultural and traditional values, causing a limitation to where footpaths can be put. Also, there is a local financial limitation, causing the village to depend on another stakeholder for funds to more easily realise footpaths and drainage systems. The last goal was to prevent subsidence of the soil. The vegetation does mitigate the sedimentation where their roots lay, but soil can still erode where there are no roots or grass placed.

THE FOLLOWING PAGE PRESENTS THE INFORMATION BOARD THAT IS PLACES IN THE VILLAGE, TO ENSURE THE KNOWLEDGE IS LOCALLY AVAILABLE AND THAT THE STRATEGY CAN BE IMPLEMENTED.

Figure 4.22: Educational board on soil erosion (authors' work).

Figure 4.23: Educational board on soil erosion placed in context (authors' work).

6.3
Strategy to address flood damage to the urban environment

This strategy address flood damage to the urban environment by sharing knowledge on where & how to build more water adaptive. It also explains how a flood early warning sytem can be set up. Figure 6.24 describes the interventions and their timeline. Figure 6.25 portrays the adressed flood damage to the urban environment

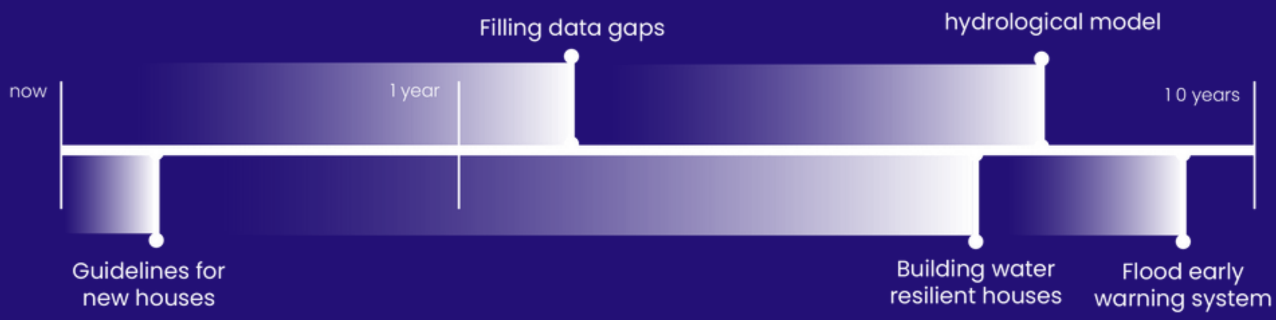


Figure 6.24: Short and long term interventions for soil erosion (authors' work)

Figure 6.25: Urban damage (authors' work)

6.3.1 Short term strategy

Addressing floods and their damage to the urban environment can be done in multiple ways, but can also be costly and carry central responsibilities. It is chosen to concentrate on an intervention plan that scores high on the DIY factor; is locally adaptable and carries low production and maintenance costs. This ensures more chances for short term implementation for the village and increases the feasibility of it actually addressing (parts of) the water nuisance.

Based on interviews with villagers and information from Vandermeeren (2022), it appears that the inhabitants are aware of the increasing water nuisance and that there is a willingness to move new constructions to other, higher parts of the village. This intervention wants to contribute to the local knowledge of which areas are expected to have less water nuisance, thus proving to be a more water-resilient living space.

When someone wants to start construction, they first have to ask permission of the captain as regards the location (Goossens, Marsboom & Plaghki, 20230). A construction plan with building guidelines is made for the inhabitants and especially the captain of Ricanau Mofo, explaining which areas are vulnerable to water nuisance and thus acquire more attention for flood-resistant housing. This is done on a four-point scale, based on the measurements of VanderMeeren (2022). Zone 1 is the most prone to water damage and zone 4 the least. It is advised to build in higher areas. This is not always possible, as cultural factors like appointing family grounds play an important part in where someone may build. The more vulnerable the area is, the more important it is to add water-resilient features in your house.

The plan includes low-cost possibilities for flood-resilient housing (see Figure 6.26):

- Option 1: Building your house on poles (is done in multiple locations of Ricanau Mofo);
- Option 2: Building your house on a terp;
- Option 3: Creating a flood-resilient (stone/cement) ground floor with a traditional house on top;
- Additional 1: Building a buffer around your house, for example with a small, stone wall;
- Additional 2: Add gutters around the roof of your house (decreases the chance of water damage on your foundation); also add storage places in your house as high as possible, so items can be stored in a more flood-resistant space.

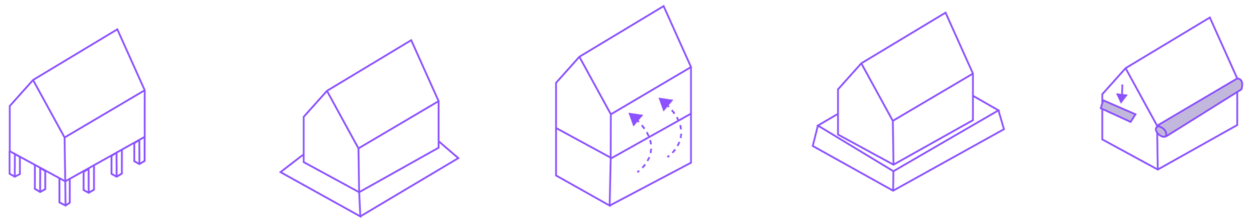


Figure 6.26: Options and additions to urban environment to mitigate damage from floods

The way these guidelines are communicated to the villagers is co-designed with the captain and other inhabitants of Ricanau Mofo. Keeping continuity in mind, the guidelines should be communicated in a tangible way. Based on interviews it suggests that villagers do want to keep the rising water levels in mind when building a new home and that providing them with more information about possibilities would help them build a more durable home. Therefore, the building guidelines are presented on an information board placed at a central place of the village: near the Cancantry tree. The information is stated in the local Language Aukaans, but also in Dutch. This, ensures that not only locals can learn more about the project of improving the quality of life in Ricanau Mofo, but also the tourists that already visit the village from time to time.

Ricanau Mofo is not the only village along the Cottica River that struggles with water nuisance. Other villages like Wanhatti also experience this phenomenon. Therefore, it is important to show the captains of these villages how Ricanau Mofo is becoming more water-adaptive as a pilot for their own villages. The design and implementation of the information board can be seen in Figure 4.30 and 4.31.

6.3.2 Long term strategy

Even though the guidelines might decrease the chance of damage by floods, it still remains possible. Therefore, a flood early warning system is introduced. In the current situation, the villagers have no knowledge of when a flood will erupt. This causes a lack of time to prepare for them. Even with following the guidelines it is important to mitigate damage by giving time to prepare.

A flood early warning system is a network of measuring sensors, data sources, and communication channels designed to monitor and predict flooding events. It collects real-time data on rainfall, river levels, and weather conditions, processes this information using hydrological models, and enables authorities to alert local communities well in advance of potential flooding. By providing timely warnings and facilitating preparedness, these systems help mitigate the impacts of floods on lives and property.

Chapter 4.3 shows that primarily water level, discharge and precipitation measurements need to be employed, both upstream and downstream in the Cottica River. In addition, a more comprehensive study should be conducted on the relationship between water levels and river discharge. Goosens et al. and Vandermeerenin 2022 conducted a first hights overview of Ricanau Mofo, see Figure 4.27).

The system goes paired with the recommendation to create or even invest in places where the villagers can store their belongings during the flood. This can range from simply placing more shelves on their walls to building a small, higher places shed (inspiration can be used from the building guidelines).

Besides a flood early warning system, the question arose from multiple stakeholders whether a dike would be a suitable intervention to address the water nuisance long term. The design, advantages and - disadvantages, and most importantly hurdles are explained in Appendix F. As Surinam struggles with maintenance resources, and financial resources (a dike requires both intensely) and as a dike interferes with the possibility of the village to realise their goal of urban growth, it is not suited to be the most efficient and feasible option.

Figure 6.27: Analysed hights of Ricanau Mofo by Goosens et all. and Vandermeeren (2022) are visualised with a range from dark purple (low) to light purple and white (high).

6.3.3 Stakeholder and Maintenance Plan

For implementation of the building advice, the possible water-adaptive building interventions should be communicated to local residents. This will be done using visual images on information boards that will be placed within the village. Besides, these plans need to be communicated to the captain. The captain is responsible for designating building land for new houses and, in doing so, may indicate the risks of danger zones.

The advice indicated on the signs is based on today's knowledge. In the future, new techniques, knowledge and unforeseen changes may cause the information to be outdated. Therefore, STEORR is responsible for updating the information boards or contacting other parties capable of updating or replacing the information.

The implementation of a flood early warning system involves several ministries. WLA is responsible for water level measurements and making a hydrological model that can be used to make predictions. In this, cooperation can also be sought with MAS, which monitors water levels at various shipping lanes, including the Traymore Harbour, further upstream from Ricanau Mofo. MDS is responsible for gathering meteorological data located at Traymore Harbour as well and will have to communicate this data and weather forecasts with WLA. Both WLA and MDS are responsible for maintaining their own meteorological equipment. At the time of flood danger, WLA must have a communication system ready to alert local residents so that they can act prematurely to the flooding. An example by the Red Cross is shown in 6.28 however the more advanced version needs additional components and responsible parties. An overview can be seen in Figure 6.29.

Figure 6.28: Examples of early warning systems by Red Cross placed in 2022 *authors' work)
Overview of components and responsible parties concerning a flood early warning system

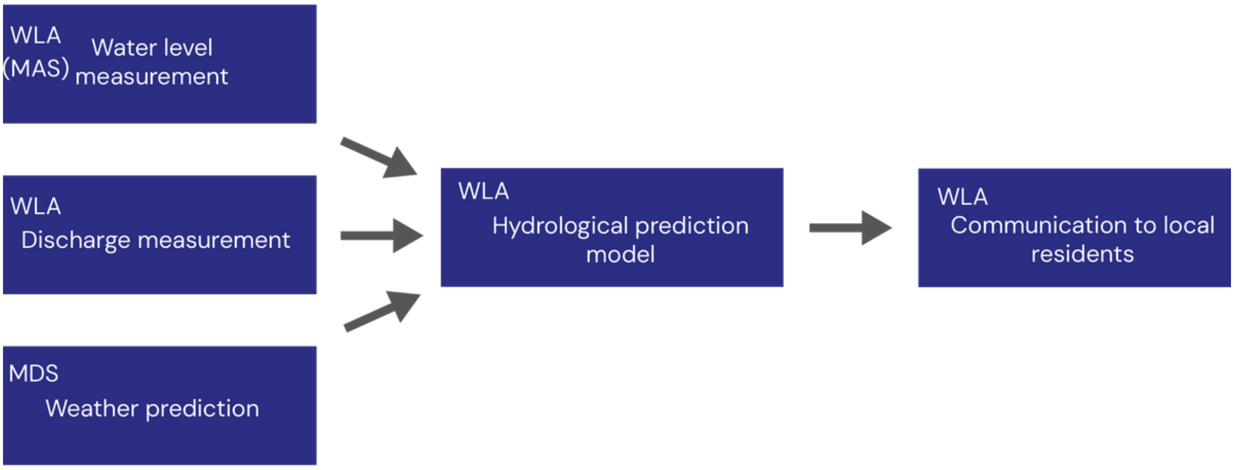


Figure 6.29: Overview of components and responsible parties concerning a flood early warning system

6.3.4 Risks and limitations

The hazard zones are based on climate projections done by CNPP. However, there are a lot of uncertainties in these projections. It is possible that some of the danger zones turn out not to flood in the end. The 'safe' zones will most likely not be flooded, based on the worst-case scenario of the climate projections of CNPP (van der Meeren, 2023). In addition, the map is based on rising sea levels, but says nothing about extreme weather and longer periods of rainfall.

The advice does not address the immediate problem of flooding. It only aims to mitigate damage in case of floods. It does not fulfil the function of preventing floods but it does help mitigate the problem. In addition, there is currently a lack of options for local residents when they are warned of flooding. It is important that they know where they can be sheltered and how to secure their belongings if necessary, which is not included in the plan.

Currently there exists a knowledge gap in terms of the hydrological prediction model, available (standardised) data and the existence of data clouds. In order to make a flood early warning system work properly, data will need to be automatically up-loaded to a cloud and good communication between WLA and MDS is essential. In addition, no communication system is currently active that can alert local residents in a timely manner. This is complicated by the fact that within Ricanau Mofo, there is poor coverage for both internet and calling.

Other factors that could potentially negatively affect the feasibility of the proposal are the language barrier between the different population groups in Suriname, the lack of knowledge on how to build the water adaptive interventions and the fact that the building structure in the village is cultural and family-based. Common spaces between different family houses are very important to local residents and when not taken into consideration may cause the given advice not being followed.

THE FOLLOWING PAGE PRESENTS THE INFORMATION BOARD THAT IS PLACES IN THE VILLAGE, TO ENSURE THE KNOWLEDGE IS LOCALLY AVAILABLE AND THAT THE STRATEGY CAN BE IMPLEMENTED.

Figure 4.30: Educational board on water adaptive housing (authors' work).

Figure 4.31: Educational board on water adaptive housing placed in context (authors' work).

Figure 7.0: Prototype development (authors' work)

7. >> Prototype development

Now that the strategies to address river bank erosion, soil erosion and flood damage to the urban environment are elaborated, a prototype can be constructed (Figure 7.0) . Two projects are undertaken: Constructing the first few metres of the river bank protection & placing the educational information boards (shown at the end of each strategy in chapter 6).

The construction duration of the prototype was five days, with one day of preparation.

7.1
Construction of short-term strategy against river bank erosion

The first prototype of +-30 metres of the Wooden Sheet Pile along the foreshore with its vegetation was constructed in Ricanau Mofo, together with the villagers (Figure 7.1). The idea was to realise the first few metres in the most urgent areas, shown in Figure 7.2, in the most effective and aesthetically pleasing way possible, so that villagers know how to continue to the river bank protection and are not disadvantaged by its view.

The company Houtmarkt Bron, situated in Albina, prepared 30 planks of Loksi Wood with measurements of 2.5 metres and 0.2x0.02m in width, that form the bulkheads. They also prepared sixteen poles of Wallaba Wood, with measurements of 3 metres in length and with a width of 0.08x0.08m. The bottom of these poles is sawn into a point for better excavation, as the soil in the village consists of thick clay. After approximately 6-8 meters, a sand layer appears in the ground, which can be seen in the CPT in Appendix G. However, it is uncertain in which year this measurement took place and which instruments were used. Therefore, there is high uncertainty in soil structure.

In various local construction markets, other materials can be bought: Screws, bolts, wood varnish, brushes and a rubber hammer. Furthermore, a circle saw, shovels and drills can be borrowed from the villagers of Ricanau Mofo. The hand piling device has been borrowed from Anton the Kom University. The vegetation has been collected through different stakeholders: the Meteorologische Dienst donated 5 Cocos palms; the Ministry of Public Works donated 5 Cocos palms; Professor Naipal from the Anton de Kom donated 2 red mangroves, which are suitable for the sweet water of the Cottica River.

Figure 7.1: Flyer that is spread through Ricanau Mofo, stating the construction planning in Dutch and in Aukaans

Location overview

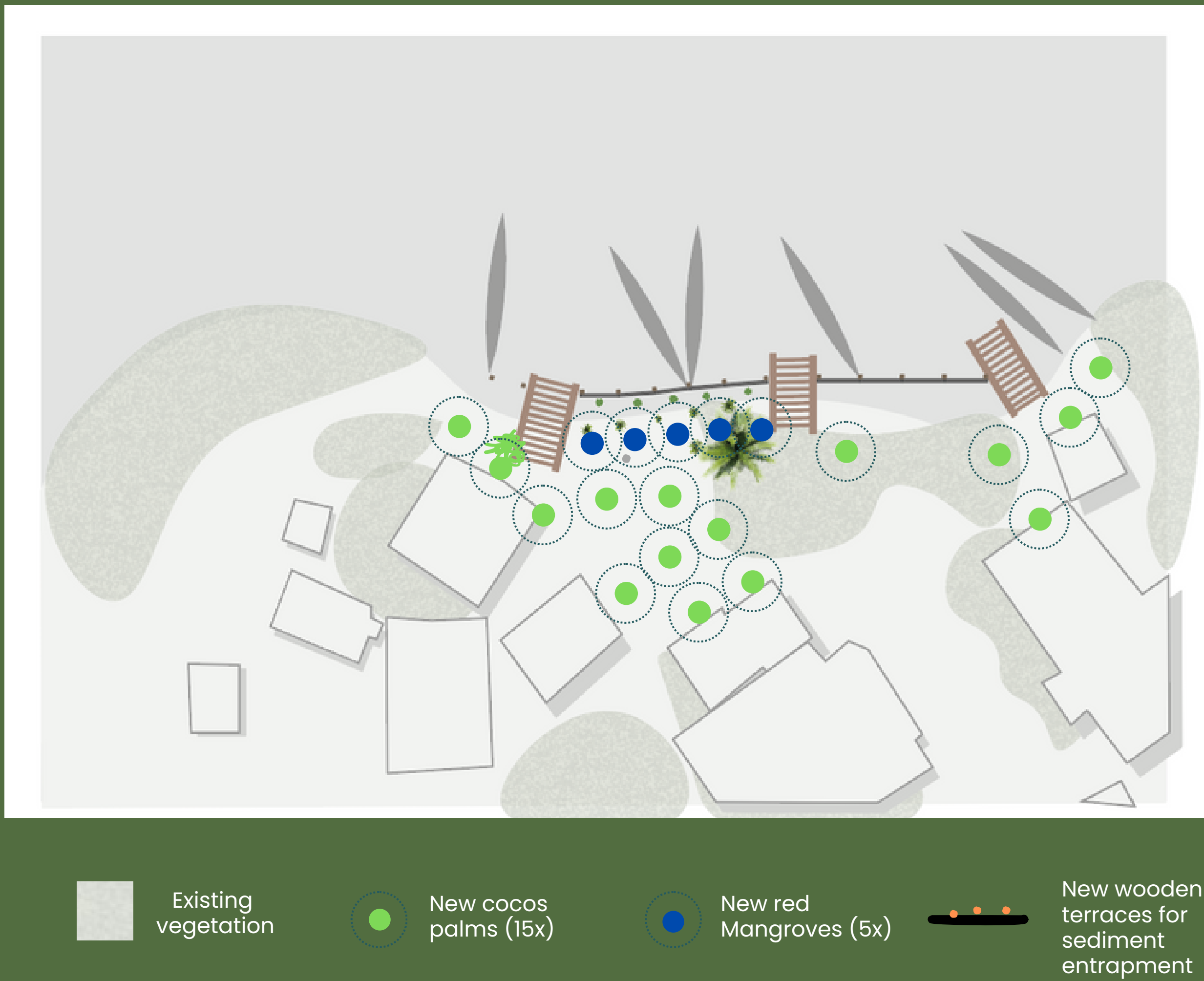


Figure 7.2 : Location of the river bank protection prototype (authors' work)

Material overview

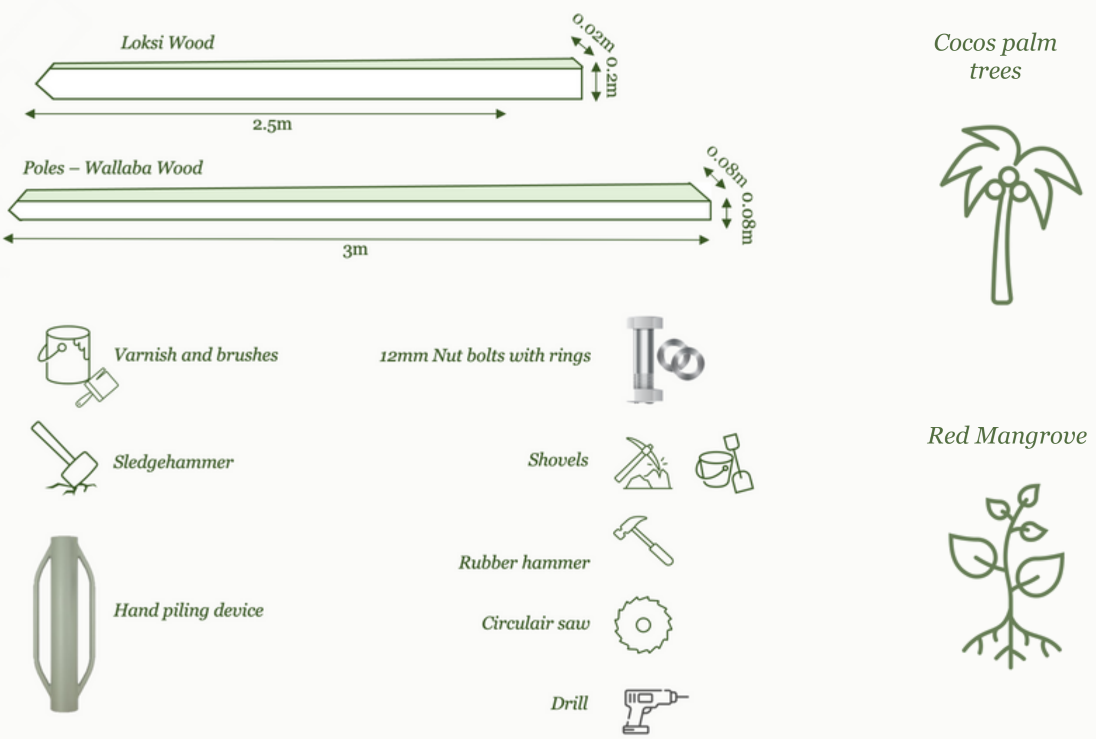


Figure 7.3: Materials needed for the river bank protection prototype (authors' work)

Step 1: Preparation
The construction started with cleaning the river bank together with villagers and varnishing the wood to make it more withstandable for extreme weather conditions. In total, more than 20 garbage bags have been filled (Figure 7.4).

