A Multidisciplinary Approach to Water Management in Ricanau Mofo

A scientific study that explores solutions for Ricanau Mofo's water management challenges, focusing on riverbank stabilization, improved drainage and responsible waste management.

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Abstract

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Located in Suriname, the village of Ricanau Mofo faces a multitude of environmental challenges. This report delves into a comprehensive study that employed a multidisciplinary approach, leveraging the expertise of students from various backgrounds to address these pressing issues.

The most critical concern identified was the relentless erosion of the riverbank, forming an existential threat to the village. The report explores interventions for both riverbank and soil erosion. Building upon the previous year's sheet pile wall construction by van Dongen et al. (2023), the report evaluates its effectiveness and proposes potential improvements for natural shore protection. It presents an analysis of structural solutions like sheet pile walls and quay walls, alongside nature-based methods that promote vegetation growth. A multi-criteria analysis is employed to objectively evaluate the effectiveness and feasibility of each intervention.

Moving beyond the riverbank, the report investigates soil erosion in Ricanau Mofo's old center. To understand the water flow patterns, a hydrological analysis was conducted. This analysis incorporated field measurements, on-site observations, and existing scientific reports. By considering factors like clay content, vegetation cover, discharge, and slope, the study categorized different flow areas within the village center. This detailed analysis lead to the proposal of a combination of targeted interventions, including roof gutters, strategic vegetation planting, and channel improvements, all aimed at effectively addressing drainage issues and mitigating soil erosion.

Waste management emerged as another critical concern. The report sheds light on the impact of inadequate waste collection systems on hygiene and even the success of other implemented solutions. Recognizing the importance of community involvement, the report proposes a roadmap and implements a physical prototype for establishing a more organized and effective waste management system, promoting a sense of shared responsibility for a cleaner Ricanau Mofo.

This report illustrates the value of a multidisciplinary approach. By combining diverse expertise and conducting thorough analyses, the study provides a comprehensive understanding of Ricanau Mofo's environmental challenges. The proposed solutions for riverbank and soil erosion control, improved drainage, and effective waste management offer a sustainable path forward for the village's future development.

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1

Introduction

This chapter introduces Ricanau Mofo, a small Surinamese village facing environmental and social challenges. Despite its agricultural importance and recent infrastructure improvements, the village struggles with flooding, erosion, and waste management. The chapter explores these challenges through a PESTLE analysis, on-site observations and both the positive and negative resident experiences. Finally, for both the short and long term, a problem statement is formulated with the derived objective.

1.1 Environmental analysis Ricanau Mofo

Ricanau Mofo is a village in the Marowijne area of Suriname. It is a small village with approximately 1500 residents and it is situated at the mouth ('Mofo' in Aukan) of the Cottica River and the Ricanau Creek, see figure 1.

Figure 1: Geographical location Ricanau Mofo

In order to gain understanding of Ricanau Mofo's current position and its potential for future development, a PESTLE analysis was conducted. This analytical framework examines the Political, Economic, Social, Technological, Legal and Environmental factors that influence the village.

On-site observations provide insight into the elements that shape Ricanau Mofo's landscape. This analysis examines the role of the Cottica river in the village, assesses threats caused by bank and soil erosion, and explores the village's current layout and drainage systems.

Complementing these analyses is understanding the perspectives of Ricanau Mofo's residents. An analysis of the experiences of local inhabitants can reveal how they perceive the village's strengths and weaknesses, what they see as obstacles for growth and the changes they desire.

PESTLE analysis

Political

The village exhibits a clear hierarchy. The elderly hold significant influence, and the captain has the final say. This hierarchical structure functions well within the village. However, for project implementation, it's important to understand this structure, as the captain, comparable to a mayor, determines the village's affairs. Individuals close to the leader, known as "Basja's", often serve as intermediaries or communication.

Ricanau Mofo thrives on agricultural plots. The village grows crops like ginger, bananas, cassava and podosirie on plots primarily located along the river. The agricultural activities have earned recognition by the National Assembly, designating Ricanau Mofo as an important agricultural area.

The Surinamese government's aim for decentralizations presents opportunities for Ricanau Mofo to have more control over its development. However, this is contradicted by the centralized nature of electoral law and financial allocation, which are still entirely decided in Paramaribo. This leaves the districts with limited financial autonomy.

Economic

Ricanau Mofo earns revenue from its agricultural plots and serves as a transit port for surrounding villages. The village facilitates the transport of harvests to Moengo, Paramaribo and French-Guyana via waterways and then by road. The government's recent construction of an asphalt road has improved accessibility, reducing travel time from Ricanau Mofo to Moengo to approximately fifteen minutes by car.

Additionally, the STEORR Foundation invests in Ricanau Mofo's development through research projects conducted by students. Over 200 students have visited Ricanau Mofo to explore ways to contribute to tits progress

Suriname's high inflation rates in recent years have significantly impacted purchasing power. Since children can earn more working on the agricultural pots than completing their primary or secondary education, the village experiences a high school dropout rate. This is perceived as a problem, as children (sometimes even influenced by their parents) choose higher short-term earnings above education.

Socio-demographic

Upon entering the village, one immediately notices the prominent kankantrie tree, a central point in the village. Further into the village, there is a 'sacred' area used for ceremonies following a death.

The village comprises various families, each owning land passed down through generations. Many families reside close to each other. The population is predominantly young, with most children under twelve years old, partly due to the COVID-19 pandemic. Furthermore, there's a migration of educated individuals to urban areas after secondary school.

Technological
Recent investments include the construction of an asphalt road and efforts for increased digitization. However, the village lacks sufficient access to the internet. For the development of the village, internet connectivity is crucial for Ricanau Mofo. Besides these technological developments, households now have access to water taps and showers, improving hygiene.

Legal
Corruption and political instability in Suriname impacts Ricanau Mofo's development. The government's control over pricing affects the village's economic prospects.

Environmental
The village lies at the mouth of two rivers and experiences the influence of tides. Consequently, the water flows inland at high tide (with a tidal range of 1.8 meters) and outland at low tide. Therefore, the tides automatically affect the direction of flow as well.

Climate change causes the water to rise. The height of the river has increased significantly in recent years. In forty years, this has resulted in the water line moving 7 meters inland. In the same timeframe, the village has subsided 3 meters over the years, resulting in water being able to get further and further into the village.

The rise of water affects the village. During heavy rainfall, the large amount of water can no longer drain properly, leading the village to flood, see figure 2. Consequently, people are forced to move every year for a short period of about three weeks. Residents can then often move to their relatives higher up in the village.

Because of the climate change's impact on the rainy season, every year villagers have to wait and see whether the harvest will be successful. In the past ten years, the harvest has failed three times.

Figure 2: Flooding in Ricanau Mofo after heavy rainfall

On-site observations

Ricanau Mofo is a close-knit community, with children playing throughout the village. A primary school, a church and a few soccer fields serve the community's needs. Villagers often gather at the river bank, a central point in Ricanau Mofo. Below, on-site observations regarding water use in Ricanau Mofo are discussed.

Function of water

Ricanau Mofo relies on agriculture, with a large number of agricultural plots located along the Cottica river. To reach these plots, the villagers have their own boats close to their houses. For agricultural activities, the river serves the function of transportation and also provides a source of irrigation for their crops. Furthermore, the river is used for household activities such as washing, bathing, and recreational activities like fishing and swimming.

Unfortunately, a significant amount of waste is found along the riverbanks. Due to limited financial resources, residents dispose of waste directly into the river. Additionally, upstream waste is carried by the river from Moengo, where it is thrown into the water.

Bank erosion

Over the past decades, significant erosion has occurred on the banks of Ricanau Mofo. As mentioned before, approximately 7 meters inland within the timespan of forty years. The causes of bank erosion are the tides creating river currents, the meandering of the river, the waves generated by shipping traffic both towards and from Moengo and the heavy rainfall.

Soil erosion

Due to the heavy rainwater runoff from roofs, significant soil erosion occurs in Ricanau Mofo. Throughout the whole village, but especially near the river the effects of soil erosion are clearly visible. Around the houses, you can see exposed foundations due to significant soil erosion (figure 3). In open areas near the river, the soil is clayey and dry, and water has formed small gullies through which it drains away (figure 4).

To counteract soil erosion, the village has installed vertical planks in the ground, which help retain eroding soil (figure 5). This method seems effective, resulting in the formation of steps. Additionally, trees visibly hold soil with their roots (figure 6). This is evident by the observed erosion of the surrounding ground caused by rainwater runoff during heavy rainstorms.

Figure 3: exposed foundations due to erosion

Figure 4: gullies in open areas

Figure 5: vertical planks that help retain soil

Figure 6: trees hold soil with their roots

Further into the village, there is an area that also floods. What stands out in this area is the presence of large grassy areas alongside the dry ground. The soil is less dry here, and there is less erosion around the houses compared to the waterfront. This could be due to a different soil type, but further investigation is needed.

Layout

The layout of the village varies. Houses directly on the riverside are closely spaced (afstand) and situated at a low elevation, leading to flooding during heavy rainfall when water cannot be drained. During periods of flooding, residents of these areas sometimes have to move from their homes for 2 - 3 weeks and stay in the school building or with their family members who live in higher parts of the village.

In the area further from the Cottica River, houses are larger and spaced further apart. This part of the village does not flood, and there is less erosion visible. There is currently minimal erosion under the houses here. The reasons for this need to be investigated further, possibly due to different soil types, better rainwater drainage, and different types of protection.

Drainage

Although some pipes on the ground individually drain water from the houses (figure 3), there is not a drainage system throughout the village. In the newer area where houses are spaced farther apart, there are small ditches or channels that drain rainwater (figure 4). However, in the areas where houses are closely spaced, there are none. Here, water flows through the ground to the river, sometimes through gullies formed by erosion.

Water usage

In the old part of Ricanau Mofo, there are many large black rain barrels donated by the government, storing rainwater. This water was previously used for drinking and washing, however recently all houses got connected to the water network of surinam (SWM) and now Ricanau Mofo is connected to water pipelines from Moengo. Therefore the rain barrels became less needed and maintenance of the gutters that collected rainwater were neglected.