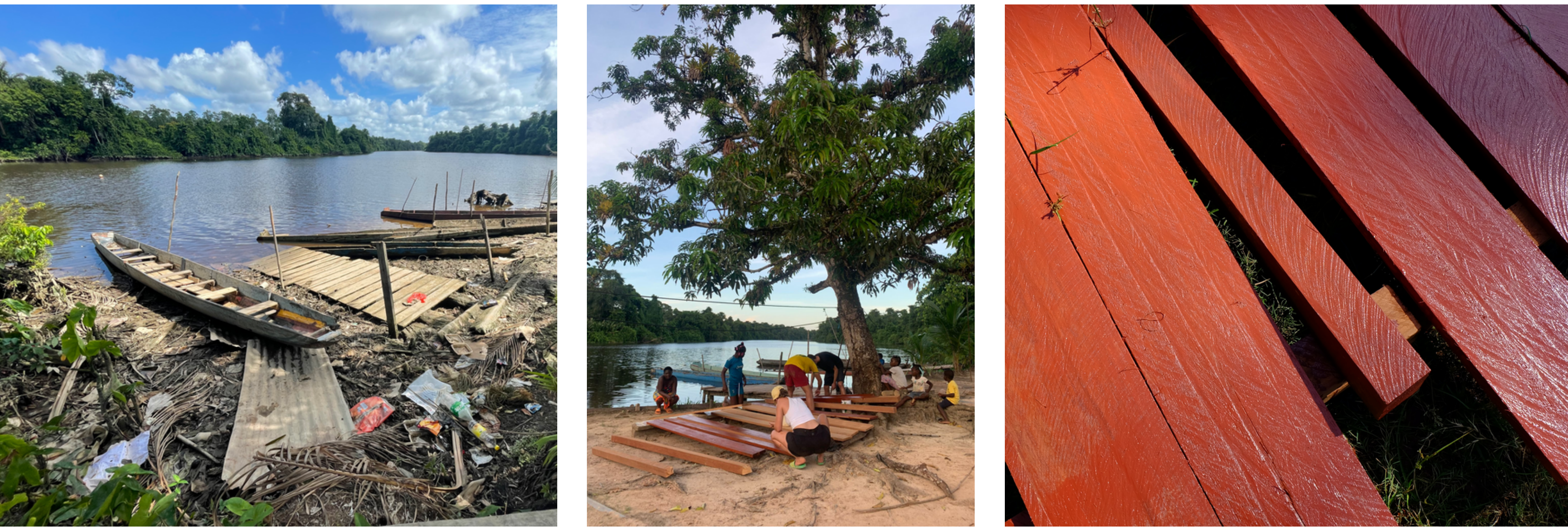


Figure 7.4: Cleaning the river bank (left), varnishing the wood (middle) and the result (right)

Step 2: Pilling
Six holes of (range: [0.5-1.0 metre]) were dug using a shovel between the two piers shown in figure 7.4, with a distance of approximately 2.5 metres between them. The six poles are then pressed in these holes using a hand piling device. The poles are 3 meter in total: they are pressed until they are 2 metres beneath the soil, and only 1 still above ground (Figure 7.5).

Figure 7.5: First, the holes are dug (left), after which the poles are pressed into the ground using the hand piling device (middle) or the slegdehammer (right)

Step 3: Attaching the planks: Subsequently, the wooden planks are attached to the poles with a 12mm bolt on the left and right sides of the plank, though the poles. Three layers of wooden planks are placed on top of each other to trap sediment (Figure 7.6).

Figure 7.6: The planks are sown at the exact length using the circular saw and then attached to the poles using a drill and 12mm nut bolts

Step 4: Elaboration phase: As there were already terraces built by the villagers themselves between the piers (Figure 7.7: the before and Figure 7.8: the after), it had been decided to construct 12 more metres of river bank protection between the two piers next to these ones, instead of adding an extra (third) layer of protection on the same river bank. Therefore, the same procedure has been used for the area on the east side of the pier. These two are connected by adding a plank underneath the pier so that sediment is not lost between the two constructions.

Figure 7.7: The 'before'-situation. There are some bulkheads placed and some trees can be seen on the left side.

Figure 7.8: After the prototype has been build: right of the pier is the original 12 meters and left the elaborated 12 meters. Mangroves and cocospalms are planted on the soil and in the water.

Step 5: Vegetation planting & workshop nameplates
During the last day, a workshop was organised in which the children of the village that had helped with the construction, made their own nameplates that they could attach to one cocos palm tree. With this, they are responsible for maintaining this plant. Instructions for it can be read on the information board of land erosion, but are also learned during school. (materials: wood; paint; markers; rope; scissors).

The vegetation is then placed at a distance of approximately two meters from each other for optimal space for growth (see Figures 7.9 and 7.10).

Figure 7.9: The landowner planting the new cocos palms (left); workshop of children creating name plates (middle and right)

Figure 7.10: The river bank protection with cocos palm trees (on dry soil), mangroves between layers of terraces (in the water), and zoomed in into these two.

7.2 Construction of educational information boards

The research and insights gained during the process are shared in the form of a summary on information boards placed across Ricanau Mofo. Villagers are able to visit the boards if they want to take action themselves towards the water challenges, whenever they have room for new information or when they want to learn about maintenance and extending the water interventions placed during this project in 2023.

For the construction of the information boards for educational purposes, different materials were needed. The boards are made from vinyl on a 3mm alucobond. It is made by the company ProGrafx Designs, located in Surinam (ProGrafx Designs, 2017), which uses the material: Oracal 3551G; method: Eco Soll II Print on a scale of A2. The designs were made in Adobe InDesign and included the information in Dutch and in local Aucaans. This translation was performed by STEORR.

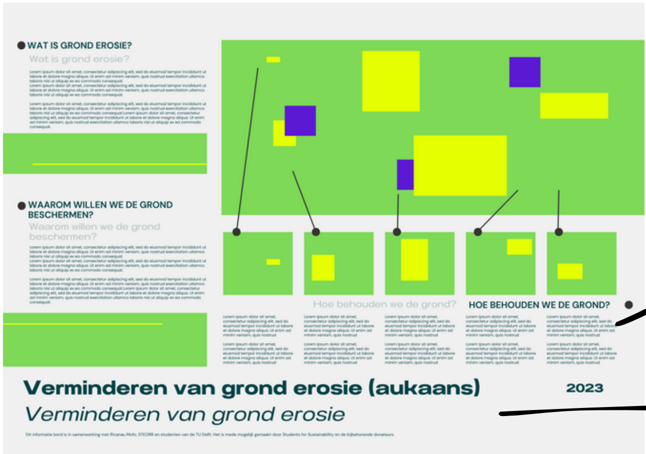
These boards were then confirmed to be two wooden poles, which have a height of 2 metres and are made out of Wallaba Wood. They were made by the company Houtmarkt Bron, situated in Albina, and their width is 8x8cm. The bottom of the pole is sawn into a point for better excavation, as the soil in the village consists of a thick bauxite and clay layer. For its implementation, a hole has been dug of approximately 0.5 metres, so that the resulting reading height would be 1,5 metres. Four holes (left above; left below, right above, right below corner) are drilled through the information board into the top part of the poles, and screws are put through it. Figure 7.11 shows the placement and 7.12 and 7.13 demonstrate the construction of the educational boards.

Figure 7.11: Placement of educational boards about bank erosion, soil erosion, water resistant building in Ricanau Mofo.

Figure 7.12: Information board of land erosion (top left); of flood damage in urban environment (bottom left); and of river bank erosion (right)

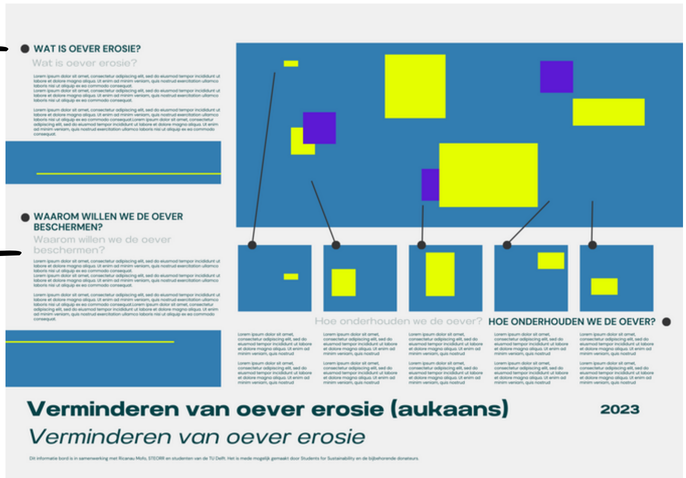
Figure 7.13 the 60cm high wooden sheet pile on the river bank further explained on the educational board at the river bank.

Argumentation for the design of the educational boards
The information boards can be seen in large in Chapter 6. Here, it explains the argumentation behind the set up, textual and visual language of the educational boards (Figure 7.13).



By addressing the situation as **a 'we-challenge'** instead of 'you-challenge', it steers towards collaboration and shared responsibility. It focusses on creating collective motivation for a 'we can do it together'-situation.

The reason the Auccaans text is positioned before the Dutch text is that **Aucaans is the local language spoken** in Ricanau Mofo.



Explanation about the challenges in **a question form** as 'What is soil erosion?' to play into the questions villagers could have or explain unknown terms.

The 'why' question is added to make the **urgency of the challenges** clear and why it is important to think about solutions. It could help villagers with explaining the situation in Ricanau Mofo when they are in **contact with external parties** as well.

The 'how question' is to move towards **an active state of 'what can we do now'** and also, to make **the maintenance of the interventions** a conversation topic.

The images **illustrate the topics visually. They illustrate the** situation in 2023, our envisioned ideal for Ricanau Mofo, and a graphical depiction of intervention placement along with potential future enhancements.

Figure 7.14: Argumentation behind the set up, textual and visual language of the educational boards.

Figure 8.0: Festive conference at Ricanau Mofo (authors' work)

8. >> Conclusion

This research addresses the need for expansion and development of Ricanau Mofo, while it faces land erosion, river bank erosion, changing rainfall patterns and sea level rise. It is urgent to intervene, as these issues are expected to increase in occurrence due to climate change. Therefore, the research question is as follows:

How can the project contribute to a sustainable and water-adaptive Ricanau Mofo, while being feasible in the local socio-technical environment?

Important factors that are taken into account while researching these questions are cultural values, financial constraints of the local community, the need for an intervention to be low maintenance and maintaining accessibility to the river, which is crucial for daily activities in the village.

>> Conclusion

This study proposes three strategies for creating a more sustainable and water adaptive Ricanau Mofo. The first strategy (1) addresses land erosion. Short term implementation involves placing vegetating with horizontally growing roots on urgent, eroding areas, while long term contribution can be made by constructing footpaths with drainage channels on both sides next to them. The advantage is soil is less likely to erode due to the obstacle of roots, due to more water drainage in areas where the ground is not hardened by walking and due to the regulation of water in the drainage channels. Also, these can be locally implemented with relatively low-cost implications or maintenance.

The second strategy (2) addresses the river bank erosion. Short-term mitigation encompasses placing two layers of wooden bulkheads on the river bank with vegetation and stones between the layers, while long-term interventions consist of constructing a river bank protection system in the water and adding groynes. The advantage is less river bank erosion as the soil is being detained by the bulkheads, roots of the vegetation and stones, and even slowly land is gained. The advantage of the long term interventions is waves are broken, the velocity of the water flow is decreased and land is gained. However, the long-term implication is not feasible for the village to realise without (financial) aid.

The last strategy (3) addresses the water damage in the urban environment. It consists of building regulations for the short term, explaining which areas are situated higher and lower and thus where the villagers can build more water adaptive. It also gives guidelines for how to build more water adaptive with local materials, which are building on poles, on a terp, building with the idea of living on the 'second floor', or adding a wall and gutters to the houses. Long term, it consists of a flood early warning system. The advantage of these interventions is that flood damage is mitigated. However, it is important to notice it does not prevent water damage if it does not prevent flooding events.

The study included the construction of a prototype of the Wooden Sheet Pile Wall on the Foreshore along the most eroded areas of the river bank, together with the villagers. Twelve cocos palms are planted on the river bank, and two red mangroves are in front of the river bank. With this, there is a local example of how it can be proceeded after the project ends. Also, educational information boards are placed in three places in the village, summarising how land erosion, river bank erosion and urban damage can be mitigated on a local level. Furthermore, a business case including a permit for the proceeding of the river bank protection in the water is prepared and given to the Captain of Ricanau Mofo, STEORR, the DC of Marowijne and the Ministry of Public Works. With this, international funding can be requested.

This project's significance lies in identifying interventions that are effective against erosion and water damage while being locally implementable in the rural areas of Surinam. It can be seen as a pilot project that is scalable to other villages along the Cottica River or in the whole of Surinam.

However, there are limitations to the project. The most important is the lack of data quantity and data quality. This caused implications for dimensioning the interventions and its financial impact. A mitigation strategy is started by installing measurement instruments to capture the water level rise, the depths and the velocity. Another limitation is that the project does not create 'dry feet' for the village; it creates a way of mitigating water damage while living next to the Cottica River. In addition, there is a limitation in financing follow-up projects. Therefore, a business case is also being delivered to the Ministry of Public Works, the District Commissioner of Marowijne South-West and the captain of Ricanau Mofo. They can use it to apply for funds from international organisations and include it in future policy plans.

To summarise, Ricanau Mofo can become more water adaptive by regulating how to build and where, by continuing the prototype of the bulkheads by planting more vegetation and, by requesting financial aid for the river bank protection long term. It not only contributes as a report, but also in a tangible form of a prototype and in educational information boards in the local tongue to enhance the continuity and help the village.

9.

Figure 9.0: Cocopalms ownership workshop for the children (authors' work)

>> Further research

This research has explored the possibilities and limitations of developing a more water adaptive and sustainable Ricanau Mofo by presenting strategies for addressing river bank erosion, land erosion and water damage to the urban environment. However, there are still (new) knowledge gaps to be addressed by future research, based on the methods and on the limitations stated per intervention strategy.

This research stated that the lack of data and its quality has formed a limitation on quantifying the water nuisance and its possible interventions. Therefore, it is still needed to create a more accurate hydrologic model. Important stakeholders to collaborate with are Anton the Kom University in Paramaribo.

The accuracy of the hydrologic analysis should be enhanced through continuous discharge monitoring, in the wet season as well. Exploring the feasibility of implementing continuous discharge monitoring for the Cottica River and potentially other rivers in Suriname using the open-source software OpenRiverCam in combination with mapping the bathymetry and water level measurements is a worthy consideration. This technology could enhance the ability to monitor and manage river systems effectively, contributing to the data quantity. Key stakeholders are Anton the Kom University and the MDS.

This research proposes building guidelines with ideas on how houses can be built more water adaptive. These ideas could be visualised by constructing example houses on a miniature level, ensuring more knowledge transfer. Key stakeholders for setting up this project are STEORR and the captain of Ricanau Mofo.

As this project poses as a pilot project, scalability has been one of the factors on which the most effective and feasible strategies are made. There is still a gap in whether interventions are already implemented in other villages along the Cottica river that struggle with floods and other areas in Surinam and whether these strategies for river bank erosion, land erosion and flood damage are implementable for them. For this, a collaboration with the District Commissioner or the Ministry of Public Works could be helpful.

Lastly, even though the local educational system educates about water quality, water quantity is not one of the subjects that are learned about. It could be interesting to look into how this can be changed so that the communities are less reliant on other stakeholders by increasing local knowledge and motivation to mitigate water quantity problems. For this, it could be collaborated with the Ministry of Education in Marowijne and the District Commissioner.

References (1/4)

Anton de Kom Universiteit. (2018). Bacheloropleidingen. Anton De Kom Universiteit Van Suriname. https://www.uvs.edu/studie/aanbod/bacheloropleidingen/

Anton de Kom Universiteit. (n.d.). Mangrove rehabilitatie project Weg naar Zee. Anton De Kom Universiteit. https://www.uvs.edu/mangrove-rehabilitatie-project-weg-naar-zee/

Augustinus, P. (2004). Project Studie: Bouw oeverbescherming distrikt Commewijne. https://repository.tudelft.nl/islandora/object/uuid:efce3243-c93f-40a3-9c71-8a7242a40434?collection=research

Beun, N. (2005). Ruimte voor nieuwe rivieren. In https://edepot.wur.nl/441596 (B31288_flyer). InnovatieNetwerk. Retrieved October 16, 2023, from https://edepot.wur.nl/441596

Bosboom, J., & Stive, M. J. F. (2021, December 20). 10.5.3: Groynes. Geosciences LibreTexts. https://geo.libretexts.org/Bookshelves/Oceanography/Coastal_Dynamics_%28Bosboom_and_Stive%29/08%3A_Coastal_protection/8.05%3A_Structures_influencing_longshore_transport_rates/10.5.3%3A_Groynes

Bryson, J. M., & Humphrey, H. H. (2003). What To Do When Stakeholders Matter: A Guide to Stakeholder Identification and Analysis Techniques. Researchgate. http://pmranet.org/conferences/georgetownpapers/Bryson.pdf

Crossman, M., & Simm, J. (2004). Manual on the use of timber in coastal and river engineering. Retrieved October 19, 2023, from https://assets.publishing.service.gov.uk/media/602bf1788fa8f5038238ea21/_Manual_on_the_use_of_timber_in_coastal_and_river_engineering_technical_report.pdf

Dean, M. (2020). Multi-criteria analysis. In Advances in transport policy and planning (pp. 165–224). https://doi.org/10.1016/bs.atpp.2020.07.001

Defacto Stedenbouw. (2022). Kansen voor gevolgbeperking overstromingen in Amsterdam. In Klimaat Effect Atlas. Gemeente Amsterdam. https://www.klimaateffectatlas.nl/l/nl/library/download/urn:uuid:8268e9e7-43a4-4f47-a243-0a7a7e86b879/kansen+voor+gevolgbeperking+overstromingen+in+amsterdam_2022.pdf#page=21

Deltares Tabellen aanleg- en beheerkosten - Climate Resilient City Tool - Deltares Public Wiki. (n.d.). https://publicwiki.deltares.nl/display/AST/Tabellen+aanleg-+en+beheerkosten

Dorst, K. (2015). Frame Innovation. In The MIT Press eBooks. https://doi.org/10.7551/mitpress/10096.001.0001

Esteves, L. (2018, September 20). Klimaatverandering: we moeten mensen beginnen verhuizen uit kustgebieden. MO Mondiaal Niets. https://www.mo.be/opinie/klimaatverandering-we-moeten-mensen-beginnen-verhuizen-uit-kustgebieden-opinie

GO FAIR initiative. (2022, January 21). FAIR principles - GO FAIR. GO FAIR. https://www.go-fair.org/fair-principles/

>> References (2/4)

Hoitink, A., & Jay, D. A. (2016). Tidal river dynamics: Implications for deltas. Reviews of Geophysics, 54(1), 240–272. https://doi.org/10.1002/2015rg000507

Karan.Saktoe. (2022). STARTSEIN MANGROVE REHABILITATIEPROJECT WEG NAAR ZEE. Overheid Van De Republiek Suriname. https://gov.sr/startsein-mangrove-rehabilitatieproject-weg-naar-zee/

Klip, H. (2020, November 11). Onderzoek: langsdam waardevolle maatregel voor rivierbeheer. H2O/Waternetwerk. https://www.h2owaternetwerk.nl/h2o-actueel/onderzoek-langsdam-waardevolle-maatregel-voor-rivierbeheer

KNMI versterkt samenwerking met Suriname. (2023, August 31). KNMI. https://www.knmi.nl/over-het-knmi/nieuws/knmi-versterkt-samenwerking-met-suriname

KNMI. (n.d.). KNMI. https://www.knmi.nl/over-het-knmi/over

Koole, E. (2023). Potential sources of predictive skill of seasonal precipitation forecasts for suriname. https://repository.tudelft.nl/.
Lamulle Constructions. (n.d.). Bulkheads. Retrieved October 19, 2023, from https://www.lamulleconstruction.com/services/bulkheads.html#gref

Lee, M., Yoo, Y., Joo, H., Kim, K. T., & Kim, H. S. (2021). Construction of rating curve at high water level considering rainfall effect in a tidal river. Journal of Hydrology: Regional Studies, 37, 100907. https://doi.org/10.1016/j.ejrh.2021.100907

Lonbois, M. (2023, March). Indonesië bouwt nieuwe hoofdstad wegens overstromingen, maar ook daar is er al wateroverlast. Vrtnws. https://www.vrt.be/vrtnws/nl/2023/03/29/indonesie-bouwt-nieuwe-hoofdstad-door-wateroverlast-maar-die-kr/

Maritime Authority Suriname. (2022). MAS. https://mas.sr/

MAS – Maritieme Autoriteit Suriname. (2020). https://mas.sr/nl/home-nederlands/
Meteorologische dienst Suriname start dagelijkse weersverwachtingen. (2023). Overheid Van De Republiek Suriname. https://gov.sr/meteorologische-dienst-suriname-start-dagelijkse-weersverwachtingen/

Ministerie van Buitenlandse Zaken. (n.d.). Embassies, consulates and other representations. Rijksoverheid. https://www.government.nl/topics/e/embassies-consulates-and-other-representations

Ministerie van Openbare Werken. (2023a). Missie. Ministerie Van Openbare Werken. https://gov.sr/ministeries/ministerie-van-openbare-werken/missie/

MINSTRY OF PUBLIC WORKS TRANSPORT AND COMMUNICATION. (2017). Paramaribo Strategic Flood Risk Assessment. Retrieved October 23, 2023, from https://documents1.worldbank.org/curated/en/463821538552629012/pdf/Suriname-FRA-REPORT-FINAL.pdf

>> References (3/4)

N. Hogendoorn & Kasteel, M. (2022). Flash floods in Cebu: monitoring, modelling and preventing. TU Delft Repositories. https://repository.tudelft.nl/islandora/object/uuid%3A7d93b43c-6973-40ff-9121-4ba6436d8277

Newmont Corporation. (2023). Newmont. https://www.newmont.com/operations-and-projects/global-presence/south-america/merian-suriname/default.aspx

Overheid van de Republiek Suriname. (n.d.-a). Directoraat Onderzoek en Dienstverlening. Overheid Van De Republiek Suriname. https://gov.sr/ministeries/ministerie-van-openbare-werken/het-directoraat-onderzoek-en-dienstverlening/

Overheid van de Republiek Suriname. (n.d.-b). Ministerie van Onderwijs, Wetenschap en Cultuur. Overheid Van De Republiek Suriname. https://gov.sr/ministeries/ministerie-van-onderwijs-wetenschapen-cultuur/over-ons/

Overheid van de Republiek Suriname. (n.d.-c) Ministerie van Ruimtelijke Ordening en Milieu. Overheid Van De Republiek Suriname. https://gov.sr/ministeries/ministerie-van-ruimtelijke-ordening-en-millieu/over-ons/

Peak traditional fencing. (2022). Willow Spiling Bank stabilisation. Peak Traditional Fencing. https://www.peaktraditionalfencing.co.uk/our-services/willow-spiling/

ProGrafx Designs. (2017). ProGrafx Designs. https://prografxdesigns.com/index.php/diensten/
PTC. (n.d.). Het Polytechnic College Suriname. https://www.ptc.edu.sr/over-polytech-college/

R, V. D. E. (2007). Leven met de overstromingen 2007. TU Delft Repositories. http://resolver.tudelft.nl/uuid:7bd30a31-80ff-4453-b384-5e439a983ba2

Redactie Waterforum. (2023, 13 juli). Nederlandse terpen beschermen bewoners in Bangladesh. Waterforum. https://www.waterforum.net/36694-nederlandse-terpen-beschermen-bewoners-in-bangladesh/

Redirect notice. (n.d.). https://www.google.com/url?q=https://assets.publishing.service.gov.uk/media/602bf1788fa8f5038238ea21/_Manual_on_the_use_of_timber_in_coastal_and_river_engineering_technical_report.pdf&sa=D&source=docs&ust=1696526349488367&usg=AOvVaw0MifNW52naORpR-wiRkCfe

Riversgroup. (2007). Groynes. Retrieved October 19, 2023, from https://riversgroup.org.nz/wp-content/uploads/2018/10/Horizons-Groynes.pdf

Sciences, U. D. C. F. W. (2015, November 17). Dutch lessons on levee design and prioritization for California. California WaterBlog. https://californiawaterblog.com/2015/02/26/21st-century-delta-dutch-lessons-on-levee-design-prioritization/

Schiereck, G. J. (2019). Introduction to bed, bank and shore protection.

Scottisch Environment Protection Agency & Natural Scotland. (2020). Sustainable Riverbank Protection Reducing Riverbank Erosion: A best practice guide for farmers and other land managers. https://www.sepa.org.uk/media/219450/bank_protection_guidance.pdf

References (4/4)

Soulis, K. X. (2021). Hydrological data sources and analysis for the determination of environmental water requirements in mountainous areas. In Environmental requirements in mountainous areas. https://doi.org/10.1016/b978-0-12-819342-6.00007-5

Traymore N.V. (2022). About us. Traymore. https://www.traymorenv.com/en/about-us
United Nations Surinam. (2020, August 20). Ook professor Naipal laat zijn stem horen. Facebook. https://www.facebook.com/UNSuriname/posts/ook-professor-naipal-laat-zijn-stem-horen-sieuwnath-naipal-is-hydroloog-en-profe/3301440853255757/

Van Vuuren, W., Mol, R., & Van Voorn, H. (1999). De QH-relatie zijn langste tijd gehad? Op weg naar het Qf-tydperk voor de Rijntakken. In Edepot WUR. Wageningen University Research. Retrieved October 17, 2023, from https://edepot.wur.nl/363506

Waterpomp. (n.d.). Waterpompshop.nl. https://www.waterpompshop.nl/regenwaterpomp?prod_ext_pompcapaciteit=318

Wijdenbosch, J. A. (1998, March 30). Wet Maritieme Autoriteit Suriname [Press release]. https://mas.sr/wp-content/uploads/2014/12/wet-mas-van-30maart1998.pdf

Wikipedia-bijdragers. (2023). Cottica (rivier). Wikipedia. https://nl.wikipedia.org/wiki/Cottica_(rivier)

Winterwerp, J. C., Albers, T., Anthony, E. J., Friess, D. A., Mancheño, A. G., Moseley, K., Muhari, A., Naipal, S., Noordermeer, J., Oost, A., Saengsupavanich, C., Tas, S. A., Tonneijck, F. H., Wilms, T., Van Bijsterveldt, C., Van Eijk, P., Van Lavieren, E., & Van Wesenbeeck, B. K. (2020). Managing erosion of mangrove-mud coasts with permeable dams – Lessons learned. Ecological Engineering, 158, 106078. https://doi.org/10.1016/j.ecoleng.2020.106078

World Bank Climate Change Knowledge Portal. (2020). https://climateknowledgeportal.worldbank.org/country/suriname

Xiao, Y., Inoue, M., & Paudel, S. K. (2008). Modern bamboo structures: Proceedings of the First International Conference. CRC Press.

Zhang, W., Yan, Y., Zheng, J., Li, L., Dong, X., & Cai, H. (2009). Temporal and spatial variability of annual extreme water level in the Pearl River Delta region, China. Global and Planetary Change, 69(1–2), 35–47. https://doi.org/10.1016/j.gloplacha.2009.07.003

>> Appendices

The appendix consist of the following sub appendices:

A Project planning

B List of Interviews

C Interventions flood damage to the urban environment

D Interventions soil erosion

E Interventions river bank erosion

F Multi-Criteria Analysis of the interventions

G CPT Ricanau Mofo

H Technical drawings timber bank protection system

I Structural strengths calculations timber bank protection

A
Project planning

The project duration was 10 weeks on location fulltime with six students, and approximately half a year if preparation in The Netherlands (+- 2 hours a week per person). The first week on location started of with a meeting to determine which would be the most efficient manner for working together based on everyones compatibilities and on expectations.

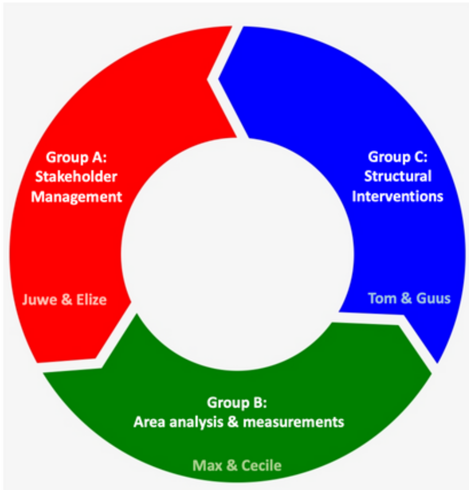


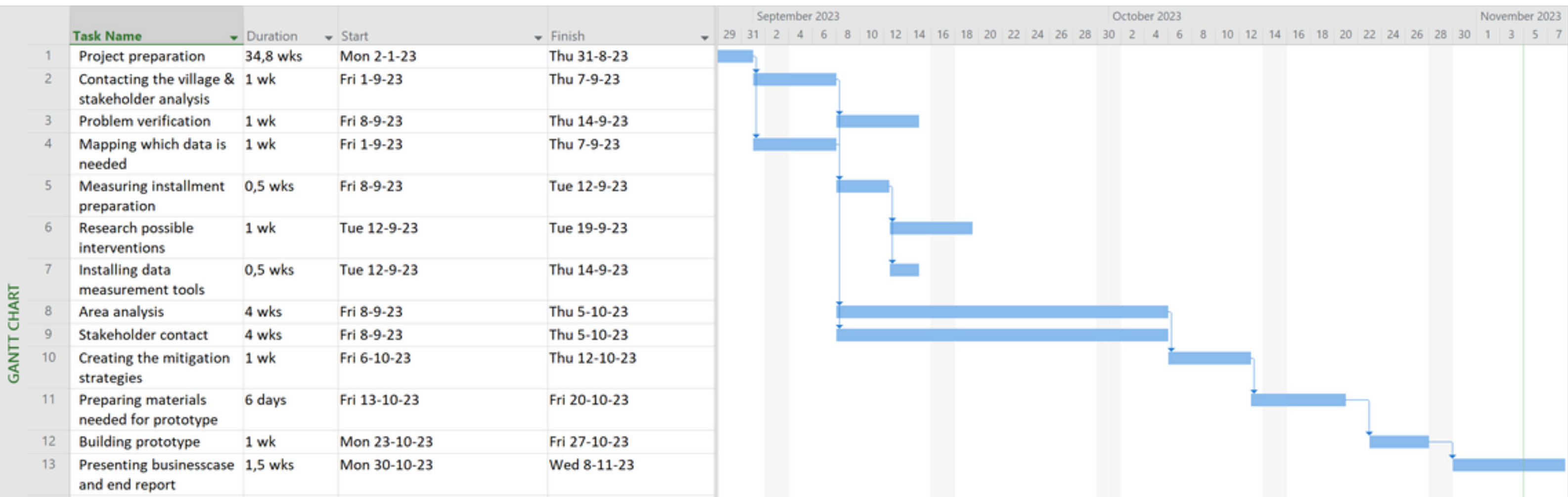
Figure A.1 Scrum sub-groups in the project group

The method 'Scrum' was chosen to use for meetings. The group split up in three sub-groups, each defining their goal - *their sprint* -for that week, formulated in a feasible and concrete way.

One sub group was responsible for stakeholder management, one for area (data) analysis and one for intervention analysis and calculations. The total group planning can be seen in figure A.2 which displays the GANTT chart. This is only a high overview of the planning. Each week was structured in the same way:

- On Tuesdays, the group did a **big scrum**. In this, each sub-group explained what their goal would be for the coming week and whether they made their goal of last week. This is combined in a meeting with overarching themes, for example financial projections, building material update and other subjects that were relevant that week.
- On Thursdays, the group did a **small scrum**. This is a 15 min short update about how far the subgroups were in reaching the defined goals for that week.
- Lastly, each Friday, the group had a feedback moment with the supervisors from STEORR. The group presented a summary of that weeks' activities, to share more knowledge and also check whether the activities were still in line with the client's needs.

GANTT CHART



	Task Name	Duration	Start	Finish
1	Project preparation	34,8 wks	Mon 2-1-23	Thu 31-8-23
2	Contacting the village & stakeholder analysis	1 wk	Fri 1-9-23	Thu 7-9-23
3	Problem verification	1 wk	Fri 8-9-23	Thu 14-9-23
4	Mapping which data is needed	1 wk	Fri 1-9-23	Thu 7-9-23
5	Measuring installment preparation	0,5 wks	Fri 8-9-23	Tue 12-9-23
6	Research possible interventions	1 wk	Tue 12-9-23	Tue 19-9-23
7	Installing data measurement tools	0,5 wks	Tue 12-9-23	Thu 14-9-23
8	Area analysis	4 wks	Fri 8-9-23	Thu 5-10-23
9	Stakeholder contact	4 wks	Fri 8-9-23	Thu 5-10-23
10	Creating the mitigation strategies	1 wk	Fri 6-10-23	Thu 12-10-23
11	Preparing materials needed for prototype	6 days	Fri 13-10-23	Fri 20-10-23
12	Building prototype	1 wk	Mon 23-10-23	Fri 27-10-23
13	Presenting businesscase and end report	1,5 wks	Mon 30-10-23	Wed 8-11-23

Figure A.2 GANTT chart of the project planning

B
List of interviews

Figure B shows an overview of interviews and obervations conducted during the Consultancy Civil Engineering project 2023.

Table B: Overview of interviews, and obervations conducted during project (part 1).

Organization/ group	Person interviewed	Date	Objective
Office of DC of Marowijne Zuid-West	Olivia Dominie; District Commissioner	07-09-2023; Moengo	Introduction of our project
Police of Moengo		05-09-2023; Moengo	Introduction of our project
Ministry of Education of Marowijne	Mavis Rynolda Botho-Anini; Minister of Education of Marowijne	05-09-2023;Moengo	Introduction of our project
Habitants RRM	Keba	07-09-2023; Ricanau Mofo	Participative research to a farming plot (kostgrondje)
Anton de Kom Universiteit	Professor Naipal; & Professor Sun	08-09-2023; Paramaribo	Knowlegde generation about the area and water management. Also, lending measurement instruments
Ministry of Public Works of Paramaribo	Directory Infrastructure, Directory coastal and river works, directory roads.	13-09-2023; Paramaribo	Exploring possibilities for collaboration

Table B: Overview of interviews, and obervations conducted during project (part 2).

Habitants of similar villages along Cottica River	Multiple villagers	14-09-2023; Tamarin, Pikien Santi, Wan Hatti, Manga Bong, Langa hoekoe, Paradijs	Exploring whether other villages also have trouble with water nuisance and what (nature based) solutions they have implemented
Ministry of Spatial Planning and Environment	Mr. Darsai; Minister	15-09-2023; Paramaribo	Exploring possibilities for collaboration
Maritieme Authoriteit Suriname (MAS)	C. Warmoen, Assistent Manager Nautical ManagementB. Mahabor; Manager Nautical Management	21-09-2023; Paramaribo	Data collection of the Cottica River itself and of shipping through the river.
Meteorologische Dienst Suriname (MDS)	N. Radj; Hoofd van de meteodienst	21-09-2023; Paramaribo	Data collection from weather station of Moengo
Dutch Ambassy in Paramaribo	Michiel Bergen's	26-09-2023; Paramaribo	Introduction project and ambassador
American Ambassy	American Ambassador; Jan-Willem XXX	27-09-2023; Moengo	Introduction project
Field trip of Ministry of Public Works	Representaties of directory of Kust & Rivierwerken; WLA; Meteodienst; Onderzoek & innovatie;	28-09-2023; Ricanau Mofo	Presentation Interventions per function; brainstorm/SWOT during field research
PTC	CEO; dean; programmanager; head of each bachelor degree.	12-10-2023; Paramaribo	Exploring options of follow-up projects with PTC.

C

Interventions flood damage to the urban environment

C.1 Elobaration on alternatives

The elaboration on alternatives started with the 'talking cards ' of VanderMeeren. They were extended with alternatives found in the literature research (see Chapter 2). Chapter 6 and Appendix F describe how interventions are selected via a multi-criteria analysis. In Figure C0.1 the selection of interventions to prevent or decrease water nuisance are listed and next pages the interventions are expanded to concept with a description, challenges and (dis)advantages.

1. Stepping stones

2. Bypass

3. Dyke

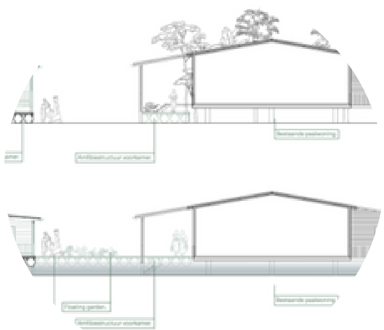
4. Boardwalks

5. Flood early warning systems

6. Relocating the village

7. Living on terp

8. Houses on poles



9. Floating (parts of) houses

Figure C0.1: Overview of intervention river bank erosion

C.2 Screening of alternatives

Figure C0.2 depicts the interventions that soil erosion. Housing on poles and floating (parts of) houses are three alternatives that are both relatively feasible and efficient. Housing on poles, especially in the zones of the village that cope with the most water nuisance can increase the liveability and decrease the material damage after a flood. Floating (parts of) houses achieve the same goal, by ensuring a 'dry' part of the house in which the inhabitants can still live during a high water level of the Cottica river. These will therefore be fully taken into account in the Multi Criteria analysis.

A flood early warning system is feasible, but not very efficient to decrease the water nuisance. This is due to the fact that even if the inhabitants know that there will be a flood in a specific period of time, there is no alternative for (most of them) to move somewhere else for that period or even store their materials somewhere else. This alternative is only efficient in combination with offering a place to move themselves and/or their materials.

Living on a terp, stepping stones, boardwalks, moving the village, a by-pass and a dyke are all efficient to address water nuisance, but have low feasibility. Living on a terp could decrease water nuisance because the houses are placed on a higher ground level. However, this would mean that the entire village is placed on a terp, which carries costs and maintenance problems. Stepping stones and boardwalks both create a dry place to walk during a flood. However, for them to be efficient they should be placed on walking paths and roads. In the historic centre of Ricanau Mofo which has a high chance of experiencing water nuisance, these are very small, which makes the paths inefficient when there is no flood. Moving the village would be effective in addressing the water nuisance as it can then be placed on higher soil. However, this would mean abandoning their homes, cultural traditions and other aspects that are connected to the area. A bypass is only efficient when it is big enough to relocate parts of the river to ease the water nuisance. This means that it would be large enough to relocate roughly 20% of this part of the Cottica River, causing it to be an enormous intervention for a relatively small village. Lastly, a dyke would be neutrally efficient as the flooding stems from the high water level and from precipitation flow all around the village. Therefore, an all-around dyke should be built for it to decrease water nuisance. However, this requires high investments, and many maintenance aspects and causes the city to not be able to expand freely anymore. As there is a high need for city expansion, this is not optimal. These alternatives are taken into account in the Multi-Criteria analysis, but due to resource management more roughly.

Building a water basin has low efficiency and low feasibility. It indicates that another area should be assigned for flooding, having the capacity to relieve the pressure of the entire Ricanau Mofo area. The waterways should then be altered to that area. It will be a costly and difficult intervention to realise. Therefore, this alternative will not be taken into account in the Multi-Criteria Analysis, seen in Appendix F.

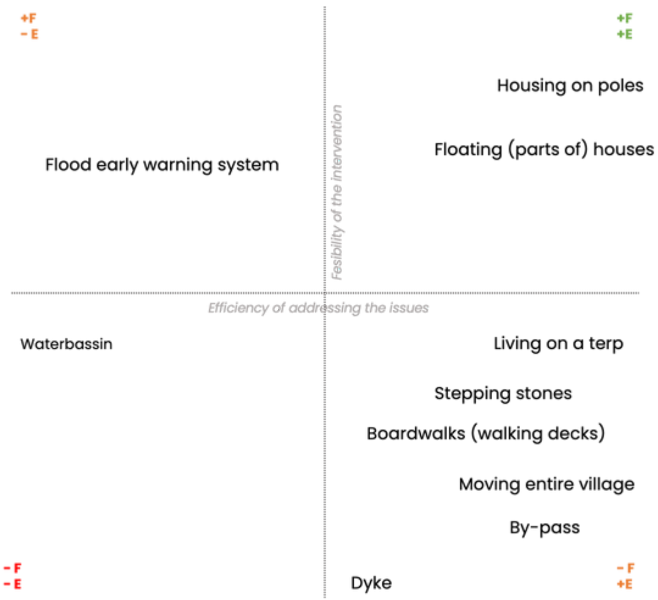


Figure C0.2 depicts the rough scores for feasibility and efficiency to address the function of mitigation water damage to urban environment.

Figure C1: Stepping stones in Nijmegen, The Netherlands (Wang, 2018)

1.Stepping stones

What it does
This alternative consists of placing stones on crucial pathways in Ricanau Mofo to ensure a ‘dry’ possibility of transport during a flood. They are placed on or closeby walking paths. With this, the transport constraints that occur during periodical floodings can be addressed (Defacto Stedenbouw, 2022).

Challenges
The challenge lies in analysing how high they must be, which pathways are important and how they are not a burden during dry periods.

Advantages and disadvantages
The advantage is, it is a relatively easy and low cost solution to implement. However, it is not a direct solution to the river's rising water during the rainy season, nor does it address the problem of houses being flooded during high water. However, when there is a flood, it does increase or maintain the accessibility. The stepping stones could still form a restriction of transport during the dry periods in a year.

Figure C2: Sketch of possible bypass in Ricanau Mofo

2.Bypass

What it does
The principle of a bypass is regulating the water level in the river by implementing an extra passage in the Cottica river as could be seen in Figure C2, which creates extra room for the river. By opening and closing a sluice, the water levels can be regulated and the water nuisance in Ricanau Mofo is reduced

Challenges
The main challenges are financing (as it is very expensive), maintenance and which party will take the lead in the construction, maintenance and operating of the bypass. Another reference project conducted in the Netherlands estimates the cost at €3 billion (Beun, 2005). However, this also depends on the price of the land on which the bypass will have to be built and may be reduced by other parties, such as mineral extraction. Crucially, the bypass must be engineered to accommodate the discharge capacity required by the Cottica River in the Ricanau Mofo region, necessitating a comprehensive understanding of the river's extreme discharge characteristics. Unfortunately, such critical data remains scarce.
Furthermore, the effective regulation of water levels through the controlled operation of the sluice gates requires the utilisation of a robust hydrological model capable of forecasting water levels under diverse scenarios. In combination with predictive rainfall models, these tools enable the estimation of future water levels, facilitating timely adjustments to the sluice gate operations.