Agriculture

There is a small amount of agriculture in the village itself. The primary school has a greenhouse to show students that crops can be grown at home without necessarily relying on their agricultural plots. The soil for these greenhouses is sourced from Paramaribo. Additionally, there are households with small agricultural plots. In the past, livestock was kept in Ricanau Mofo, but nowadays only chickens are raised.

Experiences local inhabitants

In order to formulate a correct problem statement, it is important to include the opinions and experiences of the village. Therefore, an information evening was held on February 15, 2024. This event brought together a group of residents to discuss the challenges they experience in their living environment in Ricanau Mofo, both related to water management and beyond. During the information evening, residents were invited to share their opinions on A2 papers with post-its, resulting in a large template filled with valuable information (figure 7).

This section describes the main findings, which were used to formulate an initial problem statement. This is divided into positive experiences, negative experiences, obstacles to growing as a village and finally their wishes. The table below shows the people with whom we have spoken.

Figure 7: interaction with templates and post-its

Table 1: Representatives Ricanau Mofo

Name	Age	Function in the village
Sir Mésack	25-35	Captain of the village
Sieni Saling	59	Contact in the village
Keba	+-60	Basja of the Captain
Edward Saling	65	2nd contact in the village, brother of Sieni
Lajeeti	33	Spoke dutch. She has knowledge of the damwand and its function. She translated opinions from the village.

Positive experiences:

- *Living closely by the river* and enjoy doing activities in the river
- Planting, dancing, cooking, laughing, sleeping in the village
- Going to school, playing soccer, batting practice

Negative experiences:

- A lot of *garbage* in the village
- *Flooding* in the rainy seasons where one gets wet feet
- *Snakes, cockroaches and ants* in the houses when it rains (the animals also look for dry places)
- No playground for children, no public toilet

Obstacles to grow:

- *Financial resources*. Time and effort are put into the boarding grounds. Also, harvest is uncertain due to climate change, so priorities are more short-term than long-term solutions.
- *Lack of schooling*. There is a school and there are certainly children who have an ambition to get a good job, but there is also a large proportion of young people who are insufficiently educated. There is compulsory education for children up to age 12, so many children help their parents by working once they turn 12.
- They have a *focus on the short term* and not the long term. As a result, long-term effects of rising sea levels are not prioritized.

Things the people from Ricanau Mofo wish for

- *A solution for excess waste*. More frequent collection by agencies and a waste incinerator was suggested by residents.
- *Less flooding* in the short term and a longer dam wall.
- A public *toilet*
- A *playground* for the children

1.2 Problem statement

From the environmental analysis conduction, the problem formulation is derived. The results from the PESTLE analysis, on-site observation and the experiences of the local inhabitants lead to the following short and long term problem statement.

Additionally, the goals set in advance focussed on the following topics and help provide direction for the solutions to be devised:

- To maintain and improve livability in Ricanau Mofo in the short term
- To maintain and improve the economic growth of Ricanau Mofo

Short term (0 - 5 years)

Problem: In Ricanau Mofo, the large amount of rainfall and rise in river water causes soil- and bank erosion hindering drainage and degrading the living environment.

Objective: Provide detail-level advice that can slow soil and shoreline erosion and increase short-term livability.

Long term (> 5 years)

Problem: Sea level rise, heavy rainfall, change in rainy sessions and subsidence of land threaten the development, livability and livelihood of Ricanau Mofo.

Objective: Increase awareness of the effects of rising water and erosion in Ricanau Mofo among the population.

2

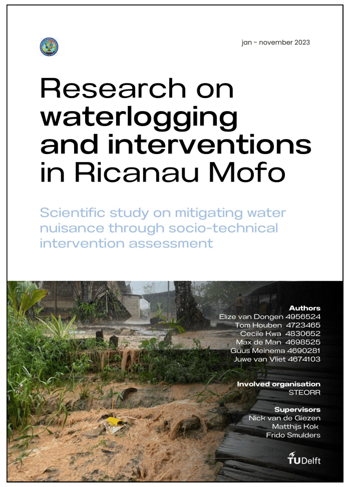
Preliminairy study

Previous research has been done by groups of students in the area of Ricanau Mofo. Building upon the valuable work of previous student research teams, this chapter delves into the existing body of knowledge. By analyzing the methods and findings of these studies (summarized in chapter 2.1), we aim to identify gaps and opportunities to further enhance our own research contribution (discussed in chapter 2.2).

2.1 Previous studies

To make significant contributions to the research on the village of Ricanau Mofo, it was crucial to gain an understanding of the methods and findings of the most recent studies, conducted between 2022 and 2023. These studies are explored in detail in the following chapter.

Van Dongen et al. - Research on waterlogging and interventions in Ricanau Mofo (2023)



This research project was conducted by students at Delft University of Technology and addresses the water-related challenges faced by Ricanau Mofo. The village's low-lying location makes it increasingly vulnerable to land erosion, river bank erosion, and flooding due to climate change.
Their approach involved initial studies to understand the community, the region, and relevant stakeholders. A hydrological analysis was then conducted to assess the water situation in Ricanau Mofo. Based on their findings, three key strategies were proposed:

1. **Strategy to address river bank erosion:** This involves planting vegetation for immediate relief, followed by constructing footpaths with drainage channels for long-term erosion control.
2. **Strategy to address soil erosion:** Wooden bulkheads with vegetation and stones are recommended as a short-term solution. Long-term plans involve groynes (rock walls) to weaken waves and slow water flow, ultimately promoting land buildup. Due to the cost of long-term solutions, a business plan is presented to acquire funding from external sources.
3. **Water Damage Management in the Village:** The research team proposes informational boards to guide villagers on building flood-resistant structures. Long-term plans include a flood early warning

Significance
The significance of this project lies in developing practical solutions that can be implemented in rural areas of Suriname. The project's findings can be a pilot for other villages facing similar challenges. The project also includes a prototype for protection of the bank and was built in collaboration with the villagers.

Goossens et al. - Leven aan én met het water (2023)

This thesis presents the findings of an interdisciplinary study, also conducted in the village of Ricanau Mofo. The research aimed to develop a resilient future vision for the village by analyzing its current situation and engaging in design-driven research.

Understanding the Context Through Fieldwork
The study, undertaken by students of the University of Antwerp, began with an intensive two-month fieldwork period in Ricanau Mofo. The collected data was then analyzed and used to develop design proposals for the village's future.

Identifying Challenges
Like the study of van Dongen et al, the research identified several challenges facing Ricanau Mofo, including erosion, flooding, housing pressure, and a lack of social and spatial structure. They concluded that these challenges have impacted the village's quality of life and limited its development.

A Collaborative Approach: Working with the Community
To address these challenges, the research team employed a participatory approach, working closely with the community to understand their needs and aspirations. The design proposals focused on developing strategies for climate-resilient housing, expanding the village while preserving its natural environment, and improving the village's infrastructure and social spaces.

Significance
The research findings offer valuable insights for the future development of Ricanau Mofo. The design proposals provide a framework for further planning and implementation, and the participatory approach demonstrates the importance of involving communities in shaping their own future.

Vandermeeren - Klimaatverandering in Ricanau Mofo (2022)

This study researches the increasing threats from climate change that Ricanau Mofo faces. Rising temperatures, heavier rainfall, and a higher water level endanger the community and its traditions. The study examines the impact of climate change on the village's needs and proposes steps to enhance its resilience.

Assessing the Impact
The study employs a social-ecological framework and Maslow's hierarchy of needs to assess the impact of climate change on Ricanau Mofo.
It identifies direct threats to the community's basic needs, such as food, water, and shelter. However, it also emphasizes the importance of considering higher-level needs, such as social connections, recognition, and personal growth, as these contribute to the community's overall resilience.

Building Resilience
The study proposes a process architecture and roadmap for climate adaptation in Ricanau Mofo. This approach emphasizes collaboration between local and higher levels of governance, with initiatives driven by the community. A core team with coordinating functions and thematic working groups addressing specific challenges will guide the process.

Community Engagement
A participatory tool, consisting of "talking cards," has been developed to facilitate dialogue between the thematic working groups, the community, and future researchers. This tool provides inspiration for actions and showcases reference projects to address challenges and seize opportunities.

Significance
While the study's findings are specific to Ricanau Mofo, its methodological approach can be applied to similar villages. The need-based approach highlights the importance of culturally sensitive interpretations and the protection of all levels of needs to enhance the village's resilience.

2.2 Own contributions

This chapter outlines the research contribution to the ongoing effort to support the community of Ricanau Mofo, building upon the valuable work done by previous groups of students.

Leveraging Existing Data
The data collected by previous researchers serves as a foundation for this work. The analysis of their findings on water management, particularly drainage patterns within the village, height maps and the localization of existing interventions, will inform on-site observations and data collection through mapping. By combining these approaches, the project aims to gain a comprehensive understanding of Ricanau Mofo's drainage network and identify areas for improvement.

Re-evaluating and Redesigning the Existing Bank Protection
The functionality of the current bank protection measures will be a central focus of the investigation. Close observation will assess their effectiveness in mitigating erosion and fostering the growth of natural bank protection (vegetation). Based on the evaluation, the project will propose potential refinements and enhancements to optimize the existing bank protection.

Expanding the Scope of Research Through Additional Fieldwork
While previous studies have provided valuable insights, the project acknowledges the need for further investigation, particularly regarding drainage. Planned fieldwork will involve in-depth data collection specifically focused on drainage patterns. This additional research will significantly contribute to the overall understanding of Ricanau Mofo's water management challenges.

Collaboration is Key
The importance of collaborating with the local community and stakeholders throughout this process is recognized. Their knowledge and experience are crucial in refining the research approach and ensuring the solutions align with the village's specific needs.

In conclusion, this research builds upon the groundwork laid by previous studies while offering fresh perspectives and a focus on drainage improvements. Through a combination of data analysis, on-site observations, and community engagement, the project aims to deliver impactful solutions that enhance Ricanau Mofo's resilience in the face of climate change.