Advantages and disadvantages
When operated properly, the bypass is a very effective method of ensuring that residents in Ricanau Mofo will keep dry feet. However, a party must be found within Suriname that is willing to operate and manage the bypass. Due to the lack of available data, a predictive model cannot yet be made, which complicates the proper operation of the sluice that lets water in or out of the bypass. This will eventually be able to interfere with the height of the navigation channel and ultimately have a negative effect on shipping. In addition, there are currently no financial resources available that could pay for the bypass.

Figure C3: Dyke in the Netherlands (Sciences, 2015).

3.Dyke

What it does
Barrier around the entire village. Could be made from different materials, depending on the needed height of the barrier, needed strengths and available resources. Its main purpose is to protect the village from floods. The dyke is located around the complete village and makes sure no water from the river is able to enter the village.
River dikes at Ricanau Mofo serve multiple crucial functions:

1. Flood Protection: Prevents river water overflow, safeguarding nearby areas from flooding during high water levels.
2. Protection of Inhabited Areas: Shields villages, homes, businesses, and infrastructure from potential flood damage.
3. Water Level Management: Manages river water levels, ensuring they remain navigable and maintaining a stable supply for various needs.
4. Ecological Functions: Supports biodiversity by creating wetlands and habitats for diverse plant and animal species.
5. Erosion Control: Prevents river bank erosion, preserving the river's natural course and preventing land degradation.
6. Sedimentation Regulation: Manages sediment deposits, crucial for maintaining water quality and river ecology.

Challenges
Building a dike would solve part of the problem. However, just building a dike will create new problems. Making the dike successful requires a global approach to the village. Besides, building the dike cannot be done just like that. This requires careful ground preparation beforehand. If this does not happen, the ground may collapse and the dike may fail in some way.

The village suffers from flooding during the rainy season, bank erosion along the Cottica River and land erosion due to heavy rainfall.
The village of Ricanau Mofo floods on all sides due to high water levels and excessive rainfall. By installing only a dike along the Cottica River and Ricanau Creek, the village will flood from the side and from the back because the sites here are also low-lying. To avoid flooding, the village will have to be surrounded by a dike, which in turn will affect the village's ability to grow.

Besides, it will not immediately add anything to bank protection. Should this be desirable, the design would have to be extended further into the river, which would also defend the bank. However, this will involve a lot of additional costs.

As for land erosion, the embankment will not provide a solution. The village will continue to sink initially and then the water will have nowhere to go. So the dykes around the village will stop the water from outside, but will also ensure that the water from inside cannot flow away. A sophisticated drainage system will be needed to achieve this. For this, well-functioning drainage channels would be crucial, well-maintained and able to drain all the water. On top of this, a pump would have to be installed, which would ensure that the water can be pumped away into the river.

Installing a dike, will give the feeling of total safety, which in itself may pose a risk. Importantly, villagers are still concerned with water levels and rainfall. When the dike fails, the damage may be many times greater, as villagers do not expect it.
The dike must be well maintained and monitored if it is to maintain optimal efficiency. Full confidence in the embankment after construction, therefore, can add to the risk.
Since maintenance of structures is a national problem, this can be seen as a critical point in this design, which could make it not work.

In addition, the pump could also fail, preventing the water from leaving and the village still faces flooding. This scenario will also have to be taken into account.

The most crucial challenges are financing (as it is very expensive), maintenance and what party will take the lead in this. Also, when there is heavy precipitation, the water must still be able to flow away. Lastly, it has a huge impact on daily social life, aesthetics, accessibility and the future expansion of the city. The last reason is interesting to keep in mind, as the city has the need to expand.Maintenance and strengthening of these dikes are vital to sustaining their effectiveness and safeguarding protected areas from water-related hazards.

Advantages and disadvantages
The advantages are that a dyke protects the village against floods from the river and is a long lasting solution. However, there are many disadvantages. The labour for the construction and maintenance is intensive. Both are expensive to realise and intensive to maintain. The drainage system, which is in the current situation not maintained, it extremely important to maintain as this regulates water outflow during heavy precipitation. Also, the severity of the dike failing is significantly high. Lastly, due to the location of the dyke, the village will not be able to expend due to it, which is at odds with the needs of the village currently.

Location of the dyke

The main purpose of the dike is to hold back the water from the rivers. In the case of Ricanau Mofo, the village is surrounded by creeks from which water will flow into the village. Placing a dike just along the bank will partially reduce but not stop the flooding. This problem requires a ring dike around the entire village. So that water from outside cannot enter the village. This will result into a total dyke length of about ±1400 m (Figure C3.1).

Figure C3.1: Sketch of dyke around Ricanau Mofo

Requirements of a Dike

- **Space**
  - Building a dike will require a lot of space and preparation.
  - A dike must have a certain crest height that can withstand high water, waves and sea level rise in the future. This will result in a high crest height, which in turn will entail a wide dike base. An inner and outer slope, will provide a spacious design, which will require more space to be made along the levee.

- **Material**
  - **Building dikes with sand**: Sand is a widely used material in levee construction because of its availability, stability and relative affordability. However, there are several important considerations and techniques that must be applied when building levees with sand:
    - Embankment angles: Embankment design must consider embankment angles (ratio of horizontal to vertical spacing) to ensure that the embankment is stable. The exact slope angles vary depending on the grain size and stability of the sand, as well as other factors such as water height and wave loads.
    - Compaction: The sand must be properly compacted to ensure stability. This means that the sand must be firmly compressed to reduce empty spaces between sand grains, which increases the density and stability of the embankment.

        - Drainage: Sand naturally has good drainage properties, but it is still important to include an effective drainage system in the dike. This helps drain excess water and prevent the sand from becoming saturated, which can reduce the stability of the dike.
        - Erosion protection: To prevent erosion, especially at the waterfront of the dike, several methods can be used, such as lining the dike with stones, planting grass or vegetation, and using geotextile materials.
        - Soil investigation: thorough geotechnical investigation is essential to understand the properties of the sand. This investigation helps engineers determine the suitability of the sand for levee construction and determine appropriate construction techniques.
        - The use of sand in levee construction is common, but it requires expert planning, design and execution to create a stable and reliable levee. Regular monitoring and maintenance are also important to maintain the integrity of the dike.

    - **Building dikes with clay:**The cohesive properties of clay provide natural strength, making it a suitable material to build a dike on and with. However, there are a number of considerations:
        - Permeability: Clay is usually less permeable than sand or gravel. This can be both an advantage and a challenge. It can help prevent water permeability through the dike, but it can also complicate stormwater runoff, causing drainage and stability problems.
        - Settlement behavior: Clay tends to settle over time, meaning it can settle and compress under the weight of the dike and other loads. This settlement behavior must be evaluated and considered during the design of the dike.
        - Stability: The design of an embankment on clay soil must be done carefully to ensure stability, especially during periods of rainfall, high water levels or other loads. This may include the use of revetment materials, such as stone or grass, to prevent erosion.
        - Drainage: To prevent water from accumulating and weakening the levee, it is important to install an adequate drainage system in the levee. This helps drain water that accumulates in the clay soil.
        - Monitoring and maintenance: Dikes on clay soil should be monitored regularly to check for signs of erosion, settlement or other stability problems. Regular maintenance and inspections are crucial to maintaining the integrity of the levee.
        - Successfully building a levee on clay soil thus requires careful planning, geotechnical investigation and engineering to ensure that the levee is stable and reliable over its lifetime.
        - Dike covering: The dike will need to be protected with vegetation and/or stones. This will prevent erosion of the dike and provide additional defense against wave action.

- **Pumping and drainage**
    - Building a dike undercuts the natural stormwater runoff to the river. Mainly during the rainy season, this will cause water to accumulate within the village levees. In urban areas, drainage is already widely regulated. In Ricanau Mofo it is not. For this reason, a pump will have to be installed to discharge rainwater to the river. Without the construction of drainage channels, the pump will only have a local effect and water will still remain in the village at a distance from the pump. For this reason, drainage channels are constructed to distribute rainwater from the village to the pump for subsequent discharge to the river.
    - The pump must be able to dewater the surface of the reclaimed area. This involves an area of about 19 hectares. Assuming that the pump may only provide 1/10 year of under-capacity, we must assume a rain event of about 25 mm in the wet months. Meaning that the pump should carry a capacity of 200 m^3/h. The pump housing should include: system and control technology to regulate the water level, filter and waste-free drainage channels, and a control party/responsible party who can act in times of emergencies.

Dimensions

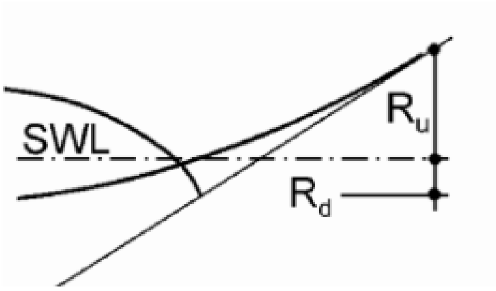
- Crest height:

The crest height is determined by the design water level, wave height, safety margin and sea level rise safety factor.

This leads to a design dike height of at least 1 + 0.01 + 0.5 + 0.5 = 2.01 meters above the lowest part of the village.

The SWL (still water level) during high water in the village is assumed to be 1 meter above the location of the lowest point in the village. This value is assumed after observation of the facades in the village.

The wave run-up on a dike is determined through the following equation:



$$\frac{R_u}{H} = \xi$$

Figure C3.2: Wave run-up and run-up (Schiereck, 2019)

The height of the waves due to the ships was assumed to be: H = 0.2 m
Generally, however, an Iribarren number between 0.05 and 0.5 is aimed for shipping waves. Within this range, the waves are usually non-fracturing and less damaging to the dike.

The wave run-up in that case will have a design value of 0.2 * 0.05 = 0.01 m

The safety margin will be 0.5 m. This value is used to provide additional protection against unexpected or variable conditions. This includes, for example; uncertainties in calculations, extreme weather conditions, maintenance problems and human error.

Safety margin for sea level rise will be assumed to be 0.5 meters.

- Embankment slope

In the case of an embankment made of sand, the embankment slope will be between 1:1 and 1:3, meaning that the base of the embankment will be at least 2 meters into the village.
This depends on the angle of internal friction. For dry sand, this is around 35 degrees.
For wet sand, this is at 45 degrees and so an embankment slope of 1:1 would suffice (see Figure C3.3).

For clay, this angle is even lower, which would mean that the slope becomes less steep and thus the foot of the dike would have to be quite a bit inside the village. In addition, the dike will be used by villagers to access the water, which again requires a less steep slope.

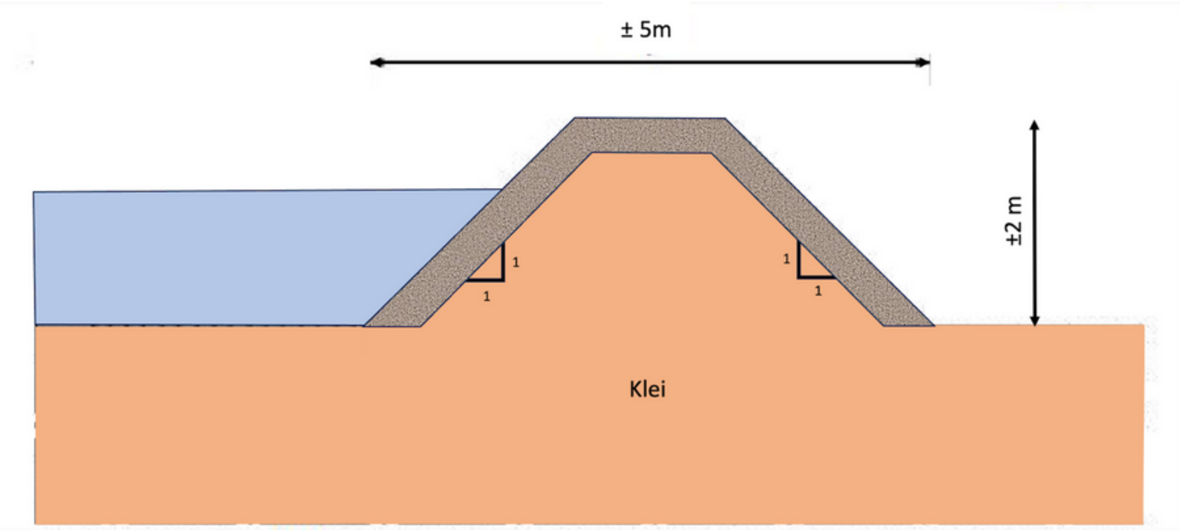


Figure C3.3: Sketch of dyke with dimensions for Ricanau Mofo

Cost estimate

The following cost estimate is based on the construction and maintenance cost estimations set up by Deltares (Deltares, n.d.). Naturally, labour costs in Suriname are lower, so the total costs will be lower. But this is an indication of the cost of a properly constructed dike (see Figure C3.4).

Deltares Prices	Costs per m2 (€)	Total width (m)	Total length (m)	Total costs (€)
Dike (around RRM)	€ 590,00	5	1400	**€ 4.130.000,00**
Installation Drainage Channels	€ 75,00	1	300	**€ 22.500,00**
Pump	nvt	nvt	nvt	**€ 3.000,00**
Maintenance Dike/year	€ 2,30	5	1400	**€ 16.100,00**
Maintenance Drainage/year	€ 0,75	1	300	**€ 225,00**
Total Initial Costs				**€ 4.152.500,00**
Additional Yearly Costs				**€ 16.325,00**

Figure C3.4: Construction costs of a dyke for Ricanau Mofo (Deltares, n.d.),(Regenwaterpomp, n.d.)

Figure C4: Boardwalks in Tinker Nature Park (Debii Bower, 2019)

4.Boardwalks

What it does
Elevated pathways around the village to ensure the possibility of transport when there is a flood (Defacto Stedenbouw, 2022). It could be made from wood or other sustainably, locally available materials. They are already implemented in several places along the world to increase accessibility of places where there is regular water nuisance.

Challenges
However, a challenge lies in the historical centre of the village, as there is a high urban density. It also lies in identifying which pathways are important enough to elevate, while not restricting accessibility during dry periods. A challenge also lies in the maintenance of the wooden structures.

Advantages and disadvantages
It is a relatively low cost solution, which can be implemented by the villagers themselves without (significant) help needed from other parties. However, it is not a direct solution to the river's rising water during the rainy season, nor does it address the problem of houses being flooded during high water.

Figure C5: Water level measurements in the Traymore harbour of Moengo that form the basis for a FEWS (authors work)

5.Flood early warning systems

What it does

A flood early warning system is a network of measuring sensors, data sources, and communication channels designed to monitor and predict flooding events. It collects real-time data on rainfall, river levels, and weather conditions, processes this information using hydrological models, and enables authorities to alert local communities well in advance of potential flooding. By providing timely warnings and facilitating preparedness, these systems help mitigate the impacts of floods on lives and property.

Challenges

Although it does not provide direct protection against flooding, implementing a well-functioning system can be quite costly. A study done in Paramaribo estimates the cost for that case for the implementation at 0.5 million US dollars and the operational and maintenance at 200,000 US dollars a year (Ministry of Public Works Transport and Communication, 2017). However, the report states that the benefits outweigh the costs as well. In addition continuous monitoring of the water level, rainfall and weather conditions is required. Although some of the required measurement stations are in place not all of them provide continuous data. Also, accurate weather predictions are required. The creation and operation of the hydrological prediction model requires physical knowledge of hydrology and mathematical knowledge on (numerical) modelling, probabilistics and statistics as well.

Advantages and disadvantages

Alerting the local community in a timely manner can be an effective method for flood mitigation. However, it requires a significant level of knowledge for proper operation. It's important to note that while early warnings are valuable, they are not a direct solution to flooding. When residents have nowhere to relocate themselves or their belongings, they will still encounter the same challenges despite being alerted in advance. However, compared to other measurements against flooding this is a relatively cheap option (Ministry of Public Works Transport and Communication, 2017).

Figure C6: The floodings in RIcanau Mofo when water would rise 120 cm. (Goossens, Marsboom & Plaghki, 2022)

6.Relocating the village

What it does
This is an alternative that is very drastic for the villagers based in Ricanau Mofo: relocating the entire village to a place where the ground level is higher. Lonbois (2023) explains that this has been done in Indonesia, where the capital Jakarta faces extreme flooding causing it to slowly disappear into the water. In 2019, a new capital is newly built on Kalimantan, with the hope there will be less water nuisance.

Challenges
The challenges that arise are creating a support base for this intervention. The village has high cultural, traditional and lifestyle related values in remaining in the same place. Therefore, the main challenge will be creating an intrinsic or extrinsic motivation for the villagers. Also, the financial part is a huge challenge as it is a significantly costly intervention. From a governing perspective, it is a challenge to decide whether villagers are expected to realise this autonomously, or if the government or another stakeholder will help.

Advantages and disadvantages
The advantage is that the problem of maintenance is less important than in other interventions. For example, delayed maintenance for a dike or bypass can have a significant fatal impact (Esteves, 2018), while this intervention does not cause more maintenance than is already performed on houses.

However, there are many disadvantages. It is a drastic change of life, it might interfere with the close family bonds of nearby villages and it is difficult to realise in an effective manner.

Figure C7: Living on a terp (Redactie Waterforum, 2023)

7.Living on terp

What it does
A terp is a manmade hill, or higher ground level using mostly clay and/or terra. Historically speaking, a terp is implemented in areas that have a low ground level, so that it could still be habitable while the chance of flooding decreases. It is a way to reduce the damage and water nuisance. This alternative consists of building one communal or multiple smaller terps for multiple houses.

Challenges
Communities need to invest in constructing these elevated platforms, which often involves the transportation and shaping of large amounts of soil or clay. Maintenance is also necessary to ensure the integrity and stability of the terp over time. Thereby, proper planning is crucial to ensure that the terps are strategically located and can accommodate the needs of the community. This includes access to basic services, transportation, and consideration of factors like drainage and sewage systems

Advantages and disadvantages
The primary advantage of living on a terp is the reduced risk of flooding. This can protect homes, infrastructure, and valuable assets from water damage. Which provides possibilities for further development of the area without having disturbances of floodings.

A disadvantage is that the construction of terps can be costly in terms of both financial resources and labour. Communities may struggle to allocate these resources effectively, especially in an environment such as Ricanau Mofo where all villagers are living from day to day. Thereby, regular maintenance is required to ensure that terps remain effective and safe. Neglecting maintenance can lead to erosion and deterioration.

Figure C8: Housing on poles in Ricanau Mofo (left); Housing on poles in Marienburg, Surinam (right) (authors' work).

8.Houses on poles

What it does
This is another way of decreasing material flood damage to houses, as opposed to a terp. The houses are not built directly on the ground, but on poles. These poles can be made from wood, concrete or other local materials. Bamboo is interesting to look into for this alternative in this area, as it is locally grown. Bamboo is strong and lightweight, resilient to wind and possible floodings (Xiao et al, 2018). It also opens the space beneath the house, which causes air flow beneath the house, cooling the interior slightly.

This construction mode is already implemented by different Maroon communities, and also a few in Ricanau Mofo, as seen in the picture below. The challenges are that even though this improves the chance for material damage, that the ground around the houses still flood. This can thus be combined with an intervening way of transport (A1: Stepping stones/A4: Boardwalks).

Challenges
The challenge is deciding at what height level the housing is most effective: the trade-off between what water level you want the heights to prevent versus the more inaccessibility of your house (Kennisportaal Klimaatadaptatie, n.d.). Another challenge is constructing the house in a way that is still resilient against heavy flooding, wind and rain. Lastly, the financial aspect of using more wood that is also water resistant in an area with low financial resources imposes an important challenge.

Advantages and disadvantages
The advantage is that the material damage that water causes due to high water levels in the village is diminished. The house is elevated to decrease water flow into the structure. It is also locally implementable and scalable. However, one aspect of the severity of the water nuisance in Ricanau Mofo is that the high water levels can remain for multiple days or even weeks, according to the inhabitants of the village. Even if the houses are elevated, the problem of transport and accessibility still exists.