3

Project scope

In this chapter, the research focus, research scope and research questions will be addressed. The focus is divided into three subdivisions, which will be elaborately treated in chapters 5, 6 and 7.

3.1 Research focus

The primary goal of this project is to enhance the quality of life for the residents of Ricanau Mofo. To be able to identify specific topics for this research, it is important to find out what matters are important to the villagers of Ricanau Mofo.

To achieve this, an inclusive approach has been adopted, beginning with a collaborative brainstorming session involving the villagers. In this brainstorm session, all matters regarding the village could be brought up. Next to this brainstorm session, multiple thorough walkthroughs of the town were conducted. These activities have provided valuable insights into the pressing issues and priorities within the community.

In this research, three main topics have been identified. These topics have been selected based on urgence, feasibility for a two month project and probability of continuity with future and previous studies (chapter 2).

Topic 1: River bank protection

The erosion of the coast is a phenomenon that came forward in both the brainstorm sessions with the villagers and during the village walks. Over the years, the river bank of Ricanau Mofo has lost about 10 meters of land to the Cottica river. Villagers of Ricanau Mofo see the riverbank receding and are worried they will lose their shoreline.

The focus of this research will be on exploring new possible interventions for shoreline erosion. This will result in natural shore protection and artificial shore protection. Previous year, a sheet pile wall was built by van Dongen et al. (2023) to protect the shoreline against erosion. The natural shore protection consists of an evaluation of this shore protection and some future improvements. The artificial shore protection is a fictitious calculation of a sheet pile wall construction based on multiple assumptions. Natural protection can also be carried out by the local people, using their own resources. The artificial protection should be carried out by the Ministry of public works.

Topic 2: Water drainage

The topic that came forward most during the village walks was the ground soil erosion. Due to the heavy rainfall, the old center of Ricanau Mofo experiences heavy soil erosion due to the water not being properly drained.

The exposed foundations of houses and tree roots show that a lot of soil particles have eroded. Because the ground level lowers every year due to erosion, the old city center becomes more prone to floods. Next to this, when the foundations of houses are exposed, the structural integrity of the house may decrease.

Topic 3: Waste management

A subject that came forward the most during the brainstorm sessions with the community was the abundance of waste in the village. Plastic waste is everywhere - it accumulates near the shore, it clogs drainage channels and is present at the sides of the road. Next to the fact it is not a pretty sight, it also pollutes the water and soil and is therefore bad for the general health in Ricanau Mofo.

3.2 Research objectives

For each research topic, the research objectives are formulated to specify the aim of each research.

Topic 1: River bank protection

The main objective of this research is to find an ultimate solution for protecting the river bank against erosion in Ricanau Mofo. To achieve this objective, the following steps will be undertaken:

1. Understand the Causes: Conduct research to understand why erosion is occurring along the river bank in Ricanau Mofo. This can be done by thoroughly inspecting the riverbank and literature research on erosion.
2. Explore Solutions: Investigate various shore erosion prevention techniques to identify potential solutions by brainstorming and research on similar villages.
3. Evaluate Interventions: Assess the effectiveness of both possible and existing interventions for shoreline protection. By creating selection criteria and rating different protection interventions, an overview can be made of the effectiveness of each criterion.
4. Select Best Solutions: Choose the most suitable interventions based on their effectiveness, feasibility, and compatibility with Ricanau Mofo's needs and environment. This can be done using a Multi-Criteria Analysis
5. Tailor Recommendations: Work out how the selected interventions can be applied effectively in Ricanau Mofo to prevent shoreline erosion or slow down the erosion processes. These worked out intervention plans can be used as a recommendation for building shore protections in the future.

Topic 2: Water drainage

The goal of this research is to provide solutions for slowing down erosion processes in the lower lying center of Ricanau Mofo. To achieve this goal, the following steps will be taken:

1. Understand Drainage Patterns: Assess stormwater drainage and hydrological catchment areas in the town center through mapping current water drainage.
2. Evaluate Current Interventions: Investigate existing interventions and identify areas that are more prone to erosion.
3. Research Erosion Prevention Concepts: Explore possible erosion prevention concepts and determine their applicability in the old center of Ricanau Mofo.
4. Application of Concepts: Determine how the identified erosion prevention concepts can be effectively applied in the town center, considering factors such as feasibility and community acceptance.

Topic 3: Waste management

The goal of this research is to identify actions that Ricanau Mofo can undertake for a less polluted town and a more sustainable waste system. To achieve this goal, the following steps will be taken:

1. Assess Current Waste Management: Understand the organization and effectiveness of the current waste management system in Ricanau Mofo.
2. Explore Sustainable Solutions: Investigate possible solutions or interventions for creating a more sustainable waste system with less waste.
3. Prioritize Actions: Identify and prioritize the most important actions based on their potential impact and feasibility.
4. Communicate with the Community: Develop strategies for communicating the prioritized actions to the community and soliciting feedback and input.

3.3 Research questions

To achieve the research objectives, research questions have been formulated for each topic.

Topic 1: River bank protection

To find a solution for the river bank protection, a main research question has been formulated:

How can the erosion of the riverbank of Ricanau Mofo be mitigated?

To answer the main research question, the question has been divided into 4 subquestions:

- **What are the causes of the shore erosion?** To find out how to protect the shore against erosion, it must first be stated why the erosion takes place. This is explained in chapter 5.1.
- **What are possible interventions to protect the shore against erosion?** An overview of possible interventions will be made. This overview can be found in chapter 5.3.
- **Which interventions can be applied to Ricanau Mofo?** When conducting a Multi-Criteria Analysis, a final result will appear on which interventions are most suited for Ricanau Mofo. This is worked out in chapter 5.3.
- **How can these interventions be applied to Ricanau Mofo?** The application of the best interventions is going to be the largest part of this research topic. The worked-out examples for river bank protection will guide as a recommendation for parties who are interested in investing money in Ricanau Mofo.

Topic 2: Water drainage

The research questions for water drainage are divided into two subdivisions. The first one is understanding the hydrological catchment area in the center of Ricanau Mofo. 4 research questions have been formulated.

- **What are the quantities and flows of rainwater in Ricanau Mofo?** Precise data regarding rainwater quantities and flows are essential for effective water management.
- **How is the drainage system of Ricanau Mofo organised?** To be able to manage the water, it is important to first identify the current drainage systems.
- **What are the current interventions implemented?** Current interventions can give insight in possible solutions.
- **Which areas are most at risk to erosion?** Identifying vulnerable areas enables targeted interventions and prioritization of resources to mitigate erosion risks effectively.

The second subdivision is the evaluation of erosion preventing concepts. Evaluating concepts ensures that proposed solutions are feasible. Three research questions have been formulated.

- **Which concepts are evaluated?** First, it is important to identify the concepts.
- **How are the concepts evaluated?** To make a thorough assessment of the concepts, it is vital to investigate how the concepts are evaluated.
- **How and where can the concepts be implemented?** When the concepts have been evaluated, locations for certain concepts can be identified.

Topic 3: Waste management

Waste management is also divided into two parts. The first part is understanding current waste management in Ricanau Mofo. 4 research questions have been formulated.

- **How is the waste system of Ricanau Mofo organized?** By identifying the current waste system of Ricanau Mofo, areas for improvement can be found.
- **What are the flows of waste in Ricanau Mofo?** To understand the waste management, it is needed to know the waste flows.
- **How is the nationwide waste system organized?** By investigating the nationwide waste system, more insight in the waste system in Ricanau Mofo is gained and possible solutions can be identified.
- **What are the current measures against displaced trash?** By evaluating existing strategies, it can be determined what is working well and what needs improvement.

The second part is about steps forward towards a more sustainable system. 3 research questions have been formulated.

- **What are the steps forward towards a more sustainable waste system in Ricanau Mofo? T**aking steps towards a more sustainable waste system in Ricanau Mofo is crucial for keeping the environment clean and healthy. By identifying these steps, actions can be taken.
- **Which actions should be prioritized?** Because there is not much time, more important actions should be prioritized.
- **How can the actions be effectively communicated to the inhabitants of Ricanau Mofo?** If the actions that need to be applied to RIcanau Mofo are not communicated well with it's inhabitants, the action will have no effect.

4

Stakeholder analysis

The stakeholder analysis describes which stakeholders are related to this project. Not all the stakeholders have the same interests and influence within this project about water nuisance in Ricanau Mofo. With the theory of Bryson & Humphrey, the stakeholders are divided into 'Players', Subjects', 'Context setters' and 'The crowd'. The types of stakeholders are described in the following paragraphs. Information is merely used from earlier research of Van Dongen et al. in 2023 together with new information of other stakeholders during our project.

4.1 Overview of stakeholders

All 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 influence they have in creating impact for Ricanau Mofo (see Figure 8).