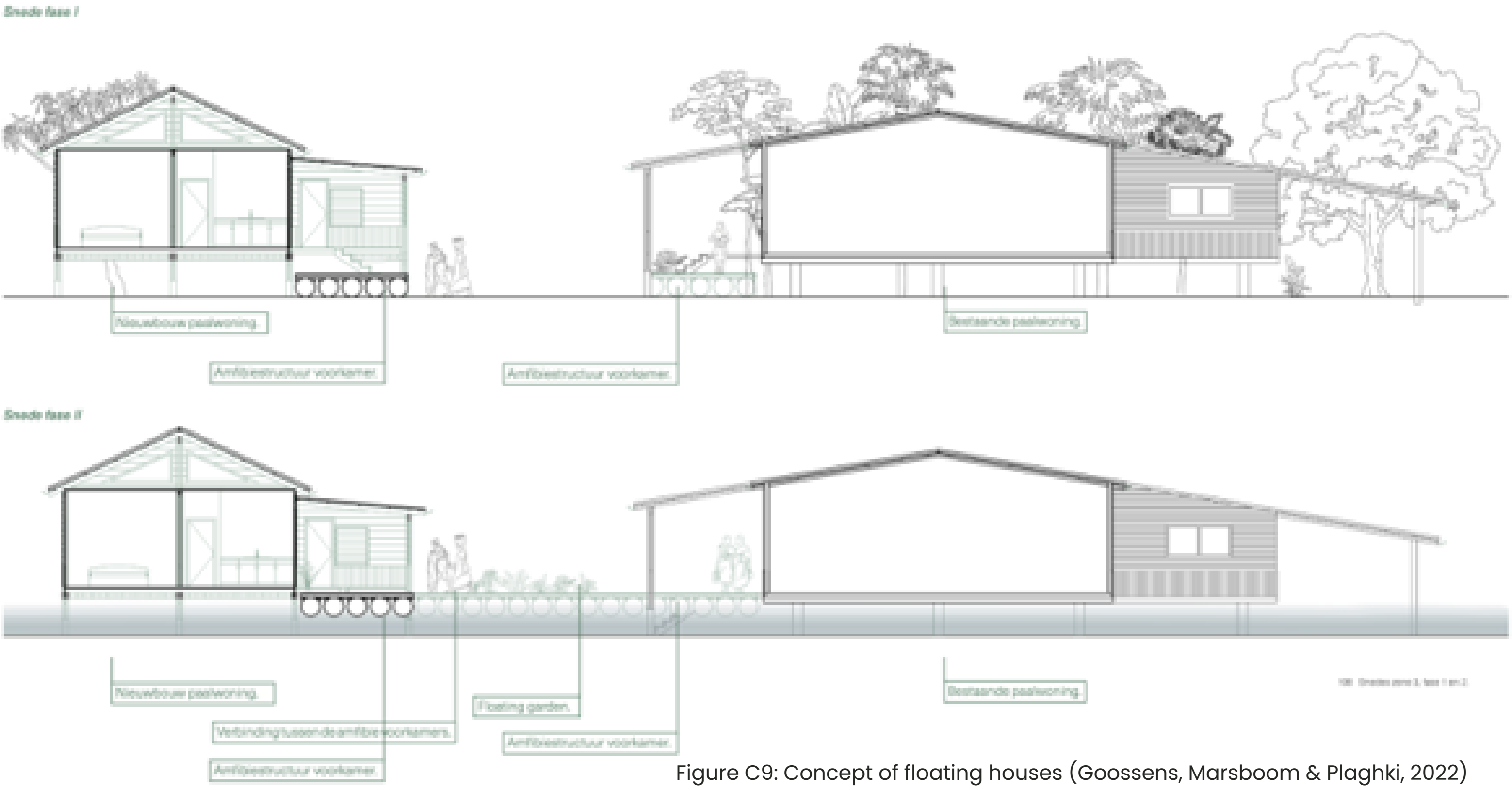


Figure C9: Concept of floating houses (Goossens, Marsboom & Plaghki, 2022)

9.Floating (parts of) houses

What it does
Creating the ability for (part of) houses to start floating during floods. For example, adding containers containing air underneath the shared frontroom of a house. Figure C9 explains this concept.

Challenges
The challenges lie in determining a structure for elevation and then determining what part(s) of the house is important to elevate with this structure. Even though it is scalable, the interventions will be more tailored than directly applicable.

Advantages and disadvantages
The advantages correspond to those of housing on poles. The house is elevated to decrease water flow into the structure, which diminishes the material damage. It is also locally implementable and scalable. An advantage in comparison to housing on poles is that when there is no flood, the area is at ground level and only in case of high water levels, the (parts of the) house elevate. However, one aspect of the severity of the water nuisance in Ricanau Mofo is that the high water levels can remain for multiple days or even weeks, according to the inhabitants of the village. Even if the houses are elevated, the problem of transport and accessibility still exists.

D
Interventions
Soil erosion

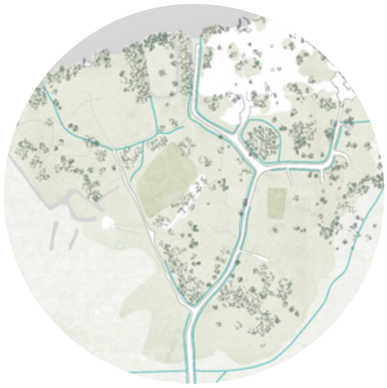
D.1 Elobaration on alternatives
The elaboration on alternatives started with the 'talking cards ' of VanderMeeren. They were extended with alternatives found in the literature research (see Chapter 2). Chapter 6 and Appendix F describe how interventions are selected via a multi-criteria analysis. In Figure D0.1 the selection of interventions to prevent or decrease soil erosion are listed and next pages the interventions are expanded to concepts with a description, challenges and (dis)advantage.

10. Planting vegetation

11.Vegetation on a hill

12 Eyebrow terraces

13 Living in clusters according to tradition



14. Dredging of drainage canals

Figure D0.1: Overview of intervention river bank erosion

D2 Screening of alternatives

Figure D0.2 depicts the interventions that address bank erosion. Clustering new housing along the road would be relatively effective and feasible. In the current situation, new houses are built mostly along the Road 'Weg naar Ricanau Mofo'. By clustering houses, specific clusters of vegetation are removed, creating the opportunity to leave vegetation in places where soil erosion is expected to be (strongly) present. It is positively feasible to advise on this, but the chance of throughput in the coming years is unsure.

Implementing bulkheads, cribs, protection by cocos, a semi-permeable wall, terraces and the 'twente-canal' all are relatively feasible and efficient for this.

They all create a base or a buffer, in which soil is protected from eroding from the river bank. All of these can be implemented in a simplified manner that is expected to decrease the current bank erosion significantly.

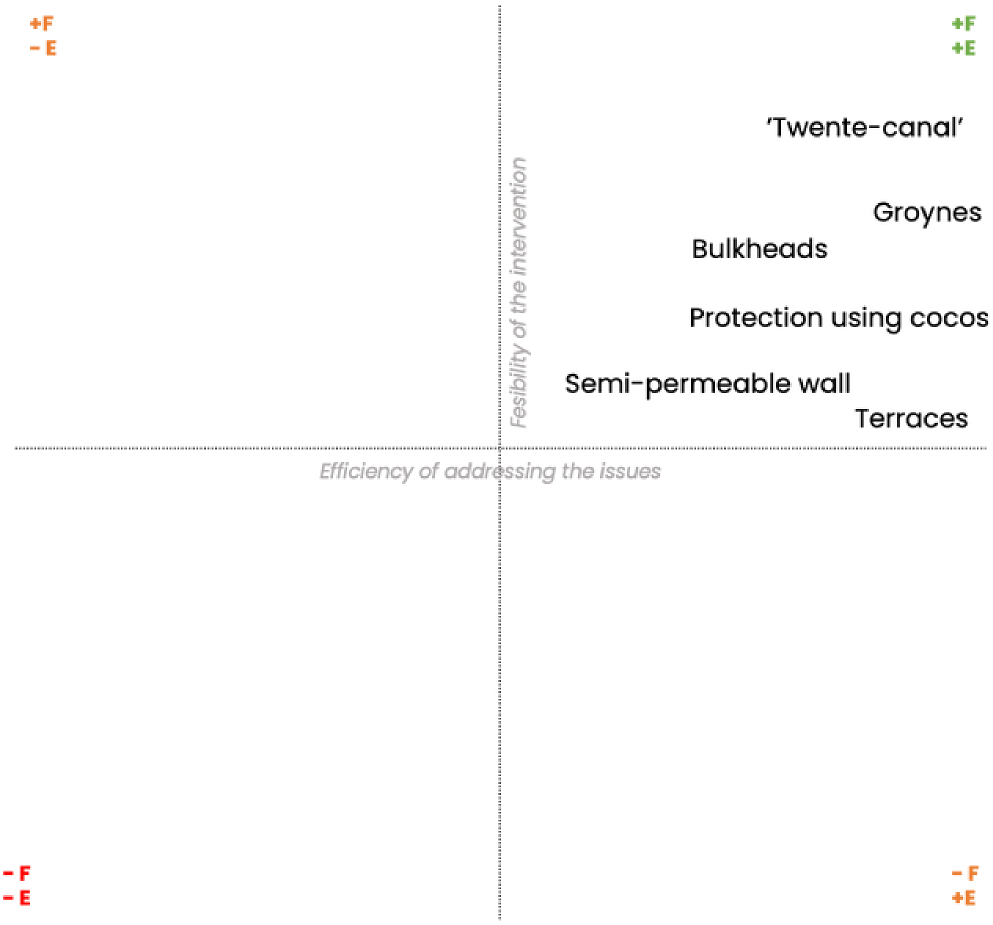


Figure D0.2 depicts the interventions to address the soil erosion, distinguished on their efficiency and feasibility.

Figure XX: Fruit trees (Jonathan Kemper, 2023).

10.Planting vegetation

What it does
Vegetation protects against the consequences of climate change. In many parts of Ricanau Mofo, trees have been removed for other purposes of the soil. However, as there are less items to hold the soil when water runs over the land, the chances of erosion increase. Vegetation placed in specific parts of the village can decrease chances of land and bank erosion, as it holds the soil back. This includes placing vegetation with high density roots, beneath the ground as well as above grounds. Could be grass, or (local) trees like the Moca Moca.

Challenges
Challenges that arise are the maintenance of the vegetation and the survival chance of them during the early growing years.

Advantages and disadvantages
Planting vegetation offers numerous advantages, including environmental benefits, erosion control, aesthetic enhancement, habitat creation, oxygen production, and temperature regulation. However, it necessitates ongoing maintenance and may attract pests, trigger allergies, limit land use, and introduce invasive species, requiring thoughtful planning to balance its pros and cons.

Figure XX: Planting Mangroves (Shaueel Persadee, 2023).

11.Vegetation on a hill

What it does
This intervention has overlap with intervention B1: planting vegetation. The difference is that this intervention includes specifically the planting of plants on a hill. A hill or slope is prone to more erosion than an area that has the same ground height level. Therefore, specific vegetation must be analysed and placed to ensure livelihood of vegetation under hard living circumstances (a slope with erosion, while enduring increasingly more precipitation).

Challenges
Vegetation on hills faces challenges including erosion, shallow soil, uneven sunlight, wind exposure, competition, landslides, wildlife impact, and maintenance difficulties. Plant selection, erosion control, and terracing are key strategies for addressing these challenges and promoting healthy hillside vegetation.

Advantages and disadvantages
Hillside vegetation offers advantages such as erosion control, aesthetic appeal, wildlife habitat, air quality improvement, and cooling effects. However, it presents challenges, including erosion risk, maintenance needs, access difficulties, landslide risk, and limitations on land use options, necessitating careful planning and management to maximize its benefits.

Figure XX: Eyebrow terraces in the Raya Vallees, Ethiopie (van der Meeren, 2023).

12.Eyebrow terraces

What it does
These are half-round walls that are built on hills to prevent soil runoff, therefore decreasing land erosion. They can be described as small dykes of stones that all form half a circle, each collecting some water. They can be combined with vegetation. These can be helpful for heavy rainfall, but their effectiveness decreases when there is a high water level in the entire village. It is also doubtful if stones will stand and sand will not flush away. Stones can be replaced by small sediment dams made out of timber. These are utilized throughout Ricanau Mofo already

Challenges
Constructing eyebrow terraces generally presents a few challenges. However, the application in Ricanau Mofo may differ from other locations. The clay soil's small particle size can be challenging for stone terraces with large gaps to effectively catch. Nevertheless, these terraces can serve as a suitable location for vegetation growth.

Advantages and disadvantages
Eyebrow terraces can be easily installed in the existing village at a relatively low cost. However, their effectiveness in reducing soil erosion is limited, particularly when it comes to capturing mud flows with a stone wall. Nonetheless, there is a notable trend of villagers piling up soil in front of their houses. While this alone doesn't provide a proper soil runoff control system, it's a step in the right direction. Implementing a simple sediment trapping approach could prove useful in the short term for Ricanau Mofo.

Figure XX: Village in clusters located in the rainforest of Thailand (AIP, 2019)

13.Living in clusters according to tradition

What it does
As Ricanau Mofo is expanding, more and more vegetation close by the Road 'Weg naar Rikanau Moffo) is initially cut down, only to subsequently experience the problems associated with that cut. The lack of vegetation causes significant bank and land erosion. On top of that, the construction of new houses in that area is characterised by single houses, not the traditional clusters of families that are clustered around one shared outside area/-kitchen. If it is advised to construct the houses in line with this tradition, there would not only be less erosion, but also more shade and water absorption (extra buffer). Cutting and then replanting vegetation is a complicated and costly process. It's better to preserve the vegetation initially to avoid disrupting ecosystems, biodiversity loss, and save time an resources.

Challenges
Planning is essential for village development to determine what should be cleared and what should be preserved.

Advantages and disadvantages
As a benefit, it helps significantly reduce erosion and results in significant time and resource savings. The downside regarding to urban development in a village is that it can lead to the loss of the open character that defines a village. And maintaining vegetation takes time and needs to be done regularly.

Figure XX: Current drainage channels in blue (author's work)

14.Dredging of drainage canals

What it does
Dredging of drainage channels is a maintenance and engineering practice that involves the excavation and removal of sediments, vegetation and obstructions from natural or man-made watercourses. In this case, handmade dugout channels illustrated in Figure XX. The primary purpose of dredging is to ensure the efficient flow of water within these channels and to prevent flooding, especially during heavy rainfall or compensating for high water tables. This process helps maintain the hydraulic capacity of the drainage system and reduces the risk of water-related problems. In the case of Ricanau Mofo, In Ricanau Mofo, the drainage canal was initially constructed solely for road drainage and erosion control. Therefore, there is a need to expand the drainage network to serve the entire village.

Challenges
Disposing of the dredged sediments can be a significant challenge. Proper disposal methods need to be in place to prevent environmental contamination or the reintroduction of sediments into the channels.This leads to the next challenge; Dredging projects can be expensive and resource-intensive. Communities need to allocate funding and labour to ensure the channels are adequately maintained. Since there is a lack of manpower and machinery, this could be a challenging task.

Advantages and disadvantages
Dredging drainage channels helps maintain their capacity to carry water, reducing the risk of flooding in adjacent areas during heavy rainfall. Properly maintained drainage channels help protect critical infrastructure like roads, bridges, and utilities from water damage. Dredging can improve water quality by removing pollutants and sediments that may negatively affect aquatic ecosystems and human health, although the drainage channels in this case flow to the river. In order to provide high quality water, filters should be placed.

Disadvantages are the maintenance and the costs of it. Dredging projects can be costly, involving the use of specialised equipment and skilled labour. Dredging is not a one-time solution but a recurring maintenance activity. Regular dredging is necessary to keep drainage channels functioning optimally.

E
Interventions river bank erosion

E.1 Elobaration on alternatives
The elaboration on alternatives started with the 'talking cards'of VanderMeeren. They where extended with alternatives found in the literature research (see Chapter 2). In Chapter 6 and Appendix F is decribed how interventions are selected via a multi criteria analysis. In Figure E0.1 the selection of interventions to prevent or decrease bank erosion are listed and next pages the interventions are expanded to concept with a desciption, challanges and (dis)advantage

15. Bulkheads

16. Terraces

17. Cocos protection

18. Groynes

19. Wooden Sheet Pile Wall in the Foreshore

Figure X: Overview of intervention river bank erosion

E.2 Screening of alternatives

Figure D0.2 depicts the interventions that address water nuisance. Eyebrow-terraces can be realised relatively inexpensively, as nature based and available materials like rocks can be used. Even a minimal viable product can decrease soil erosion. Vegetation can also be added in an inexpensive and needed materials are available locally. With the right vegetation, soil erosion can be decreased efficiently. The same goes for planting the vegetation on a hill. This assures more soil to be captivated within the roots of the plant.

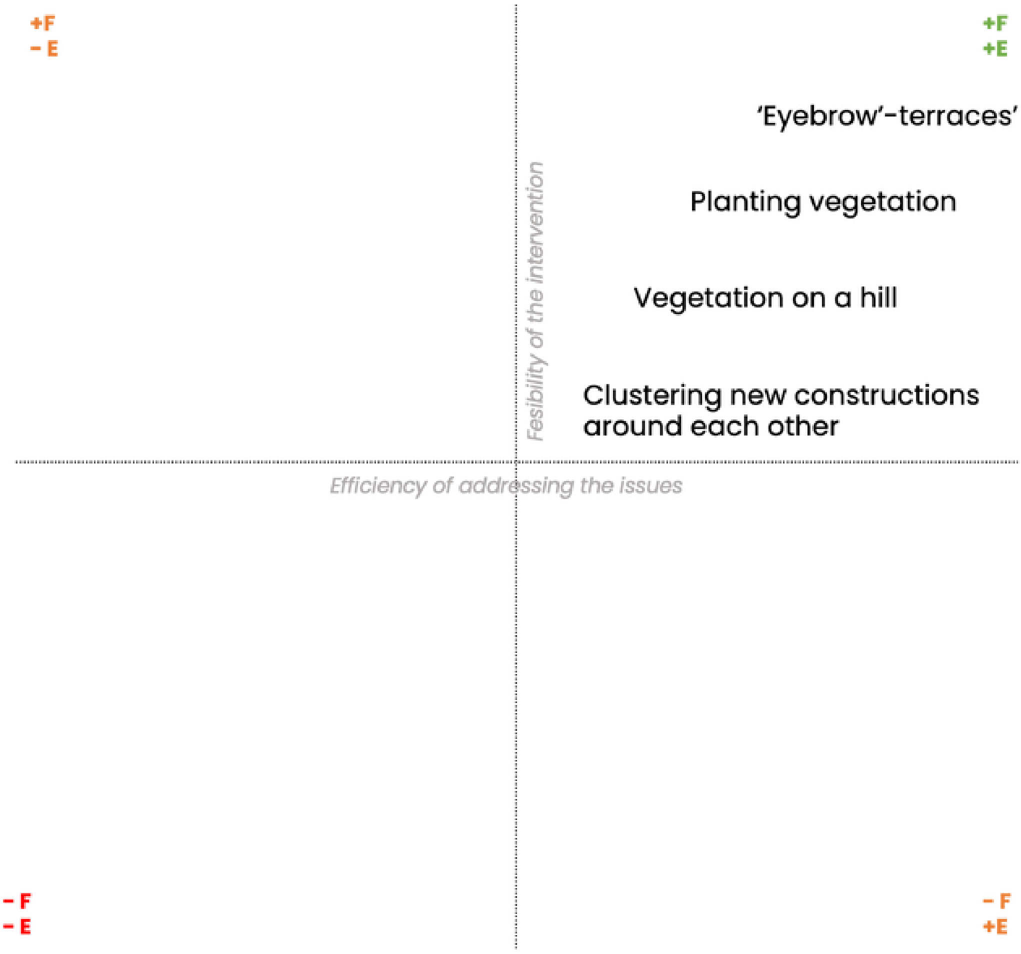


Figure E0.2 depicts the interventions to address the soil erosion, distinguished on their efficiency and feasibility.


Figure XX: Example of bulkheads (Lamulle Constructions, n.d.).

15.Bulkheads

What it does
TOne of the primary functions of waterfront timber bulkheads is to protect the shoreline from erosion caused by wave action, water currents, and tides. They act as a barrier, preventing soil and sediment from being washed away. Thereby, timber bulkheads can also help in reducing the risk of flooding during high water events. By acting as a barrier to rising water levels, they provide a degree of flood protection to properties located near the water.

Challenges
Timber bulkheads require regular maintenance to ensure their long-term effectiveness. Exposure to water, weather, and biological factors can lead to rot and decay, necessitating repair or replacement. Building and maintaining timber bulkheads can be expensive, making them less accessible to individuals or communities with limited financial resources.
among adjacent landowners.

Advantages and disadvantages
Firstly, the do it yourself factor is high, which means that it could be easily implemented with simple tools and materials. This is already done in a very primitive way, as mentioned in part XX of this report. Secondly, timber bulkheads effectively protect against erosion, helping to preserve the shoreline and adjacent properties. Lastly, they provide some level of flood protection for properties close to the water, reducing flood risk.These structures offer stability to the shoreline, safeguarding real estate investments and reducing land loss.

A disadvantage is that even with maintenance, timber bulkheads have a finite lifespan compared to some other construction materials.

Figure XX: Terraces in another context (Peak traditional fencing, 2022)

16.Terraces

What it does
Terraces consist of levelled, horizontal steps or platforms, typically constructed using materials such as stone, wood, or earthworks (Figure XX) to prevent soil erosion. These steps are arranged in a stair-like fashion, creating a series of flat surfaces. On steep slopes they can be used to reduce the runoff speed of water during rainfall, minimising soil erosion. Next to a riverbank the terraces are often constructed in parallel, running horizontally along the riverbank. The alignment of the terraces helps control the flow of water and prevent soil erosion. They can also function as barriers that intercept and capture soil particles and sediments carried by the river's current. This trapped sediment helps prevent further bank erosion and can be repurposed to enrich the topsoil. The construction of terraces reinforces the riverbank by providing physical support and preventing soil slumping or collapsing. This helps maintain the integrity of the bank and prevents further erosion. During heavy rainfall they can store rainwater runoff and facilitate gradual infiltration into the soil, preventing excessive surface runoff and reducing the erosive power of the runoff. The flat, terraced surfaces provide opportunities for the growth of vegetation. Plantings can further stabilise the soil and provide additional protection against bank erosion.

Challenges
Determining the location of the terraces is essential for their effective operation. In places where water runs off fastest, they will be most effective in trapping sediment. In addition, maintaining riverbank terraces is essential to their long-term effectiveness. This involves ongoing repair, removal of debris, and vegetation management, which can be labor-intensive and require financial resources.Moreover, the construction of the terraces requires space, often in people's residential areas. This space must be available. Ownership and maintenance responsibilities for riverbank terraces may lead to disputes and conflicts among adjacent landowners.