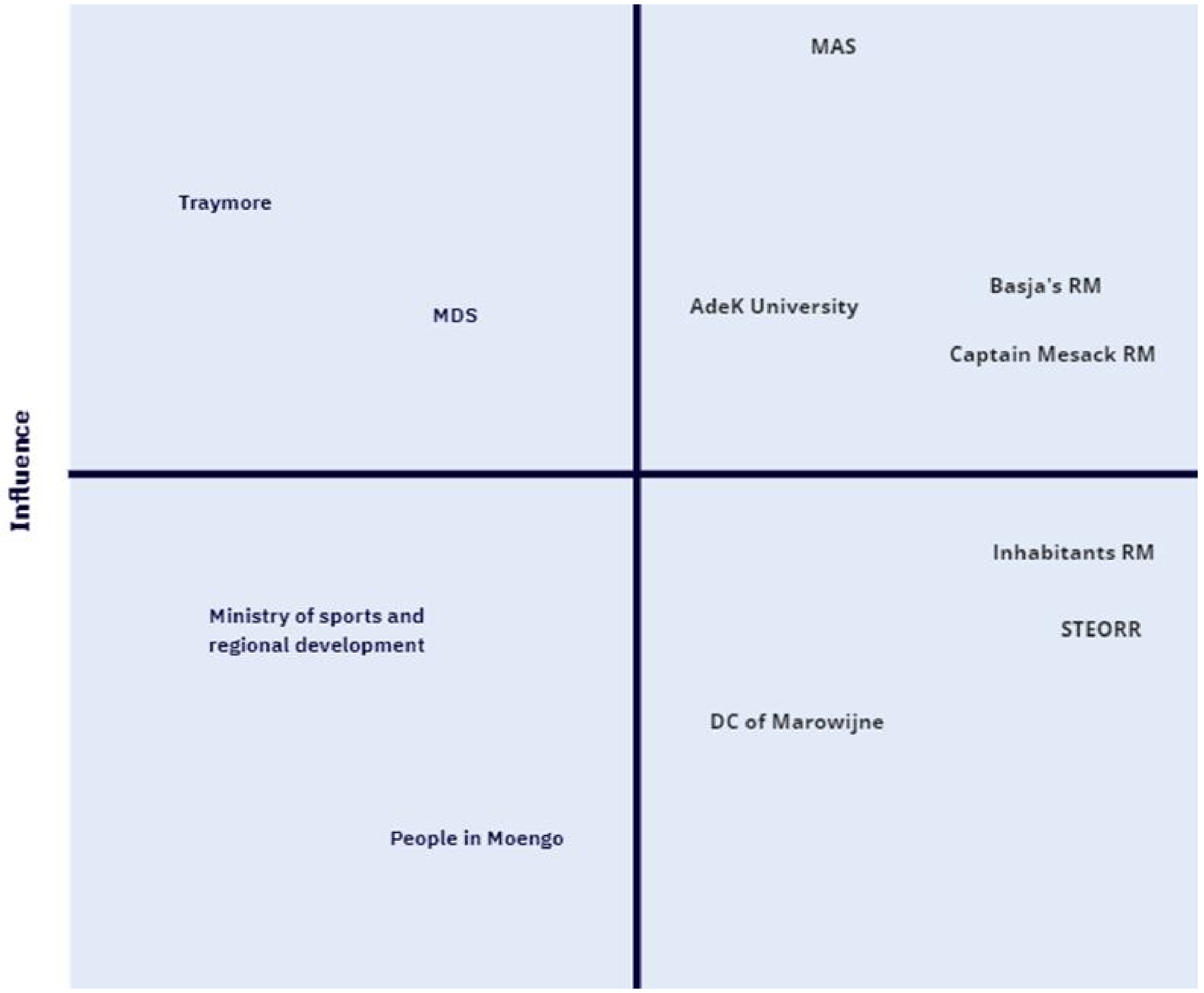


Figure 8: Interest-Influence stakeholder diagram

4.2 Players - many resources, high interest

These actors have many resources to create impact and have high interest in the project and the situation in Ricanau Mofo.

Ministry of public works (OW)

The Ministry of Public Works (Openbare Werken) is responsible for developing, building and maintaining public works for a livable, 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 ministry of public works has the most resources to invest in water management interventions. This ministry is not only interested in the proposed solutions, but also in the engagement of the local people during the project.

Maritieme Autoriteit Suriname (MAS)

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 Surinam, for example, depth measurements, which is interesting for this project (Maritime Authority Surinam, 2022). Thereby, MAS could provide information about ships, maximum lengths and depths, tidal reports, and charts with water depths for the entire Surinam. Together with the earlier mentioned ministry, the MAS provides permits on construction projects alongside the Cottica river.

Anton de Kom University (AdeK)

The university of Paramaribo is called the Anton de Kom University. This university offers various bachelor's degrees, but during the project, students from agriculture, geosciences and civil engineering bachelors were involved in the workshops. A collaboration is created between the students, which is interesting for the involvement of the Anton de Kom university in future projects in Ricanau Mofo. The knowledge of these students is very helpful while doing projects in Surinam.

Captain Mesack Ricanau Mofo

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).

Basja's Ricanau Mofo

The Basja's of Ricanau Mofo support the captain in directing the decisions regarding the village. Usually, the Basja's are old and wise people, who preserve traditions in the village. During a "Krutu" all the people in the village come together to discuss issues and make decisions. Finally, the Captain and Basja's make the decisions. The Basja's have less resources, but do have a lot of influence in the village as they make the final decisions.

4.3 Subjects – little resources, high interest

These actors have little resources to create impact, but have a high interest in the project and the situation in Ricanau Mofo.

Stichting Economische Ontwikkeling Ricanau Ricanau Mofo (STEORR)

The foundation STEORR strives to develop the area between Ricanau Mofo and Moengo. They stimulate the development of a sustainable economy of Ricanau Mofo and strive to be an example for Marowijne and Surinam on how to develop an agricultural area (STEORR, z.d.). By setting up knowledge sharing projects and include students from universities in Europe, STEORR stimulates the local people to invest in themselves and the development of the area.

Inhabitants Ricanau Mofo

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, anursery, and an agricultural greenhouse. Some of these facilities are supported by organisations like STEORR or international funding bodies (Goossens, Marsboom, Plaghi,2022).

DC of Marowijne

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 DC is responsible for order in the district and the public spaces.

4.4 Context setters – many resources, low interest

These actors have many resources to create impact, but have little interest in the project and the situation in Ricanau Mofo.

Traymore

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.

Meteorologische dienst Suriname (MDS)

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 startdagelijkse weersverwachtingen, 2023). They carry power as they have non-public data about precipitation but might not share high interests.

4.5 The crowd – little resources, low interest

These actors have little resources to create impact, but overall also not a lot of interest in the project. Therefore these actors can be included, but they won't add a lot of value to the project.

Ministry of sports and regional development

The Ministry of sports and regional development is responsible for the regional authorities and the connection between regional and national government. They strive to create a coherent policy aimed at cooperation between districts to promote common interests. The ministry is also focusing on inland reconstruction. In this project, the ministry of sports and regional development was involved very little. They were interested in the final result and the engagement of the local people, but weren't needed for support during the project (Ministerie van ROS, z.d.).

People in Moengo

In Moengo a lot of people feel connected to Ricanau Mofo. Some of them are born in Ricanau Mofo and moved to Moengo because of work or family. A lot of people still have connections or family living in Ricanau Mofo and thereby feel connected to projects regarding Ricanau Mofo. During the project, people are curious about the erosion interventions, but they don't have resources to create impact. Some of the people are really interesting connections for borrowing equipment during the project.

5

Bank protection

The erosion along the shoreline of Ricanau Mofo presents a pressing threat to the community's stability and well-being, impacting homes and daily activities. To address this problem, in the chapter some interventions, from structural to natural solutions, are proposed and evaluated through a multi-criteria analysis. These assessments identify the construction of a sheet pile wall and a quay wall with and without water retaining function. Both interventions are explored thoroughly and finally a conclusion is drawn.

5.1 Problem definition

Over the last 30 years, the river shore of Ricanau Mofo has moved about 8 meters. This is based on the remains of an old mango tree lying approximately 8 meters off the shore that is pointed out by the villagers as the place where the shoreline used to be 30 years ago.

Problem quantification

The erosion of the shore is due to different factors. The first and most important one is the meandering of the Cottica river. The flow velocity is a very important factor in the transportation of sediment particles. When a curve occurs in a river, the flow velocity is larger at the outer part of the curve. Due to the increase in flow velocities, the chance of erosion occurs as well, this can be seen in figure 9 (Earle, 2019).

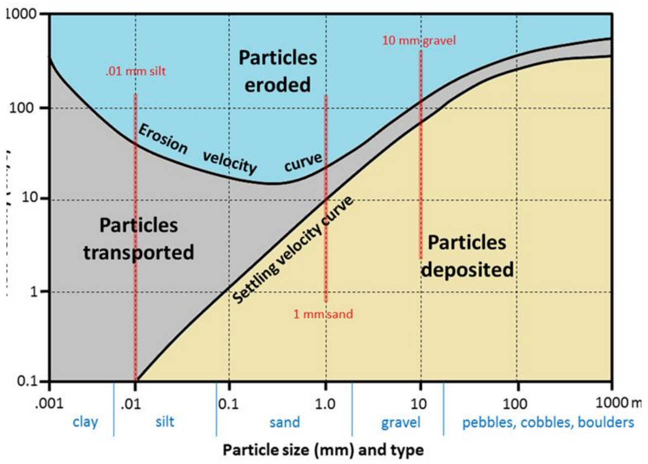


Figure 9: particle movement based on flow velocity and particle size (Earle, 2019)

Figure 10: location of Ricanau Mofo

Ricanau Mofo is located exactly at the outer band of this curve (figure 10). Due to the increased flow velocities, erosion occurs. The second cause of erosion is the impact of waves generated by passing ships. When these waves hit the shore, the sudden increased flow velocity at the surface of the water also causes soil particles to erode from the shore. The establishment of the village Ricanau Mofo has led to deforestation, which in turn has encouraged erosion. Additionally, the movement of tides in the Cottica river further facilitates erosion. Therefore, to protect the shore against erosion, two different measurements can be considered. First, slowing down the flow velocity and second stabilizing the river shore. In this way the shore can be protected.

Impact on society

The loss of the coastline has a huge impact on the people living near the shore. Over time, people have lost their houses to the receding shoreline. The current villagers living near the shore fear they may have to leave their houses if the shore erodes any further. Currently, the shore is used for many activities. The main activities the shore is used for is washing, bathing and swimming. At the shore, jetty's are placed that provide for a safe space to enter the water.

From this problem follows the research question; how can riverbank erosion in Ricanau Mofo be reduced by implementations? The sub-questions to answer this are the following;

- What are measures that can be taken into account?
- How can various measures be implemented?

In November 2023, a group of students placed a sheet pile wall in front of the coast. The goal of the wall is to encourage the growth of vegetation which can help reduce erosion. The evaluation and improvements are discussed in paragraph 5.3. Other measurements are briefly discussed and in paragraph 5.4 a quay wall will be highlighted.

5.2 Exploring solutions

To protect the shore against erosion, there are a lot of interventions to be thought of. This project focuses on identifying practical solutions to apply to the shore. Building upon previous research conducted by van Dongen et al (2023), several options are selected from their proposals that are relevant to the objectives of this report. Additionally, several new solutions are introduced. Utilizing these shore protection options, a multi-criteria analysis will be performed to determine the most effective strategies for further research.