Advantages and disadvantages
Terraces are an effective and relatively low-threshold method to minimise the effect of land and bank erosion, as they can often be built with local materials. The cost of comparable projects ranged between 75 and 150 pounds per metre (Scottish Environment Protection Agency & Natural Scotland, 2020) . However, it does take up part of the bank on land and needs maintenance for long-term effectiveness. Also, effectiveness depends on local factors such as soil type and when poorly constructed can provide little or no solution against land and bank erosion.

Figure XX: Cocos protection as bank protection (Heyrman de Roeck, 2023)

17.Cocos protection

What it does
Both slope and shore, cheap to produce, plants takeover the job of cocos appearing in dissolving stage, local use of materials, people have to learn how to make new matts and instalment needs technical expertise but this can lead to new market/business, scalable to other villages but need of maintenance and local investment for effective use, lifespan. (Goossens, Marsboom & Plaghki, 2022)

Challenges
Challenges of using coconut fiber rolls for riverbank protection include susceptibility to decay, especially in waterlogged conditions, limiting their long-term effectiveness. Additionally, they may require frequent replacement and can be displaced by strong currents or flooding, necessitating consistent maintenance and reinforcing measures for durable riverbank protection.

Advantages and disadvantages
Advantages of coconut fiber rolls include their biodegradability, erosion control capabilities, and eco-friendliness. They can enhance soil stability and promote plant growth. However, disadvantages involve potential decay in waterlogged conditions, limited durability, and vulnerability to displacement by strong currents or flooding, requiring regular maintenance and supplementary measures for effective riverbank protection.

Figure XX: Groynes in the Netherlands (Bosboom & Stive, 2021).

18.Groynes

What it does
Groynes are constructions that are placed perpendicular to the river flow in the outer bank of the Cottica Rivier. They could be made from wood, concrete or other materials. Because of their position, they deflect the currents. This leads to a reduction of the erosion alongside the river bank at Ricanau Mofo and will stimulate sedimentation. It is already implemented in one other project in Surinam: the 'Weg naar Zee', where they used natural based resources like wood and leafs (Karan.Saktoe, 2022). It could be interesting to combine this alternative with B2: planting vegetation on a hill.

Groynes could be permeable or impermeable, depending on its location, desired impact and available resources. In the case of Ricanau Mofo, a permeable groyne would be sufficient and the most feasible solution. Permeable groynes may be used on beaches, but are widely perceived to function best in locations where there is a current but minimal waves, particularly rivers (Crossman & Simm, 2004). This is the case in the upstream part of the Cottica River. An additional benefit of the permeable groynes besides the silting they encourage, is that it in turn facilitates planting and ultimate restoration of a desired bank alignment (Riversgroup, 2007).

The spacing between the piles and level of the piles above the bed or beach will depend on the intended influence of the groyne, but whilst the spacing is often approximately equal to the diameter of the pile, no established relationships are available for design purposes (Crossman & Simm, 2004).

Challenges
LThe challenges with this intervention lie with the construction and the maintenance.
The construction could be difficult because of the present soil. It mostly consists of clay, which requires very long wooden piles to prevent them from sliding in the soil. The placement can therefore become highly intensive and should be done by an external party.

The second challenge would be the maintenance. Wooden piles are constantly exposed to the forces of the river and the weather conditions. This may lead to a reduction of the pile strength and indirectly the efficiency of the construction. Frequent monitoring and maintenance is required for this intervention.

Advantages and disadvantages
Groynes offer cost-effective riverbank erosion reduction by diverting river flow and promoting sediment deposition. Their construction, often using locally sourced materials, minimizes expenses. However, they require labor-intensive maintenance and the use of long piles, which can pose challenges.

Figure XX: parallel sheet piling on the river bank (Klip, 2020).

19.Wooden Sheet Pile Wall in the Foreshore

What it does
A sheet pile wall, is a multi-purpose design that copes with the present bank erosion. This design will break and reduce the incident waves and will create a flow-free area close to the bank. Eventually, this will lead to secondary functions of the design, including the stimulation of vegetation growth and gaining land. Gaining land is established by the capture of land sediment that is being transported by the rainfall towards the river.

Challenges
The challenges within this intervention lie with the construction and the handling of the construction by the villagers.
The construction could be difficult because of the present soil. It mostly consists of clay, which requires very long wooden piles to prevent them from sliding in the soil.

When the wooden sheet pile wall is installed, it is crucial that the villagers know how to handle the construction. It should not be used as a catchment area for trash. This will lead to the contamination of the soil in which plants will not be able to settle.

Advantages and disadvantages
Wooden sheet piles in the foreshore are a versatile solution for mitigating river bank erosion. Their advantages include reducing river flow and breaking ship-induced waves, thereby protecting the riverbank. Additionally, they facilitate sediment settlement, potentially creating new land, and are often cost-efficient, thanks to the use of locally sourced materials.

However, implementing this solution may require very long piles, a clean construction area, and labor-intensive efforts. The construction process involves multiple steps, demanding careful planning and execution.

F
Multi-Criteria Analysis of the Interventions

For the multi criteria analysis (Dean, 2020), multiple criteria have been identified that align with several different perspectives. The interventions can score from the range [-2;-1;0;1;2] on the criteria. When the intervention has a highly positive effect, the score of two is assigned. When the intervention had a highly negative effect on the criteria, a negative 2 is assigned. When there is no effect, a zero is assigned.

C1: Effect on the return period of floods; 15/100 weight
This criterion assesses the effect of the intervention on the frequency of flooding events. A flooding event occurs when at least zone 1 is submerged. It provides valuable insights per intervention from the perspective of nuisance for the local community.

C2: Restorative maintenance costs; 7/100 weight
This criterion assesses the estimated costs when the periodical, restorative maintenance needs to be performed. This is important as finances and maintenance possibilities in decentral Ricanau Mofo are low.

C3: Time Periods between maintenance; 3/100 weight
To create a full image of the maintenance expectations, it is also important to assess how many times maintenance needs to be performed, by how long it can go without maintenance. It reflects the ongoing upkeep required for water management.

C4: Construction costs; 10/100 weight
For this, the production, transportation and implementation costs are compared roughly. As there are many interventions that range from millions of euros to relatively free, only an estimate will satisfy the screening. It provides an economic perspective and intervention feasibility.

C5: DYI-factor; 7/100 weight
This examines whether the implementation can be implemented by local forces, or if it needs to be outsourced in a more central manner. The estimate consists of not only the ability to implement the specific interventions, but also the ability to finance and maintain them. It represents the community centric perspective.

C6: Flexibility for modifications for future needs; 5/100 weight
This criterion assesses the adaptability of the interventions to meet local needs in the future: they can be evolving. This thus focuses on the ability of the intervention for later modifications and flexibility, reflecting a long-term perspective.

C7: Scalability - Pilot project; 5/100 weight
This criterion assesses on the feasibility of scaling up the implemented intervention(s) in Ricanau Mofo to other geographical areas that cope with the same issues.

C8: Expected Lifespan; 5/100 weight
The lifespan criterion assesses from a long-term perspective how long the intervention will last. It encompasses what the intervention will endure, heavy weather conditions and density of usage.

C9: Sustainability; 5/100 weight
To also represent the environmental perspective, the Sustainability criterion is added. This gives a rough indication of the expected CO_2-emissions that arise during fabrication of the intervention, and the expected increase or décrease of these emissions during the usage phases of the intervention. For example, vegetation takes CO_2 from the air.

C10: Severity of Failure Probability; 7/100 weight
This criterion assesses the reliability, and to be specific: the severity of failing of the intervention. This might be important, keeping in mind that maintenance problems and low financial resources might affect the failure probability in a negative way.

C11: Social Impact; 10/100 weight
This last criterion represents an important viewpoint from the local community: the social impact of the intervention. It is a relatively subjective criterion, thus only an expected indication. It takes into account the effect on the accessibility to the river, as this is the centre of the village. Also, it incorporates impact on aesthetics, and other important areas of the village and creates extra work opportunities (tourism etc).

These criteria provide a multi-perspective approach to the multi-criteria analysis. This ensures a higher feasibility, a higher chance of actual execution or at least continuation of the project.

The evaluation of interventions involved the application of weighted criteria to assess their overall value. By assigning different weights to these criteria, it became possible to account for the relative importance of each criterion in comparison to others (see Figure F). The weights assigned varied, namely 15, 10, 7, 5, and 3. Some of these criteria were determined based on their connection to a primary (15/100), secondary (10/100), or tertiary (7/100) function within the function analysis. For criteria that aimed to enhance the intervention's value, they were distributed in a manner that collectively contributed to the concept of "valuability," encompassing viability, feasibility, and desirability, with respective proportions of 7/100, 5/100, and 3/100. The project drive consists of the entire MCA.

Interventions/Criteria	Normalised scoring
Dike	0,00
Longitudinal dam	0,08
Bypass	0,22
Terraces	0,25
Living on terp	0,27
Bulkheads at the river bank	0,30
Flood early warning system	0,36
Relocating village	0,42
Houses on poles	0,51
Boardwalks	0,52
Floating houses	0,59
Living in clusters	0,70
Twente Canal solution	0,74
Stepping stones	0,75
Cocos protection	0,76
Eyebrow terraces	0,80
Groynes	0,81
Vegetation on a hill	0,82
Planting vegetation	1,00

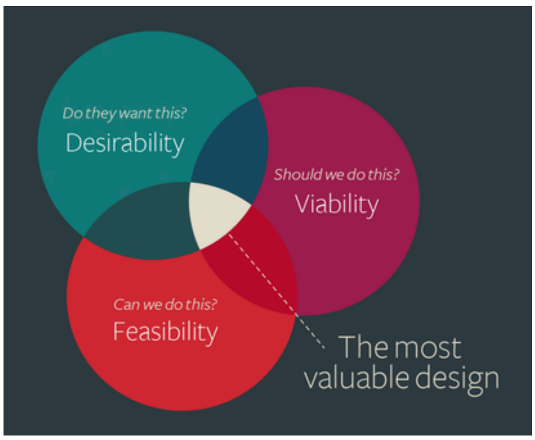


Figure F: Final list of interventions ranked by the conducted criteria (left) and how valuability of an intervention is decided (right) (authors' work and CrowdFavorite)

G
CPT Ricanau Mofo

These are CPT results received from the ministry of Spatial Planning and Environment (see Figure G). This helps in classifying the soil strata at different depths near the bank of the Cottica River at Ricanau Mofo. Different soil types, including clay, silt, sand, gravel, or rock layers can be identified using the shear strength.

This information is crucial for designing the wooden piles. The length is importont to ensure stability and load-bearing capacity.

According to the given CPT, at a level of 9 meters depth a sand layer can be found, which would give sufficient stability and load-bearing capacity for the construction. This means the required length of the piles need to be ± 10 meters.

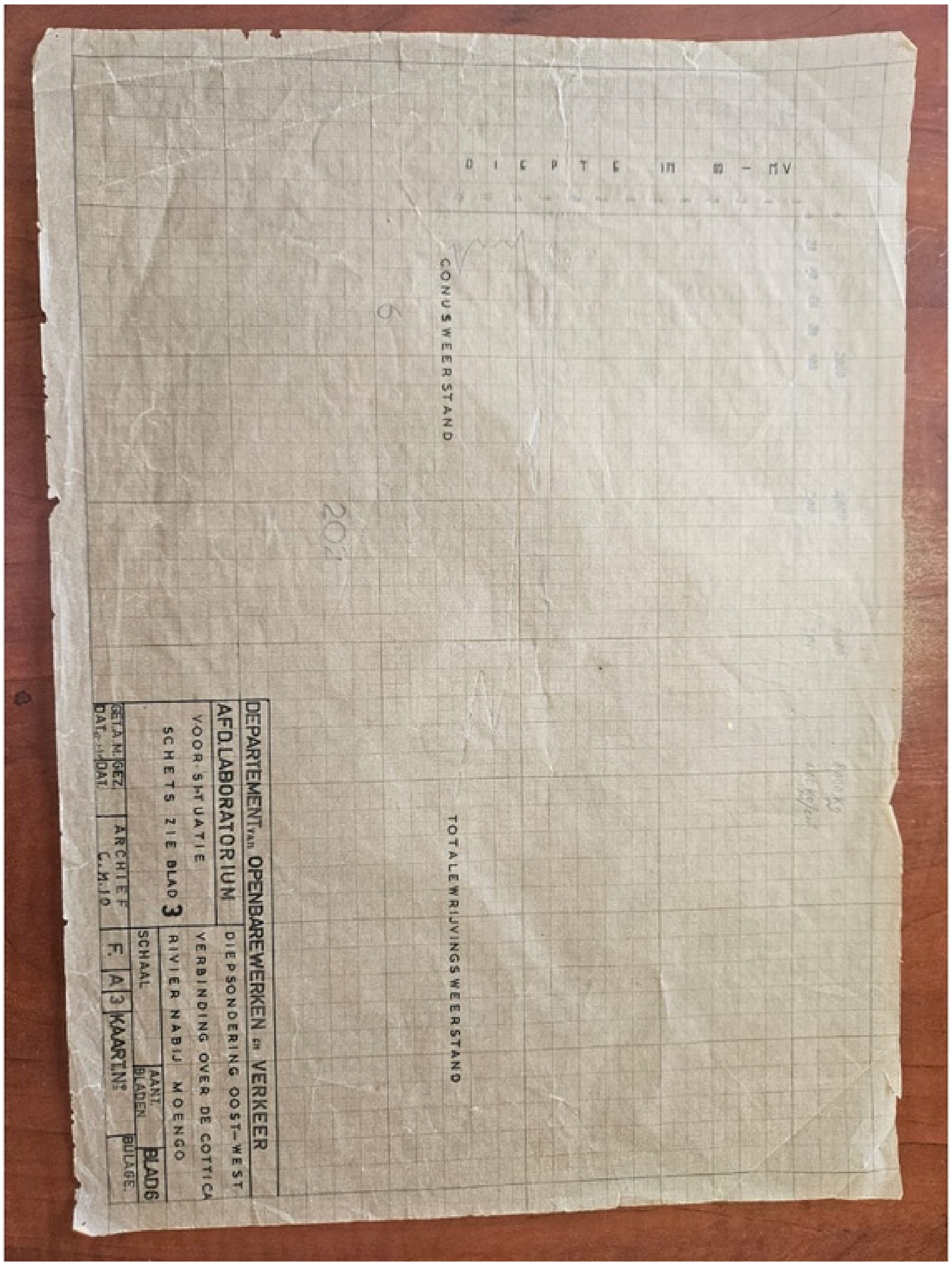


Figure G: Cone penetration test at the Oost-West verbinding in the Cottica River near Moengo

H
Technical drawings timber bank protection system

Within this section of the appendix, the structural drawings created using Tekla Structures for timber bank protection will be explored. The featured structure is designed with a long-term perspective in mind, intended to serve as an enduring solution for bank protection. Through the examination of these structural drawings, we aim to provide valuable insights into the construction and design considerations of this sustainable timber bank protection system.

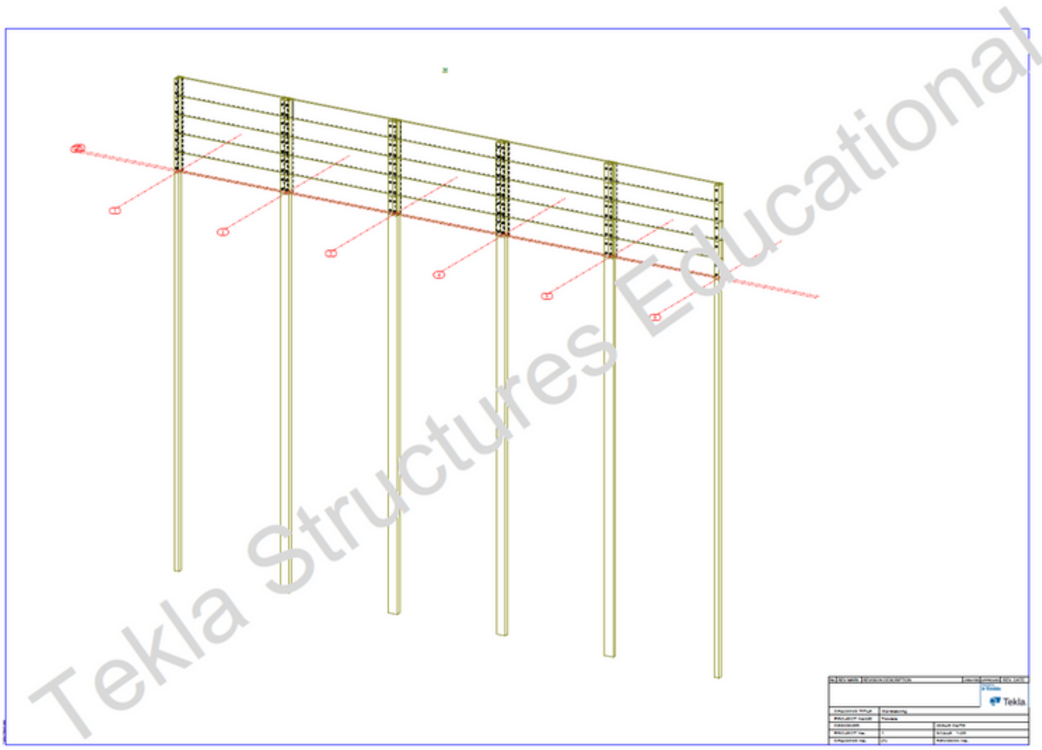


Figure H1: 3D-view timber bank protection

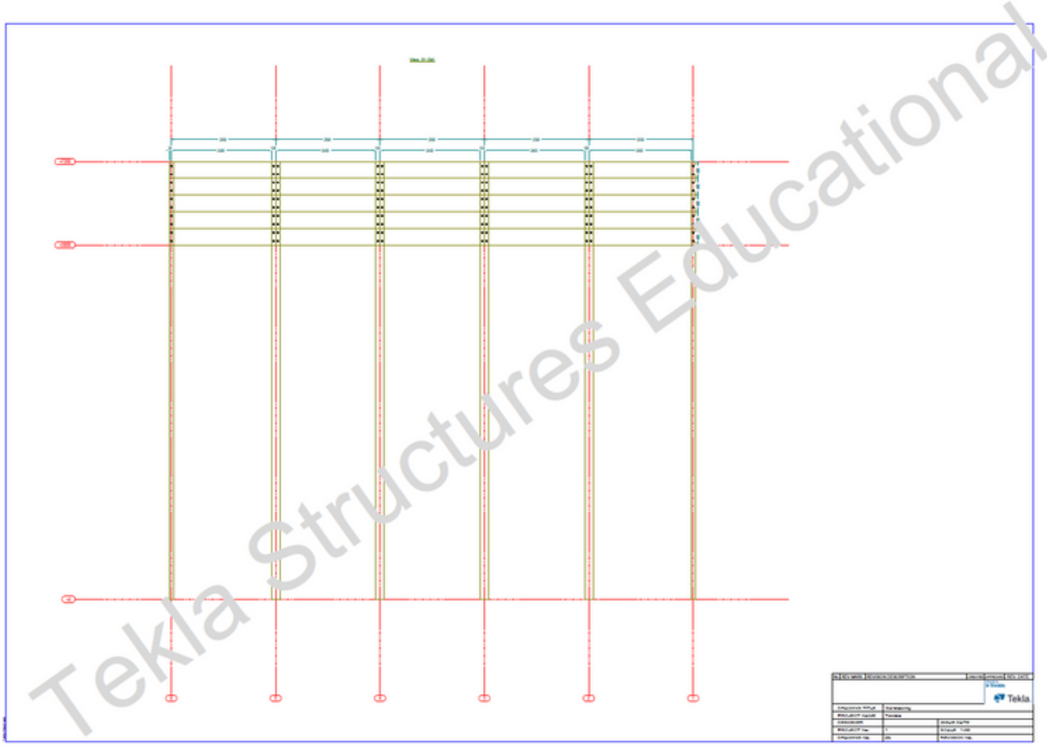


Figure H2: Front view timber bank protection

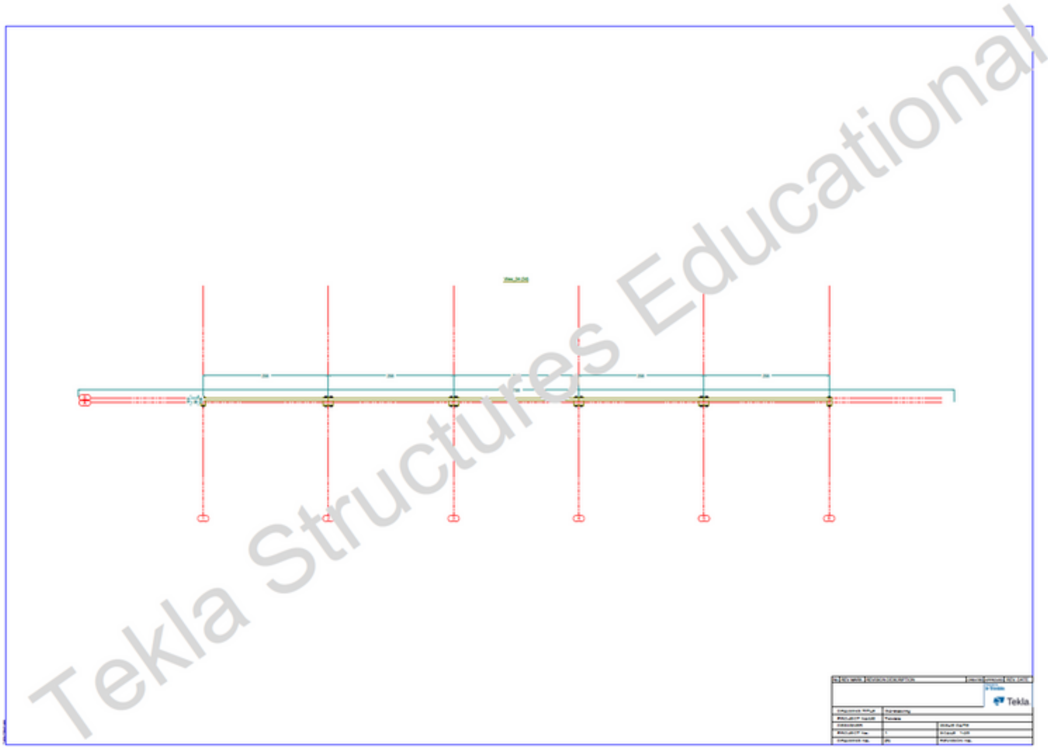


Figure H3: Top view timber bank protection

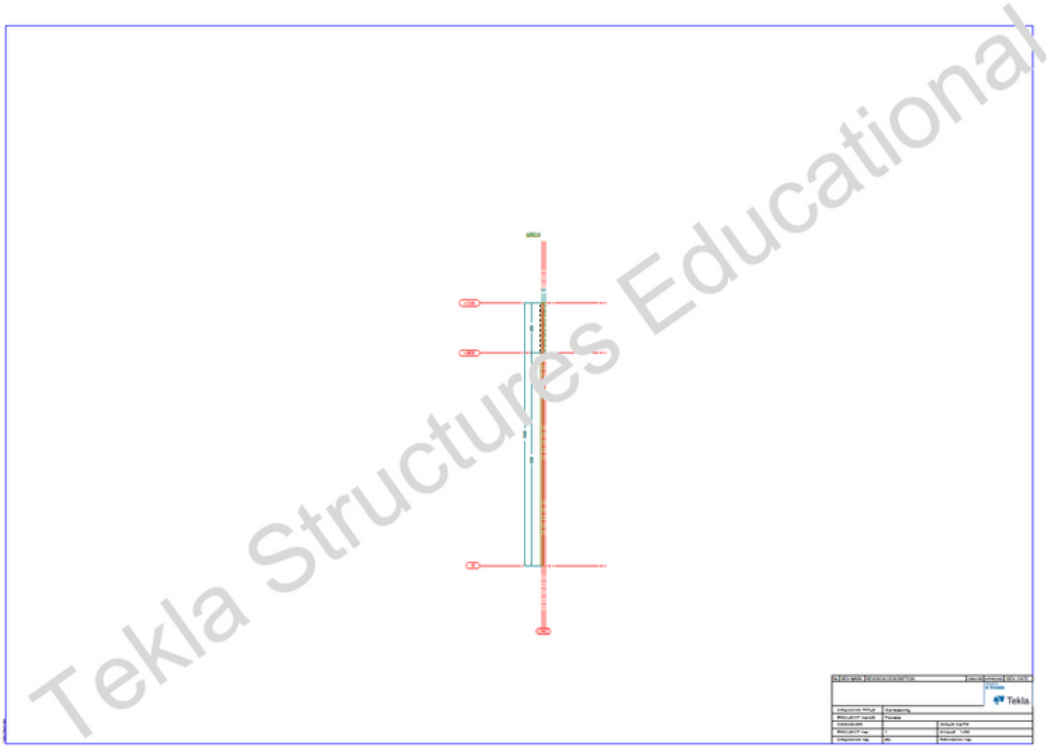


Figure H4 : Side view timber bank protection

Structural strength calculations timber bank protection

This section of the appendix discusses the calculation of forces resulting from a boat colliding with timber bank protection. It will examine the relevant formulas employed to assess structural integrity, focusing on parameters like pressure perpendicular to the fibre direction, bending moments, and shear forces. Furthermore, this part of the appendix will explore the important properties of the wood used and its associated strength classes. This analysis aims to provide valuable insights into the performance and durability of timber bank protection systems when subjected to external forces, such as boat collisions.

The force of a boat collision can be calculated using the formula:

Force = mass x acceleration

For a typical boat in Suriname, approximately 12 meters long, carrying about 15 passengers, a motor, and a motorist, the estimated mass is as follows: Approximately 15 passengers x 75 kg/person + motorist and motor (75 kg) = 1200 kg. The boat's velocity is approximately 10 km/h, which corresponds to an acceleration of approximately 2.76 m/s². Using these values, we can calculate the force: Force = Mass x Acceleration Force = 1200 kg x 2.76 m/s² Force ≈ 3.36 kN. With a safety factor of 1.2 this gives 4.032 kN as governing force.

Formulas used to calculate the unity checks:

$$\sigma_{c;90;d} = F_{c;90;d} \; / \; A$$
$$u.c. = \sigma_{c;90;d} \; / \; k_{c90} \times f_{c;90;d}$$

$$\tau_d = 3\,V_{Ed} / 2bh$$

$$\sigma_{m;y;d} = M_{ed,y} \; / \; W_y$$
$$u.c. = \sigma_{m;y;d} \; / \; f_{ym;d}$$

Results on the unity check are:

Pressure perpendicular on the fiber direction

f_c;90;d	4,98	N/mm2
k_c90	1,5	-
F_c;90;d	4,03	kN
A	10000	mm2
σ_c;90;d	0,40	N/mm2
u.c.	0,05	-

Bending moment

f_ym;d	19,82	N/mm2
W_y	166666,67	mm3
M_Ed,y	2,015	kNm
σ_m;y;d	12,09	N/mm2
u.c.	0,61	-

Shear force

τ_d	0,60	N/mm2
u.c.	0,25	-

Karakteristieke eigenschappen en sterkteklassen van gezaagd loofhout									
	D18	D24	D30	D35	D40	D50	D60	D70	
$f_{m,k}$	18	24	30	35	40	50	60	70	N/mm²
$E_{0,mean}$	9,5	10	11	12	13	14	17	20	kN/mm²
ρ_{mean}	570	580	640	650	660	750	840	1080	kg/m³
ρ_k	475	485	530	540	550	620	700	900	kg/m³
$f_{t;0;k}$	11	14	18	21	24	30	36	42	N/mm²
$f_{t;90;k}$	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	N/mm²
$f_{c;0;k}$	18	21	23	25	26	29	32	34	N/mm²
$f_{c;90;k}$	7,5	7,8	8,0	8,1	8,3	9,3	10,5	13,5	N/mm²
$f_{v;k}$	3,4	4,0	4,0	4,0	4,0	4,0	4,5	5,0	N/mm²
$E_{0,05}$	8,0	8,5	9,2	10,1	10,9	11,8	14,3	16,8	kN/mm²
$E_{90,mean}$	0,63	0,67	0,73	0,80	0,86	0,93	1,13	1,33	kN/mm²
G_{mean}	0,59	0,62	0,69	0,75	0,81	0,88	1,06	1,25	kN/mm²
$G_{0,05}$	0,50	0,53	0,58	0,63	0,68	0,74	0,89	1,05	kN/mm²

Tabel 2. Karakteristieke eigenschappen en sterkteklassen van gezaagd loofhout

Figure I: Characteristic properties and strength classes of sawn hardwood (Houtinfo, 2014) jan - november 2023

Business Case Riverbank Protection

Continuing A Pilot Project in Ricanau Mofo

Scientific study on mitigating water nuisance through socio-technical intervention assessment

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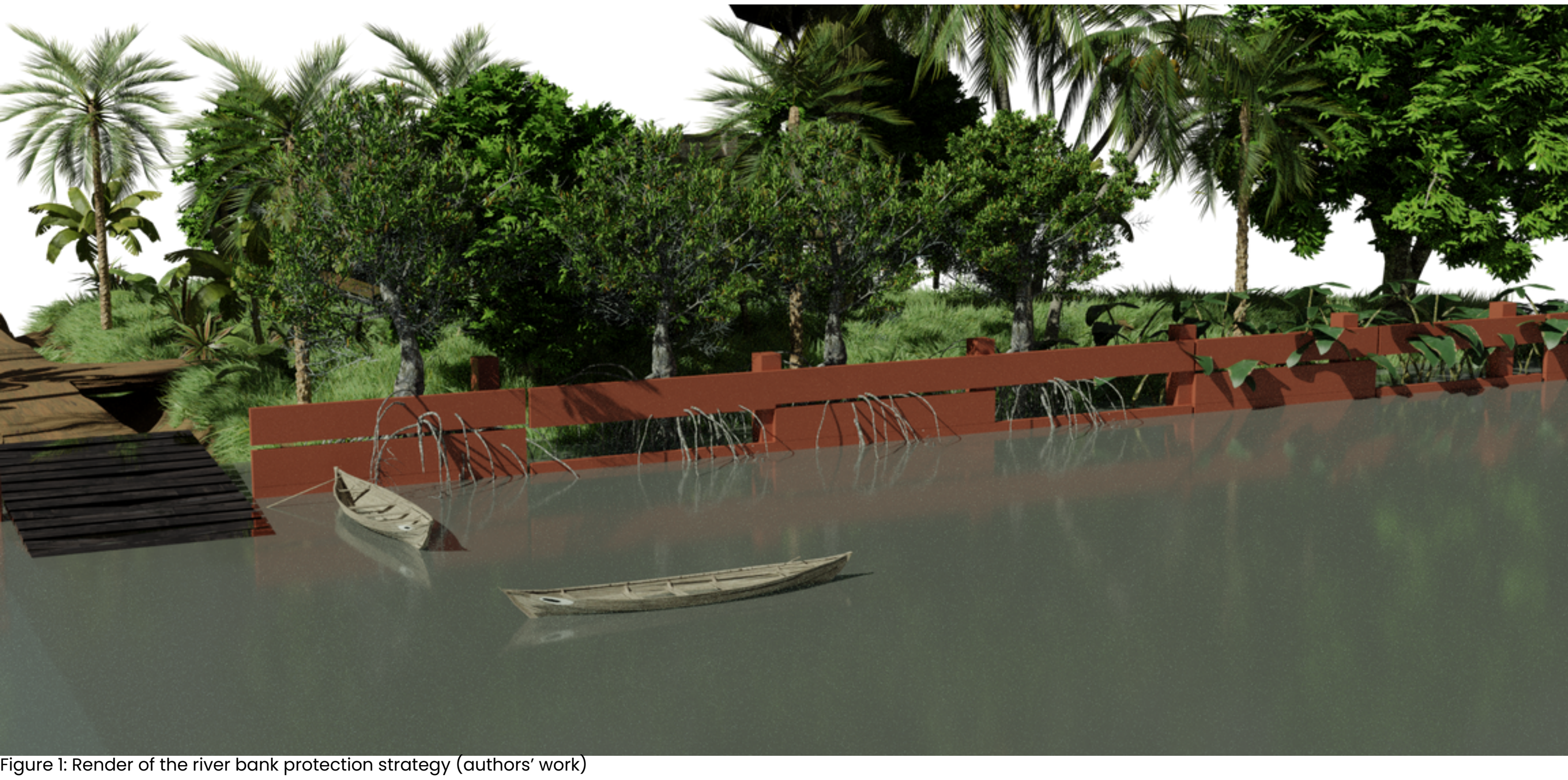

Figure 1: Render of the river bank protection strategy (authors' work)

>> Executive summary

Project title: Riverbank Protection and land Gain pilot project for Ricanau Mofo, Surinam

Location: Ricanau, Ricanau Mofo, Marowijne District, Suriname.

Project Overview
This project focuses on Ricanau Mofo, a low-lying village situated along the Cottica River in northeast of Surinam. Over the past few decades, the village has experienced increasingly frequent and severe flooding, a trend expected to intensify due to the impact of climate change, including rising sea level and more intense rainfall.

One of the primary causes of these issues is the Cottica River, a wide and deep river with a significant tidal range and regular container ship traffic. Another cause is the high intensity rainfalls that takes a significant amount of soil with it, flowing from the village towards the river. These factors contribute to severe riverbank erosion in the village, ultimately increasing the risk of damage during floods.

Project objectives
The main objective of this initiative is to introduce a multi-purpose design that addresses the existing riverbank erosion and seeks to transform the current situation of not only Ricanau mofo as a sustainable Pilot, but other villages in Surinam. The proposed design, implementable in other areas as well, aims to:

- **Mitigate riverbank erosion:** By breaking and reducing incident waves, creating a flow-free area near the river bank
- **Stimulate Vegetation Growth:** The design encourages the growth of vegetation, providing additional protection against erosion, enhancing the village's natural environment and ensuring a positive effect on CO_2-emissions.
- **Land gain:** The project intends to capture sediment transported by rainfall towards the river, effectively expanding available land for the community.

Design
The riverbank protection will be a construction approximately 500 meters along the Cottica River and about 210 meters along the Ricanau Creek, prioritizing areas with most urgent riverbank erosion issues. The protection consists of long vertical poles that are each placed 3 meters from the river bank, with in between planks, alternated with holes to let water flow through. This construction causes waves to break, creating a flow-free area behind it where vegetation can grow and captures sediment for land gain.

Scalability
This project serves as a pilot project in Ricanau Mofo, given its accessibility and relatively straightforward implementation. If successful, it holds significant potential for broader adaptation in other villages along the Cottica River experiencing similar water-related challenges, as well as in other regions across Surinam.

Legal framework
The legal and regulatory approvals of the village's captain, the district commissioner of Marowijne Southwest, and approval for building from ministry of Public Works have already been received. The missing piece is funding.

The need for international funding
To realize the ambitious goals of this project and ensure its long-term success, we seek international funding and support. The magnitude of this initiative and complexity of addressing climate-induced challenges require resources beyond the capacity of local stakeholders.

>>

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Appendix B: Approval letter of ministry of Public Works, Surinam ... p. 15

Figure 2: Prototype of 30 meters built in Ricanau Mofo by the students from the TU Delft (authors' work)

1. Project background

This study focuses on Ricanau Mofo, a small, rural village that is located directly next to the Cottica River in northeastern Suriname. It is a low-lying village. Over the last decades, it has increasingly faced flooding. This phenomenon is expected to become more frequent and intense because of climate change. Climate change causes a higher water level of the Atlantic Ocean and higher intensity and frequency of rainfalls. This both causes significant river bank and land erosion throughout the village; which then increases the chance of damage in case of a flood. The river that causes these problems here is the Cottica River. This river is a deep river that experiences a high tidal range (up to 1,8 meter), high flow rate and regular container ship traffic.

In this request, a multi-purpose design is given to cope with the present bank erosion, breaking through the current situation. This design will break and reduce the incident waves and will create a flow-free area close to the bank. Eventually, this will lead to secondary functions of the design, including the stimulation of vegetation growth and gaining land. Gaining land is established by the capture of land sediment that is being transported by the rainfall towards the river. An important aspect of this is 'Building with nature', creating a more sustainable and natural river bank protection and relatively low maintenance needs.

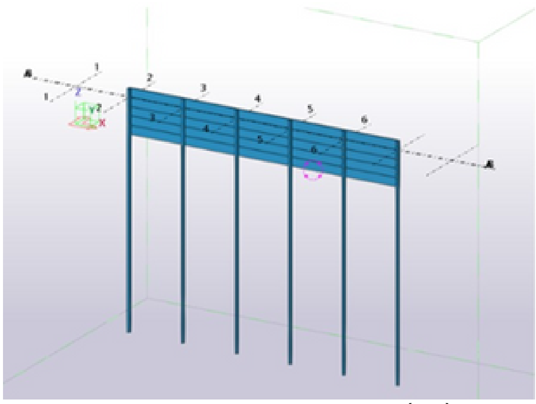
This design is a pilot project in Ricanau Mofo, as it is a relatively accessible intervention to implement. It has the potential to be more widely implemented in the other villages along the Cottica river that struggle with water nuisance, or even other villages in Surinam. It is based on a scientific research performed by six students from the Technical University of Delft on mitigating flood damage to urban environment, soil erosion and river bank erosion.

2

Project technical design

Ricanau Mofo is situated in the district Marowijne in the east of Surinam, at the Cottica River. Along the Cottica River, the system will span approximately 500 meters, and along the Ricanau Creek, it will extend about 210 meters. The red areas are the areas where the bank erosion is most urgent to address; the yellow the least, relatively. This creates a logical timeline for where to start building (from the creek into the river).

Figure 3: Geographical location of riverbank protection



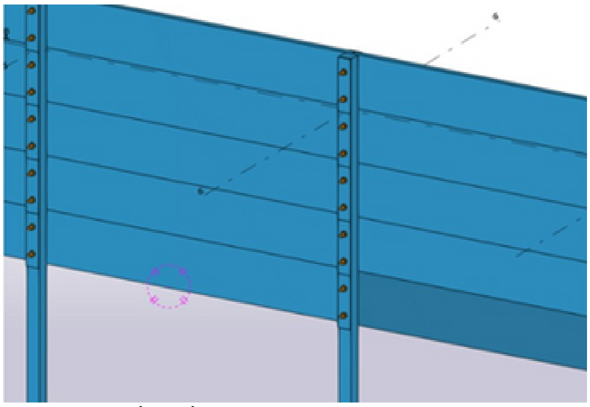


Figure 4: Design of the first few meters (left); drawing of the assembly (right);

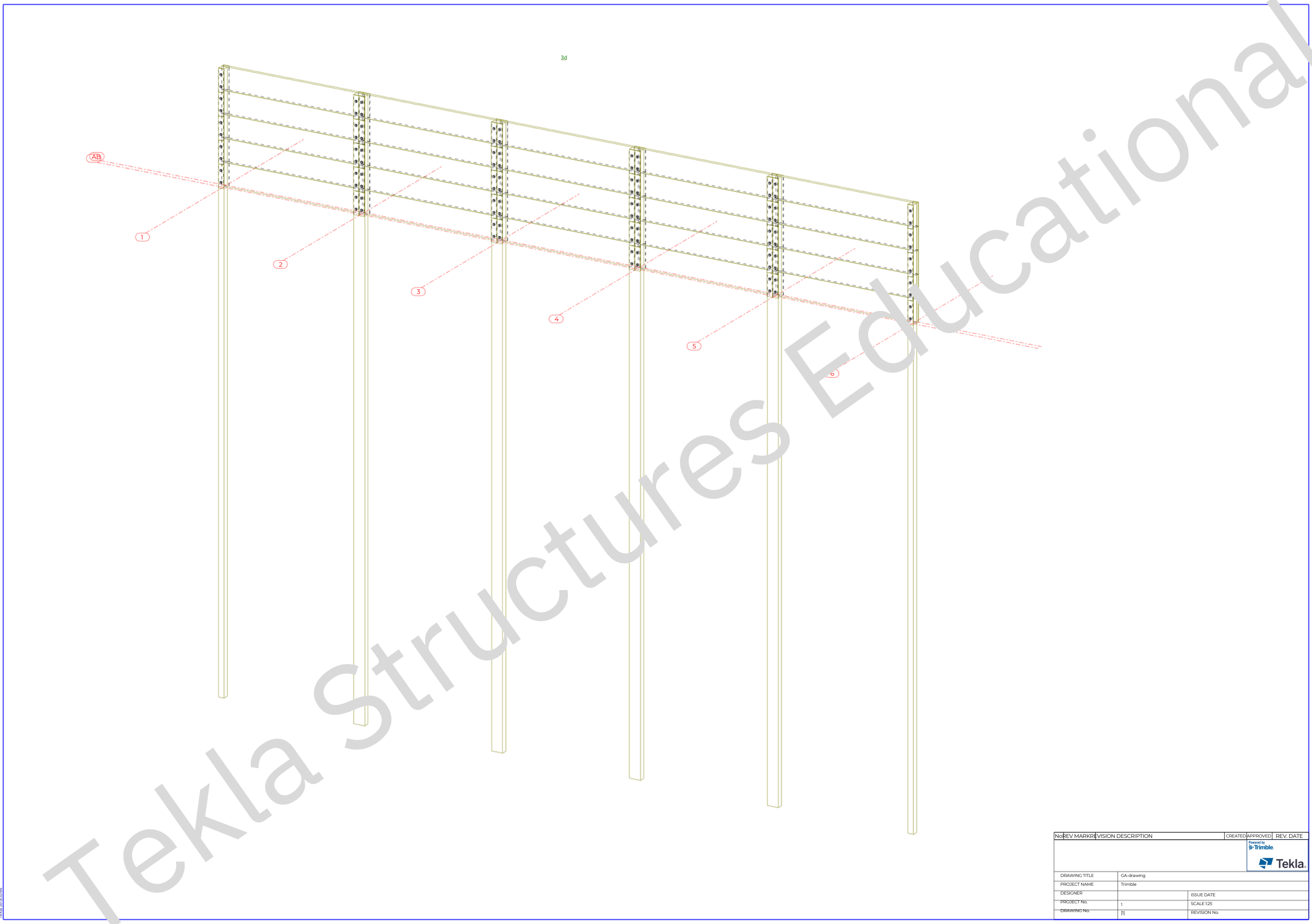


Figure 5: Side view of the design (authors' work)