Possible solutions

In this section, eight possible solutions for the protection of the shore are briefly discussed. The solutions consist of measures that reduce the flow velocity which results in less erosion or of measures that preserve the coast.

1. Quay wall

A quay wall made from steel (figure 11) is a stable solution with a long life expectancy. Firstly, its structural integrity effectively stabilizes the shore and is also prone to structural decay. The solid construction of a quay wall serves as a barrier, effectively absorbing and dissipating the energy of incoming waves and currents, thereby reducing the erosion of the shoreline. This is an expensive solution that requires a lot of time and resources to build, but has a very long lifespan and requires very little maintenance.

Figure 11: Steel quay wall in The Netherlands

2. Wooden sheet pile wall

The wooden sheet pile wall (figure 12) is the solution carried out by van Dongen et al (2023). This wooden wall is built approximately 2 meters from the shore to protect the shore from waves, catch sediment from the town during periods of rainfall and allow for vegetation to grow. The vegetation serves on the long term as a protection for the shore. This wall itself effectively protects the shore from currents and waves. However, the wall does not have a very long lifespan and requires some maintenance. Besides this, it is important that the vegetation grows as this reduces the velocity with its roots and holds sediment which is in this way a protection for the shore.

Figure 12: Sheet pile wall in Ricanau Mofo

3. Groynes

Groynes (figure 13) are also an option proposed by Van Dongen et al (2023). Groynes, placed perpendicular to the river flow, deflect currents and stimulate sedimentation near the coast. The proposed design consists of poles, with a spacing between the poles approximately equal to the diameter of the pile.

By deflecting the streamlines (figure 14) of the river, the flow velocity near the shore will effectively decrease. By decreasing the flow velocity, sedimentation near the shore is stimulated and the erosion due to the river flow will decrease. However, by decreasing the flow velocity, the polluted water due to washing and waste disposal from septic tanks may not be refreshed as quickly as it did before with the higher flow velocity. Also, the groynes may disrupt the route of the boats that depart from the shore.

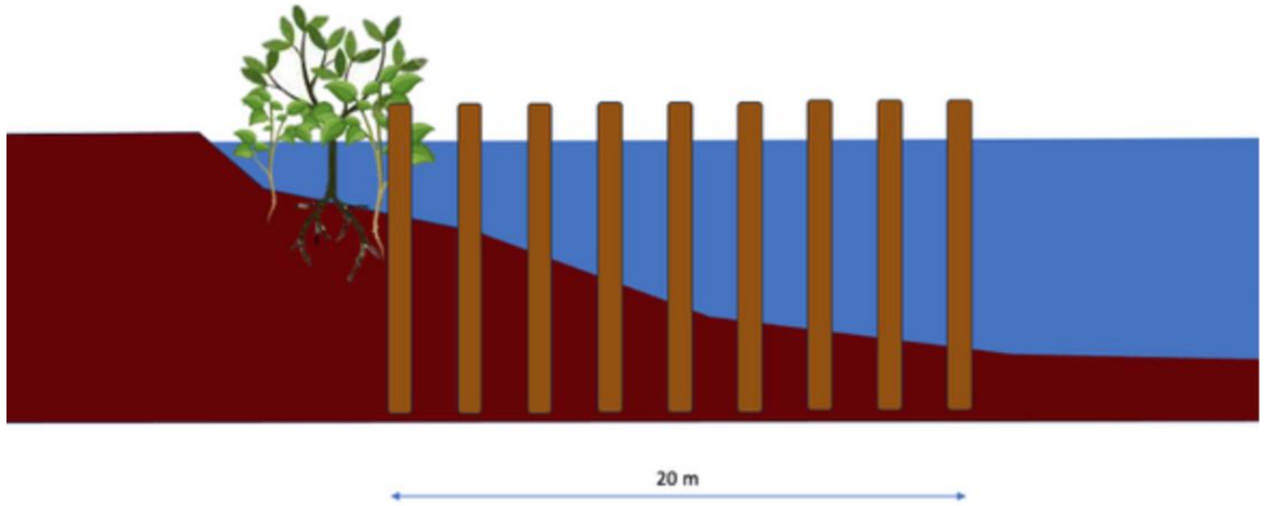


Figure 13: Proposed design of Groynes

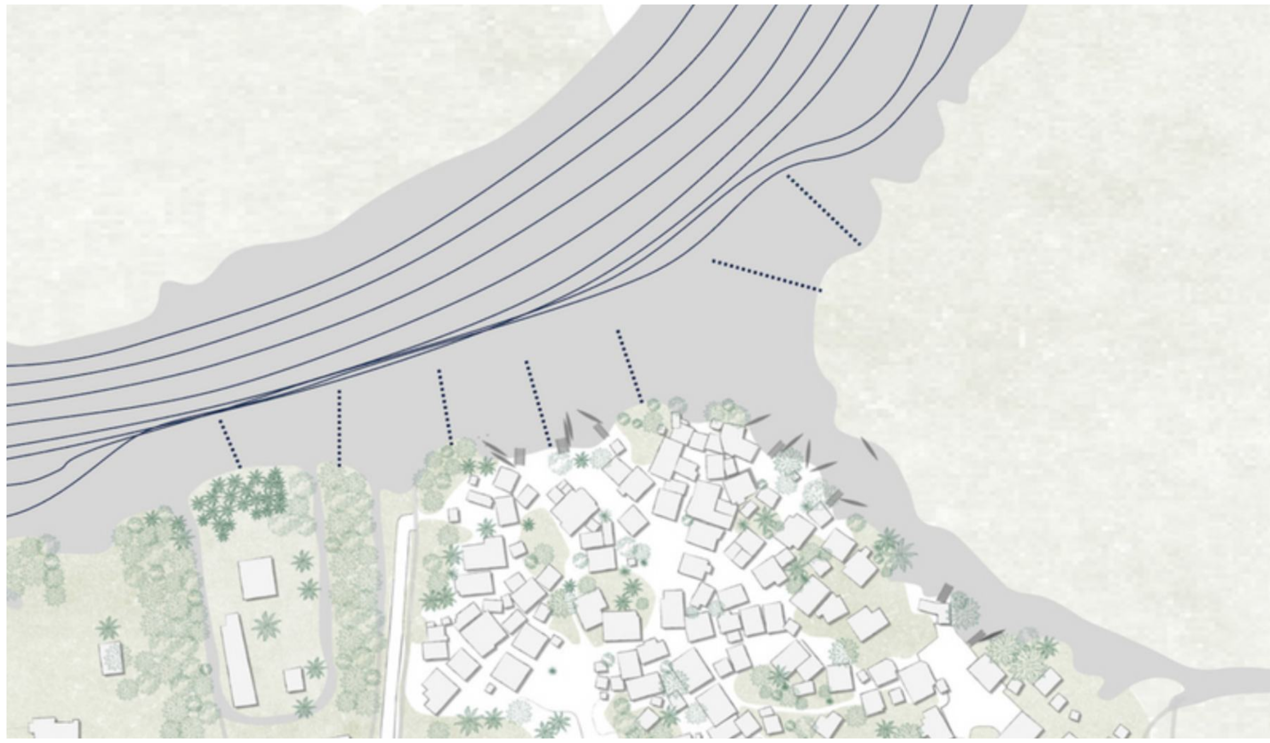


Figure 14: Illustration of deflected streamlines

4. Large stones

By placing large stones on the riverbed next to the shore (figure 15), the wave energy from the waves generated by the passing ships (partially) dissipates. The stones also stabilize the riverbed. However, there is little stabilization of the shore. Over time, the gaps between the stones may be filled with passing sediment from the rainfall. Instead of large stones, bricks from abandoned houses can also be used, which makes it an economically attractive solution because the material is already available there. This method is used in for example Paramaribo (figure 176.

Figure 15: Large stones on riverbed

Figure 16: Protection of shore in Paramaribo using blocks of leftover houses

5. Gabion Wall

A gabion wall (figure 17) can be built to stabilize the shore and also dissipate a part of the energy from flow velocities and waves. This option visually matches the shoreline and does not interfere much with the daily life of the residents of the town. However, research must be conducted on the shore's stability and if extra foundation piles are needed. Because of the weight of the wall, there is a good chance the construction may sink into the soil. Also, it is not sure if this solution will be accepted by the community and it may turn out to be very pricey. On the other hand, it is a solution with a long lifespan, almost 50 years (Gabion Baskets | Phi Group, 2023), and requires very little maintenance.

Figure 17: Gabion wall

6. Vegetation on a hill

One of the most effective and sustainable ways to stabilize the coast is by planting vegetation (figure 18). The roots will make sure that the soil stays into place, absorb water from the ground and will also protect the shore against waves. Along the shore, it is visible that the parts with more vegetation have eroded less than the shores without. However, it takes time to establish a good root system and a firm and stable implantation in the ground.

Figure 18: Mangrove plant to stabilize ground

7. Cocos protection

Cocos fiber rolls are utilized for shoreline stabilization and to prevent the shore against erosion and scour (figure 19). It is a natural material that allows for plants to grow and is semi-permeable for water drainage. It has a lifespan of 2-5 years and after it's lifespan the coconut protection will start to biodegrade.(Coconut Fibre Rolls (z.d.)) (Coconut Fiber Erosion Control | Budget friendly prices. (z.d.)) Cocos rolls are not available in Surinam, so they have to be imported from other countries (Nurmohamed, 2024).

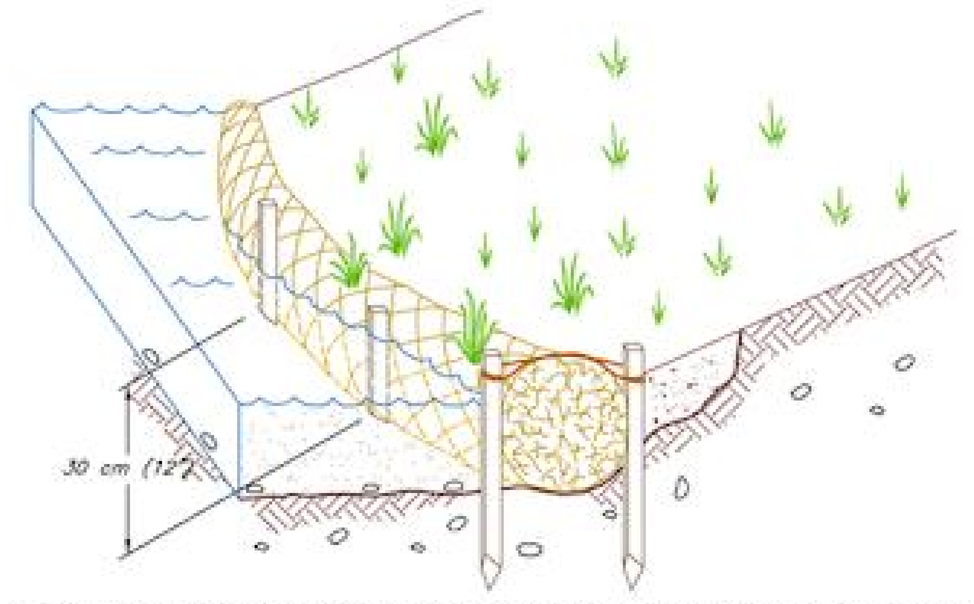


Figure 19: Design of coconut fibre rolls parallel to the streambank of the shore

8. Wooden sheet pile wall protection as seawall

Instead of the currently built wooden sheet pile wall placed 2 meters from the shore, a smaller sheet pile wall can be built right next to the shore (figure 20) It will help stabilize the shore and make sure the wall is protected against erosion. This option could be combined with other options, like stones or groynes. Because of the materials and its varying contact with water and oxygen, it may decay fast.

Figure 20: Seawall made from timber

5.3 Multi-Criteria Analysis (MCA)

To be able to conduct a thorough assessment of possible interventions for the protection of the river bank, 8 selection criteria are formulated. The criteria are mentioned in order of significance.

Selection criteria for solutions

1. Protection of shore against high flow velocities

The most important role of the shore protection is the protection against the high flow velocities. The shore can be protected in two ways; slowing down the flow velocity near the shore or building a protective structure to physically separate the shore from the water.

2. Maintainability

One factor that is necessary for success is the maintainability of the structure. In the village, there is not much material or expertise available for the maintainability of structures. The people of Ricanau Mofo prioritize other things above the maintenance of the current construction. That is why it is necessary that the intervention requires minimal maintenance and, if it requires maintenance, it should not be difficult.

3. Life expectancy

Another important aspect of a structure, next to fulfilling its main purpose, is the life expectancy of the structure. When the need for frequent replacements is reduced, the functionality of the structure is sustained and materials are used more sustainably.

4. Impact on daily life

The shore is an important aspect in the daily life of the villagers. For the intervention to be accepted by the community, there should be no negative impact on the daily life of the villagers. This includes washing, bathing and navigating boats along the shore.

5. Stabilization of the shore

By stabilizing the shore, the shore is better resistant against sudden forces appearing on the shore. These forces can appear due to a sudden large wave, extreme weather environments that cause water flows with high flow velocities or impact by boats. A stable shore is more likely to stay intact over time and is less prone to erosion. The shore can be stabilized by placing a structure that will keep the soil in place, preventing the shore against erosion and sedimentation processes.

6. Aesthetics

The villagers who live close to the water assign a lot of value to the aesthetics of the shore. The shoreline is viewed as one of the prettiest places of Ricanaumofo and is used for relaxation and recreation. When the villagers do not think it is pretty enough, they will remove it. Therefore aesthetics play a crucial role.

7. Holding sediment after rainfall

When rainfall occurs, large water streams may occur that carry lots of soil particles from the city center. It is not the main focus of the shore protection, but catching sediment and keeping it from entering the river is a nice benefit to the structure because it can serve as an extra protection for the shore.

8. Sustainability of materials

By prioritizing sustainable materials practices, you can support both local communities and global efforts towards a greener, more sustainable planet.

For the multi-criteria analysis, each selection criterion of the section above has been assigned a weight score (table 2). These scores vary from 0 (not important at all) to 10 (very important). Because the main function of the bed protection structure is the protection against flow velocities, it is given a 10 as score. Then, the other criteria have been scored in order of importance. Overall, the structure must be maintainable, have a long life expectancy and not have an impact on daily life. Store stabilization, aesthetics, holding sediment and sustainability must also be considered, but are less important than the first 4 criteria.

Table 2: Selection criteria and their weight scores

protection against flow velocities	10
maintainability	8
life expectancy	7
(negative) impact on daily life	7
stabilization of the soil / shore	5
aesthetics	4
holding sediment	3
sustainability of materials	2

Then, each intervention has been assigned a score for each selection criterion varying from 0 (does not meet the desired criteria) to 2 (meets desired criteria very well). In [appendix X pdf staat in final draft], a detailed breakdown and explanation of the weight scores assigned to the criteria are given and explained.

In the MCA, the score of the intervention per criterion is multiplied by the score of the importance of the criterion. The final score is the total score of the intervention on a scale of 0 to 2 (table 3).

Table 3: Interventions and their final score

Quay wall	1,77
Wooden sheet pile wall	1,27
Groynes	1,15
Large stones	1,16
Gabion wall	1,31
Vegetation	1,45
Cocos protection	1,11
Wooden seawall against shore	1,33

The quay wall and vegetation come forward as the best options, followed by the wooden sheet pile wall against the shore or 2 meters from the shore and the gabion wall.

Cost & Benefit analysis

By systematically assessing both the costs and benefits associated with the different interventions, informed choices can be made that optimize decision-making process.

Quay wall - high costs, high benefits
The construction of a quay wall is expensive, but it results in an extremely sturdy structure with a long lifespan. For shoreline protection, this is the ideal choice as it effectively protects the coastline from erosion and structural damage.

In conclusion, a quay wall is the best solution for the protection of the shore. It requires very little maintenance, has a long lifespan and protects the shore entirely against erosion. An inevitable downside is that it is very expensive.

Vegetation - low costs, but takes time to grow
Establishing vegetation as shoreline protection is relatively inexpensive compared to hard structures such as a quay wall. Benefits are that vegetation in the waterline can break waves and protect the coast from erosion. Certain trees are also highly valued by residents and are easy to maintain when they are fully grown. However, building up vegetation as effective protection requires time and care. It requires healthy soil, good plant and tree growth, and it takes time for them to develop a sturdy root system that protects the soil.

In conclusion, when vegetation is fully grown it serves as a very effective protection of the shore against erosion. However, plants and trees require a lot of time and care to grow and develop a sturdy root system.

Wooden sheet pile wall - low costs, low lifespan
The construction of a wooden sheet pile wall is generally cost-effective due to the use of inexpensive materials and the possibility of self-construction. It effectively serves its function of shoreline protection and can be easily installed by the residents.

A major drawback is its limited lifespan of only 5 years, during which it may require regular maintenance or replacement by residents. This raises concerns about the willingness and capacity of residents to perform this maintenance. Therefore, the use of a wooden sheet pile wall should be combined with a long-term plan, such as planting vegetation, to ensure sustainable shoreline protection.

In the MCA, two types of wooden sheet pile walls are considered. The first one is placed a few meters from the shore and was built by a previous group in november. Behind this wall, space is created to provide a safe place for vegetation to grow. The second type of wooden sheet pile wall is placed directly next to the shore. This would provide a sturdy protection of the shore that stabilizes the shoreline. The downside to this is that it does not give space for vegetation to grow as a long-term solution.

In conclusion, both solutions are a good choice for shore protection, depending on which function you want the wall to fulfill.

Gabion wall - high costs, long lifespan
A gabion wall is generally more expensive than other available options for shoreline protection. Gabion walls provide a viable solution for coastal protection to stabilize the shore, although more research is needed on their stability. Gabion walls also have a long lifespan and are therefore very attractive. However, compared to wooden structures, gabion walls are likely not the optimal choice given the higher costs and the need for further stability research.

In conclusion, gabion walls are a less attractive option than timber alternatives.

Groynes - high costs, long lifespan
Groynes do not have a good score in the MCA because of their impact on society, possible obstruction of the view and inability to stabilize the shore. However, they are a very attractive option just looking at their ability to slow down flow velocities. In the report of Van Dongen et al (2023), they are proposed as a viable alternative to their sheet pile wall. This is an option certainly worth considering for governments. Placing groynes requires machinery to place piles into the river bottom, but it requires little maintenance over time. Due to the installation using heavy machinery, placing groynes becomes expensive.

Large stones - low costs, little influence
Leftover stones could be used to prevent the rivershore against high flow velocities. However, its influence on the shore is too small compared to other alternatives.

Cocos protection - high costs, low benefits
Cocos protection has a lot of good qualities. It is sustainable, stabilizes the shore and is also semi-permeable for water flows. However, it has a very short lifespan and is not available in Surinam; it has to be imported from abroad. Because of the transportation, coconut rolls are an expensive and climate unfriendly option compared to other options.

Location of feasible solutions

The location for both the quay wall and extension of the sheet pile wall would be placed on the location shown on the map (figure 21). These parts of the shore are chosen because they suffer the most from river bank erosion. Villagers confirmed that over 30 years +/- 8 meters of land disappeared due to erosion and water level rise on these locations. On the right side of the marked shore, the erosion is negligible compared to the location shown on the map. Villagers mentioned that this location hasn't changed a lot during the last 30 years. Reasons for the significant lack of erosion on the right side of the shore is the lack of ship generated waves and the presence of large trees with firm roots. On the left side of the marked shore, the shore is covered with natural shore protection and the slope is more stable and steep.

Figure 21: Location of sheet pile wall

First, we will investigate extending the sheet pile wall, followed by an examination of the quay wall.

5.4 Solution A: Sheet pile wall

To protect the shore of Ricanau Mofo against erosion due to floods, heavy rainfall and ship-generated waves, an idea was conceived to protect the shore using mangrove trees. The sheet pile wall was initially constructed as a protective measure for the mangroves being planted. Its primary purpose was to shield the mangroves from ship waves and to trap sediment, allowing the mangroves to grow to a full-sized mangrove tree. In October 2023, this sheet pile wall was built and mangroves were planted (Dongen et al., 2023).