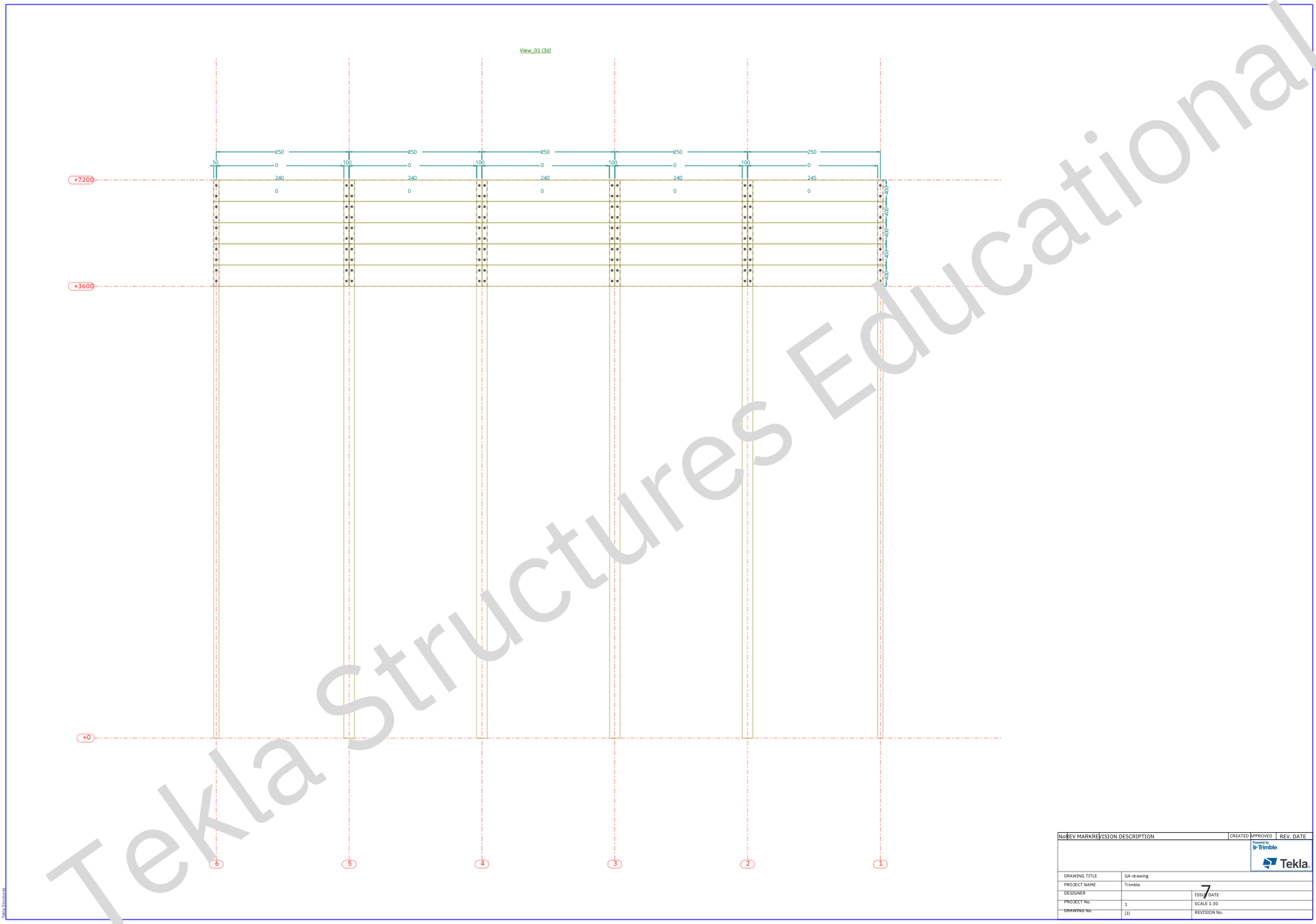


Figure 6: Front view of the design (authors' work)

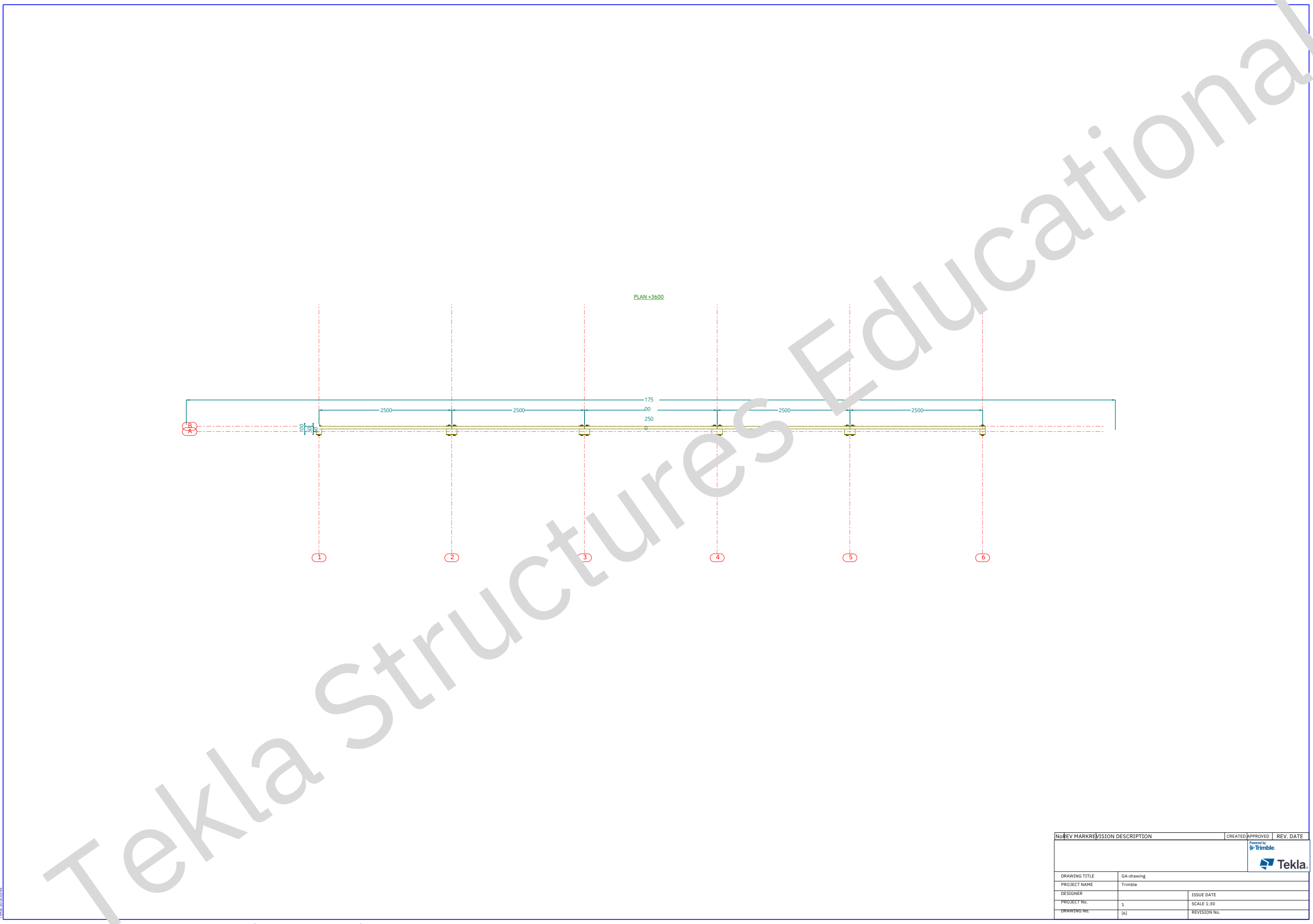


Figure 7: Top view of the design (authors' work)

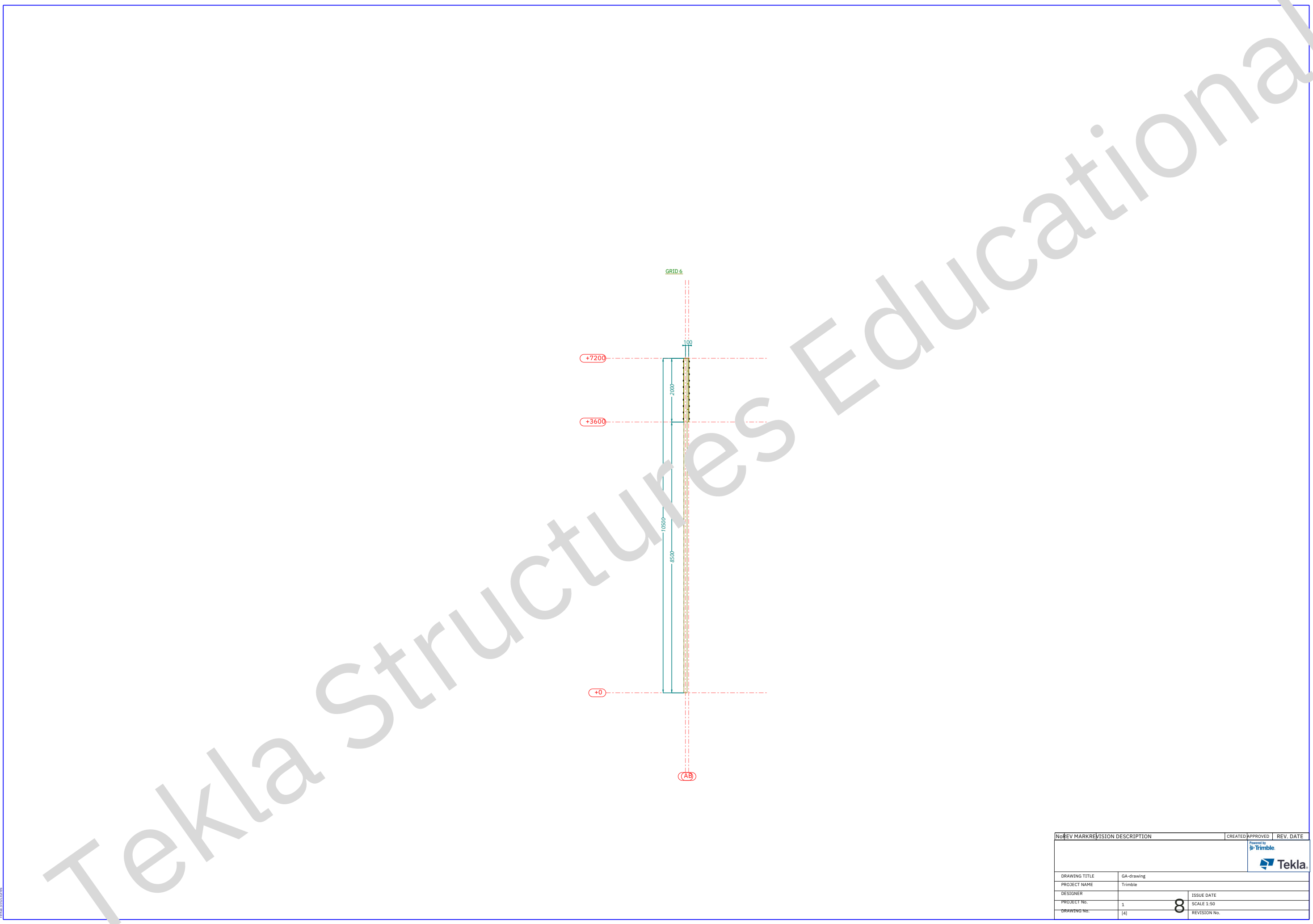


Figure 8 Side view 2 of the design (authors' work)

Construction materials

- Poles of 8-10 meters long and 10x10cm wide, preferable of Wallaba Wood, Greenheart or other strong, water resistant material. These materials are locally available, which causes low transportation costs and a more sustainable life cycle. For the prototype of , 12 poles are used (2,5 meter between each of the poles). Based on that, approximately 700/2.5 = 280 wooden poles are needed.
- Planks that go between the poles, 2.5-3 meters long and 20x>2cm wide. Also Wallaba or same kind of material. In the prototype, three planks are placed on top of each other. It should thus minimally be three planks per 2,5 meter, but could be more depending on the river depth. This creates a minimum of 280 * 3 = 840 planks needed.
- Varnish & brushes
- Screws
- Fill sand
- Root cloth
- Bolts
- Iron anchor

The successful implementation of the bank protection system hinges on acquiring the necessary materials and tools. Here is a comprehensive list of items required for the project:

- Saw: 1 unit (Available for rental)
- Drill: 1 unit (Available for rental)
- Excavator. Requirements: one of biggers models (needs to able to put in the pressure for getting the pole in the thick ground layer). It also needs to be stable: so it should not be on wheels but a fixed one.

Construction plan

Step 1: Preparation
This consists of clearing the river bank and varnishing the wood to make it more withstandable for extreme weather conditions.

Step 2: Pilling
The first holes of (range: [0.5-1.0 metre]) were dug using a shovel between the two piers shown in figure XX, with a distance of approximately 2.5 metres between them. The poles should be pressed in the ground, approximately 3 meters from the river bank and with a distance of approximately 2.5 metres between them. For this, the excavator is needed.

Step 3: Attaching the planks:
Subsequently, the wooden planks should be attached to the poles with a 12mm bolt on the left and right sides of the plank, though the poles. **XX** layers of wooden planks are placed on top of each other. This can start when the first poles have been pressed in the ground and can only be done during low tide.

Step 4: Finishing
The last steps are repeated during the project time to create wooden sheet pile of 500m in the Cottica River and 210m in the Ricanau Creek.

Figure 9: Varnished Wallaba Wood that was used for the prototype (authors' work)

3.
Legal and regulatory framework

In the pursuit of our riverbank protection project, it is essential to highlight the existing legal and regulatory approvals in Surinam and locally in Ricanau Mofo that have already been secured. Before constructing, approval of the District Commissioner of Marowijne, of the ministry of Public Works, the captain of the village (the mayor) and the MAS (Maritieme Autoriteit Suriname) should be received.

The captain Mésak has been active in co-designing this project. He has expressed his approval to the project team of the TU Delft that set up this business case. The same goes for the district Commissioner of Marowijne South-West. After that, approval of the Ministry of Public works has been requested as it is a construction in a river in which container ships sail. As this does not obstruct the fairway, the directory Coastal and River Works has also approved the construction. Lastly, a building permit has been requested to MAS, which is still a work in progress.

The design has been made according to the building regulations of the Ministry of Public Works, incorporated in the permit. The regulations are added in the appendix.

Figure 10: Water side Ricanau Mofo (Guus Meinema, 2023)

4.
Risk assessment

The strategy that is set up creates a feasible and efficient way of realising the goals:. strengthening the river bank, while maintaining accessibility to the Cottica River and Ricanau Creek, slowing down the stream close to the river bank and breaking waves.

The wooden sheet pile strengthens the bank but cannot fully prevent bank erosion. It even creates the risk that in the areas where it is not implemented, the erosion might increase until it is constructed there as well. Therefore, it is important to create a continuity support base. Another risk that arises is that the holes in the river bank protection are placed too high, in which case the sediment will not (optimally) be trapped in the structure. Even though the river bank protection mitigates river bank erosion, it has a negative impact on the accessibility to the Cottica River and the Creek.
The risk arises that the inhabitants rely on the structure to prevent high water levels in the village. It is important to mitigate this risk by communication and visualisation. Therefore, education/informating is an important key to creating awareness of which functions these constructions fulfill, and which do not.

Project limitation consists mainly of the excavator that is needed. Due to the high urban density in the villagers centre, it is not possible to get it there by road. It should thus be done using a boat (ponton). This creates a limitation and a risk.

5.
Stakeholder engagement

The success of the Riverbank protection and land gain initiative also hinges on the collaboration of key stakeholders.

Here follows a short overview of stakeholders:
- Local community. The local community co-designed the construction by brainstorming and giving regular feedback. They have several resources that could be useful. For example, wood can be locally cut which enhances the project's sustainability but also fosters a sense of ownership for maintenance;
- Ministry of Public Works. The ministry provides vital support and guidance in regional and national infrastructure development objectives;
- MAS. Could be helpful for transport of excavators;
- Newmont. This is a company that sails large boats through the Cottica River, which have an effect on the river bank erosion and creation of waves.
- STEORR (Stichting Economische Ontwikkeling Ricanau Mofo): On behalf of STEORR, a project team from students at the TU Delft conducted the research behind this intervention. Also, this business case has been made by the group. STEORR facilitates more knowledge on the environment and topic of water management in the area.

6.
Project management

The project management depends on the initiative taker and their tendering. It is important to take into account how and by whom the intervention is monitored, which reporting mechanisms they implement and how and by whom maintenance is performed based on this information. The Technical University of Delft and the Anton de Kom Universiteit both have collaborating or supporting possibilities for this project, which could be interesting to look at. For example, a prototype of 30 meters has been built in Ricanau Mofo by the students from de TU Delft, as well as this business case has been written by them.

Figure 11: Prototype of river bank protection at low tide (authors' work)

7.
Conclusion

Ricanau Mofo, a low-lying village situated along the Cottica River in northeastern Surinam, faces a significant threat of recurrent and increasingly damaging flooding. Climate change, characterized by rising sea levels and intensified rainfall, increases the bank and land erosion in the village.

The Riverbank Protection and Land Gain Initiative presents a scalable, relatively low-cost multi-purpose design. It mitigated the impact of incident waves and established a protected buffer along the riverbank for vegetation growth. It also expands the land through sediment capture.

As a pilot project, it stands as a model for the other villages in the region that suffer from the same issues. Yet, successful implementation depends on international support in the current financial situation. The scope and complexity of the project is beyond the capacity of the ministry, STEORR and the village. We urge international organizations, governments and other organizations to join the project. By joining, you not only contribute to the quality of life in Ricanau Mofo, but also to similar, flood prone villages.

Business Case Appendix A
Verify Compliance with Local Building Regulations and Permits

To ensure that our bank protection system complies with local laws and regulations, it is crucial to consult with the Ministry of Public Works. They will provide vital information regarding the specific building codes and permits necessary for the project. This step is essential to avoid any legal complications during the construction process.

Local building regulations with respect to a river bank protection are published by the ministry of Public Works, in the sub directorate Coastal, river and nature preservation.
Requirements for a construction;

1. The ground mass on which the construction rests must be and remain in balance;
2. The construction as a whole must be in balance, despite ground water pressure and settlement;
3. The structure must be constructed in a way that no soil material is lost as a result of suction;
4. The construction must be resilient against mechanical, organical and chemical damage;
5. The construction plan must be feasible;
6. It must be able to perform maintenance on the construction;
7. The construction must be cheap to install and maintain;

Requirements for slope covering.

1. The structure must be and remain in balance, despite water streams, waves and groundwater flow;
2. The structure must have a filter effect to prevent rinsing;
3. The structure must be flexible for settlement;
4. The structure must be resilient against mechanical, organical and chemical damage;
5. The maintenance must be easily performed.

Business Case Appendix B
Approval letter of ministry of Public Works, Surinam

MINISTERIE VAN OPENBARE WERKEN
(DIRECTORAAT CIVIELTECHNISCHE WERKEN)
Mr. Jagernath Lachmonstraat no. 167
Paramaribo-Suriname
Tel.:464088

Aan : De directeur van Maritieme Autoriteit Suriname
T.a.v. MR. M. Amafo LL.M
Cornelis Jongbawstraat 2
Paramaribo, Suriname

Paramaribo, 18 OKT. 2023

Ons Refr. : SM/KRN/SB/Ag.no. 2370

Betreft : Verzoekschrift oeverbescherming en Wateroverlastpreventie

Bijlage(n) :

Geachte directeur,

Onder verwijzing naar het schrijven d.d. 16 oktober 2023, van mw. E. van Dongen, een student aan de Technische Universiteit Delft (Nederland), betreffende het verzoek voor het uitbrengen van het constructief advies inzake de onderwerpelijke aangelegenheid, moge ik u hierbij het volgende mededelen.

Mevrouw Van Dongen heeft een zorgvuldig uitgewerkt plan ingediend voor erosiebescherming en wateroverlastpreventie langs de oever van de Cottica rivier in Ricanau Mofo te Moengo. Dit plan heeft als voornaamste doelen het beschermen van de oever tegen optredende erosie en het dorp Ricanau Mofo te beschermen tegen potentiële wateroverlast als gevolg van, scheepvaart, hoogwaterstanden en hevige regenval.

Het Ministerie van Openbare Werken heeft deze documenten zorgvuldig geëvalueerd en heeft vastgesteld dat het voorgestelde project van groot maatschappelijk belang is. Het plan omvat technische specificaties, milieuoverwegingen voor de uitvoering van de voorgestelde maatregelen.

Na grondige evaluatie van de aangeboden documenten, zijn wij verheugd om te informeren dat het Ministerie van Openbare Werken geen bezwaar heeft tegen het verlenen van toestemming aan de verzoeker, mevrouw E. van Dongen. Wij zijn van mening dat dit project aanzienlijke positieve impact zal hebben op zowel de lokale gemeenschap. Het zal niet alleen bijdragen aan de bescherming van ons milieu, maar ook de veiligheid van onze burgers vergroten.

Bovendien, om de levensvatbaarheid van het voorgestelde project verder te onderzoeken en om mogelijke voordelen te demonstreren, is de verzoeker van plan om een pilotproject te starten. Dit pilotproject zal zich richten op de eerste 10 meter van het tracé langs de oever. Het Ministerie is vastbesloten om de resultaten van dit pilotproject te gebruiken om de effectiviteit en duurzaamheid van de voorgestelde maatregelen te evalueren.

Ik verzoek u vriendelijk om de nodige stappen te ondernemen om de benodigde vergunningen/ goedkeuring te verlenen. Dit zal bijdragen aan een succesvolle uitvoering van het plan en het realiseren van de beoogde doelen.

We kijken uit naar een constructieve samenwerking om ervoor te zorgen dat dit project op efficiënte en effectieve wijze wordt uitgevoerd.

De wnd. Directeur van het
Directoraat Civieltechnische Werken,

Dhr. S. [illegible] MPM BSc.
cc. Dir. CTW/[illegible] KRN/Eliza van Dongen/ Juza /Post & Arch. Zkn.

Figure 12: Approval letter of ministry of Public Works, Surinam