Evaluation

When evaluating the wall 4 months later, a lot has changed. The mangrove trees are dead and a lot of sediment has accumulated behind the wall. When speaking to the community of Ricanau Mofo, everyone had mostly positive feedback about the wall. It protects the village from waste washing ashore from the water, it is very effective at breaking the waves from the ships and it holds sediment. However, they were not positive about the chosen vegetation. Mangrove trees were considered ugly and too fast growing. The families who live next to the wall were afraid they would not be able to reach the shore anymore to do their washing chores and reach their boats. Together with the feedback from the community and our own observations, we have made an evaluation of the sheet pile wall (table 4).

Table 4: Advantages and disadvantages of the sheet pile wall

Advantages	Disadvantages
Holds sediment (clay) coming from the village	Due to rainfall erosion, holes are created under the sheet pile wall
Creates a new soil for vegetation growth to protect and stabilize the shore	Planted vegetation (mangroves) are not accepted by the people living next to the shore
Protects the shore against wave erosions caused by cargo ships	The wall is not long enough and could be extended to protect more parts of the shore, however villagers do not take this initiative.
Acts as a barrier to prevent plastic waste entering the shore	Some sewage pipes end up just behind the river bank, which causes contaminated soil
Slows down the water speed during high and low tide and thereby decrease erosion	Beneath the clay layer there is a lot of trash in the soil, which obstructs the growth of vegetation
	Low water flow between high tide and low tide causes a swamp
	The sheet pile is not closed at the sides and thereby not functioning as waste prevention
	There are holes in the wall through which both water and sediment seep through
	Pools of water are created which become a swamp and a breeding nest for mosquitoes

Advantages

The sheet pile wall effectively holds soil and clay, preventing wave erosion and providing stability to the riverbank, see figure 22.

The sediment accumulated behind the wall is fertile at some spots and podosiri trees started to grow, see figure 23.

The wall acts as a barrier, preventing plastic waste from entering the shore from the river and concentrating the waste behind the wall for easier disposal, see figure 24.

People in the village see a lot of differences after 3 months. Therefore, the sheet pile wall is considered to be successful. However, we unfortunately also discovered some disadvantages.

Figure 22: Sheet pile wall

Figure 23: Podosirie behind sheet pile wall

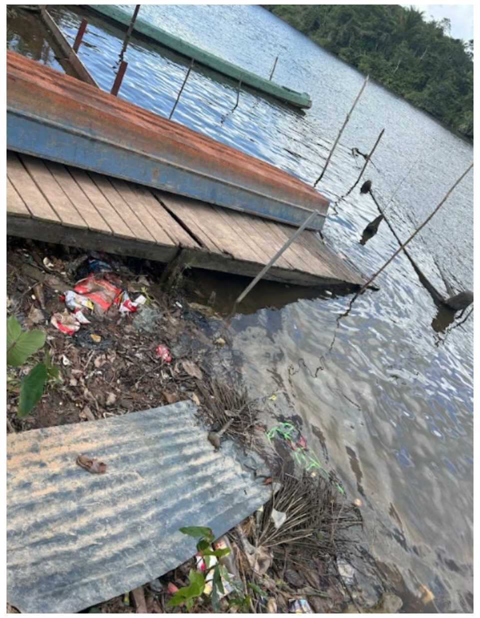


Figure 24: Waste behind sheet pile wall

Disadvantages

Due to erosion, holes occur at the bottom of the wall, see figure 25. When there is low tide and the water recedes, a current is created that causes more erosion i.e. a scour. At the moment, one of the residents plugs the holes at the bottom of the wall with pieces of clothing she finds in the river.

Figure 25: Holes at the bottom of the sheet pile wall

The mangroves, that were supposed to grow behind the sheet pile wall, will obstruct the view of the river and residents fear their roots may encroach upon their homes. Additionally, the dense mangrove growth limits access to the river for washing purposes. Therefore, people in the village prevented the mangrove growing by spraying poison. Furthermore, the wall is not long enough. The residents would like to see more parts of the village protected against erosion by extending the sheet pile wall. Also, three sewage pipes extend from the side of the embankment, discharging waste that contaminates the soil between the embankment and the retaining wall. This is creating contaminated soil between the river bank and the sheet pile wall. It is of great importance to improve the quality of the soil to stimulate the growing of vegetation. Beneath the clay surface, there is also a lot of trash in the soil. The huge amount of trash will obstruct the growth of new vegetation.

A combination between the contaminated soil and the low water flow between high tide and low tide causes a swamp next to the sheet pile wall. This swamp causes nasty smells and is unhealthy for the people washing themselves in the river next to it. Besides this it is a breeding nest for mosquitos which isn't preferred.

What must be considered is that the area by the water serves as a crucial function in both recreation and boat docking. It holds a significant value for the community as a place of relaxation due to the green surroundings and the abundance of fresh air. Additionally, it serves practical purposes such as bathing, laundry and dishwashing. The residents also attach great importance to the aesthetics of the vegetation in this area. The area must "be able to breathe", which means that the air that comes from the river must not be blocked by large bushes or plant leaves. Residents attach great importance to the aesthetics of the vegetation in this area, as they are more likely to maintain it if they find it visually appealing.

Short term improvements

In this paragraph, multiple steps are described to improve the functionality of the current sheet pile wall. As the main function of this sheet pile wall is to create an extra soil layer where vegetation can grow and in that way protect the current shore, the improvements are focused on the soil quality.

Sewer pipes (figure 26)

Figure 26: Sewer pipes

Potential solutions

By creating a new barrier along the shore, a new piece of land arose behind the sheet pile wall. After a few months it was clear that the sheet pile wall retained a lot of sediment, which is very positive. However, the soil was contaminated. When the wall was constructed, the residents, who own the sewer pipe, promised to extend their sewer pipe beyond the wall. Unfortunately, four months later, this extension has not been completed because people do not feel the urge to do this, resulting in the accumulation of waste water behind the wall. Although residents claim they are still intending to extend the pipe, we anticipate this may not occur within the near future. Consequently, there is a need for us to independently expand the pipe to prevent contamination and to improve the soil quality between the wall and the shore. By improving the soil quality, vegetation growth is no longer hindered. For the extension of the sewer pipe, three solutions are considered.

Solution 1: Extension through the sheet pile wall

In figure 27 the extension option through the sheet pile wall is shown. When extending the sewer pipe through the wall, under normal conditions and if the slope is not overly steep, the end of the sewer pipe remains above the water level. This helps venting the pipe. However, a disadvantage of this approach is the necessity to create a hole in the sheet pile wall, which can compromise the structural integrity and stability of the construction.

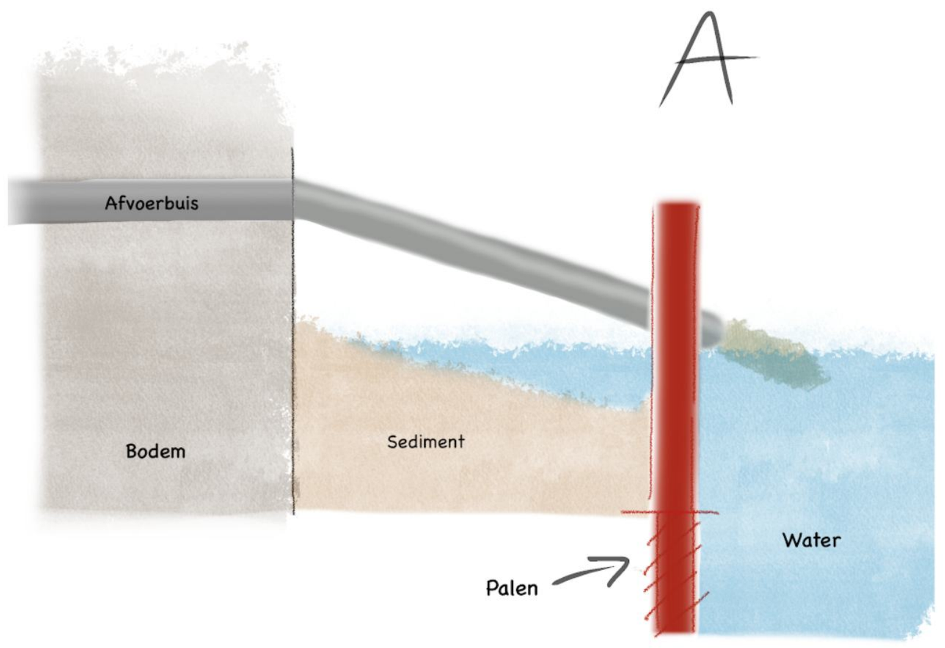


Figure 27: Pipe extension solution A

Solution 2: Extension beneath the sheet pile wall

In figure 28 the extension of the pipe beneath the sheet pile wall is shown. One of the advantages of this option is that the sewer pipe is lower and that it will be covered by soil or vegetation sooner. A disadvantage is the need for a longer pipe, because it will be filled with sediment if you place the pipe in the already existing soil. Also, to prevent scour, an additional measure must be implemented underneath the existing wall. When extending the wall, a decision needs to be made whether the pipe will run beneath the existing construction planks or a new one. Regardless of the chosen solution, there will be a period during which the pipe remains submerged underwater. Consequently, this may trap the unpleasant odors of sewage water, resulting in an odor in the affected house. To mitigate this issue, a vent pipe can be installed. The advantage of this approach is that it preserves the structural integrity of the wall.

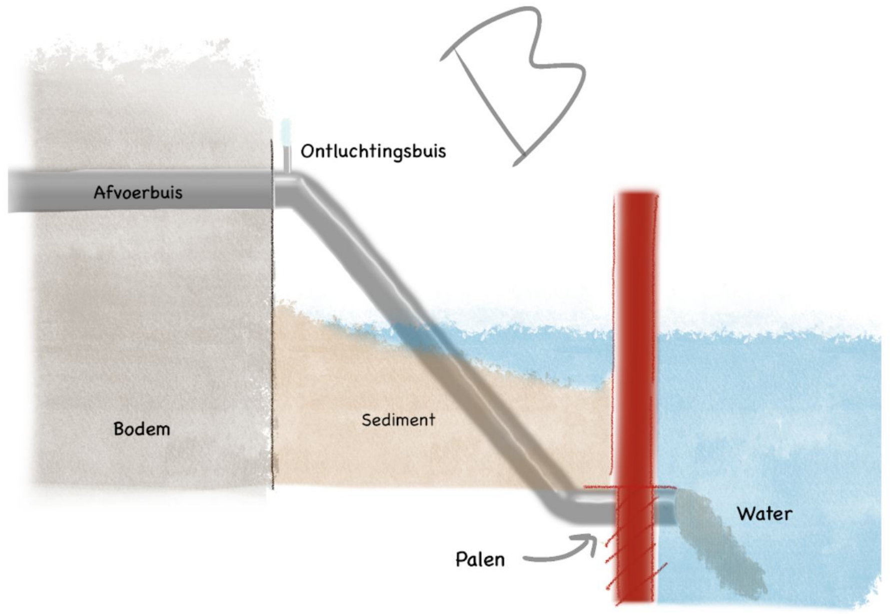


Figure 28: Pipe extension solution B

Solution 3: Rerouting the sewage pipe

Rerouting the sewage pipe (figure 29) could be a prevention of the contaminated soil. Rerouting includes adding an extra bypass alongside the shore. An advantage of this option is that you keep the sheet pile wall intact and don't need to burrow beneath the wall. However, the length that needs to be covered to reroute the sewage pipe is too much. The height difference is not enough to create a steep enough slope for the sewage to flow out of the pipe.

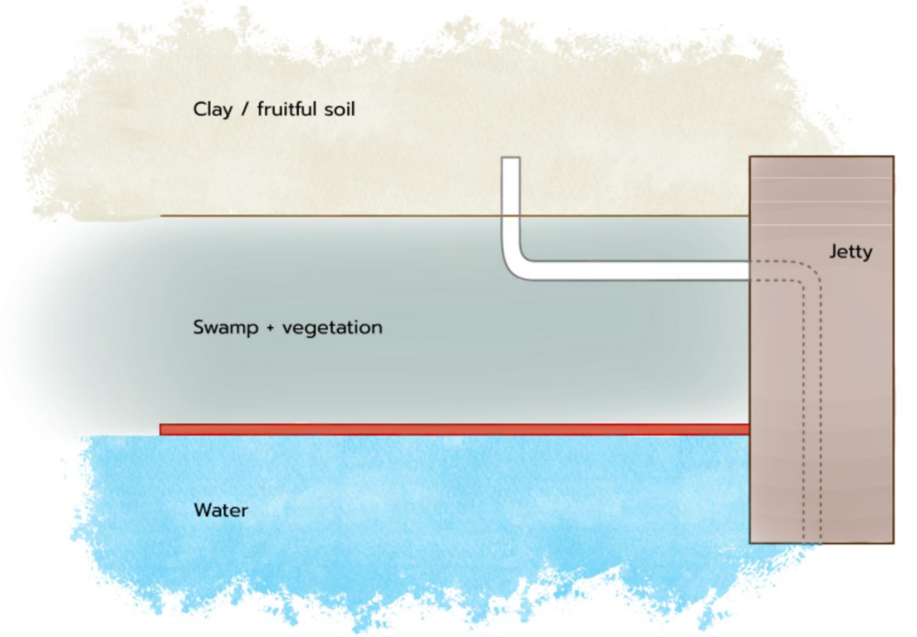


Figure 29: Pipe extension solution C

Decision making process

Because there is a chance that the pipe can silt up when it lies on the ground in option B and a lot of material is necessary to reroute the pipe in option C, option A was chosen to be the best solution.

Stakeholder discussion

After weighing the options, we leaned towards option A. We believed it was the best fit since it wouldn't damage the sheet pile wall much and the slope would maintain water flow. However, villagers preferred option B due to concerns about water slope during high tide, fearing water might enter their homes. This led to a design dilemma. Before proceeding, we had to convince villagers that our choice wouldn't cause more problems. It was challenging, given their familiarity with the area. Thankfully, we reached a compromise: extending the larger pipe as per their preference and the two smaller pipes our way. This allowed villagers to witness both options' effects during heavy rains. Clogging was addressed by extending the larger pipe further into the river, not an issue for the smaller pipes. Once villagers approved the compromise, we began constructing the pipe extensions.

Results

The final solution (figure 30) to prevent the soil from being contaminated is to extend the sewage pipes. Together with the residents of Ricanau Mofo we have extended the three sewage pipes and decided to combine options 1 and 2.

Figure 30: Results pipe extension

Vegetation

Figure 31: Vegetation in Ricanau Mofo

Current problem

After the construction of the sheet pile wall, a lot of weeds started to grow. This is a positive effect of the construction, because it means that vegetation can grow in the soil (figure 31). However, this type of vegetation is not creating a lot of roots and therefore will not strengthen the soil. Unfortunately, the planted mangroves were not accepted by the local people as mangroves grow too fast and may hinder the daily activities of the people. To figure out which type of vegetation would fit this location best, we investigated which types of vegetation will grow and flourish between the sheet pile wall and the shore. To have an idea on which types of vegetation are desired by the villagers of Ricanau Mofo, we spoke to some people who live nearby the shore. To be able to make a decision between the various types of vegetation, we had a discussion about the preferences of the local people. With their preferences in mind, we considered the following options.

Potential solutions

There are different types of vegetation which are possible to plant. Different options will be analyzed.

Parwa (black mangrove)

This is the black mangrove tree (figure 32). The leaves are opposite and are often covered with salt crystals. The seeds are small, 2-3 cm in diameter and resemble flattened beans. The root system consists of long underground cable roots from which hundreds of aerial roots sprout above the surface. These aerial roots are dotted with pores that provide oxygen to the root system. In Suriname, Parwa forests are very important for stabilizing a dynamic coast. If mud banks silt up high enough, parwa can settle there. The roots and trunks will break the waves to protect the shore. Also the roots increase the roughness of the soil, reducing the current velocity and allowing more sediment to be retained. Black mangrove growth is thus an important mechanism of coastal conservation and accretion. Although the plant tolerates salt, experiments show that it germinates and grows best in freshwater. In areas where mangroves have been cut down, rapid erosion of the coastline often occurs.

Figure 32: Black mangrove

Low land Podosiri tree (Pinapalm)

This Podosiri tree (figure 33)is also called the Pinapalm. It grows 3 - 20 meters tall and has black fruits. The trunk of the tree is bare, so fresh air is not blocked. The tree is part of the palm family. Palm trees need well-drained soil, they don't like waterlogging and may experience problems if the soil is too heavy or clayey. However, this lowland Podosiri is an exception. Lowland Podosiri grows in the swamp forest, a humid climate, where clay soil causes no problems. The soil is very saturated with water, which is good for this tree. Acidic to neutral PH, PH value of 6-7 is ideal. This tree grows a lot of roots which will stabilize the soil at the shore. Podosiri grows next to Ricanau Mofo and the villagers eat it a lot. Therefore they have a very strong preference for this.

Mosiri tree (Mauritiuspalm)

The Mauritius palm (figure 34) can grow up to 35 meters tall. The trunk grows to a thickness of 60 cm and is ring-shaped segmented by the nodes of fallen leaves. The tree produces clusters of stone fruits. Palm oil can also be made from the oil from the trunk. Mauritius palm grows in wet areas. Right along the river is a suitable location for this palm. The large leaves will create a lot of shade and this tree will also block fresh air a little more than the Podosiri tree.

Figure 33: Podosiri

Figure 34: Mosiri

Kumbu tree (Koemboepalm)

This Kumbu tree can grow up to 20 meters tall (figure 35). The trunk grows up to 25 cm thick, with aerial roots at the base. The leaves are 10-17 cm wide and grow up to 6 meters long. This tree is very similar to the Podosiri tree. The tree grows mostly in dryland forest. Even though this tree tolerates the sun, it grows in the lower layers of the rainforest.

Bugrumaka tree

This solitary palm grows up to 12 meters tall (figure 36). However, the trunk only grows to usually up to 2 m high, completely covered with spiny leaf remnants. The petiole consists of rings of 1-25 cm long, black, flat spines. The leaves are 10-14 cm long. The tree grows well in wet soil. The tree also has beautiful flowers and drupes. However, it does develop many short spines on the trunk. Not very suitable for planting in locations with lots of activities and children playing.

Figure 35: Kumbu tree

Figure 36: Bugrumaka tree

Decision making process

Due to the existence of multiple possible options with minor differences between them, a Multi-Criteria Analysis has been performed to gain insight into the optimal choice.

Multi criteria analysis

The multi criteria analysis is based on different criteria. This are the possibility of growth in water. This is important because due to the tides, the vegetation will be underwater half of the time. It is also important that the vegetation has roots which can hold the sediment. Besides this it is crucial that the people accept the type of vegetation, otherwise they will remove it and that when they want to continue the wall, the vegetation is available in the area.

Weights are given to the criteria and an analysis is made (table 5). The Podosiri palm is according to this analysis the best option.

Table 5: Vegetation Multi-criteria analysis

Vegetation	Grows in water	Grows roots	Safety of tree trunk	Availability in area	Local acceptance	Total
Weights	8	6	4	6	8	
Parwa	2	2	2	1	-2	26
Podosiri	1	1	2	2	2	50
Mosiri	2	1	2	1	1	44
Kumbu	-1	2	2	1	1	26
Bugrumaka	2	1	-2	0	1	22

Stakeholder discussion

Together with people in Ricanau Mofo we discussed the availability of certain vegetation in the area. This rural area is known for growing Podosiri. Therefore, people were immediately convinced of planting small Podosiri trees. The Kumbu tree is very similar to the Podosiri tree, but less available in this area, because this type of tree prefers growing in dryer areas. Also there is a lot of Parwa growing alongside the Cottica river. Because these types of mangroves grow a lot of roots in a short period, it would fit perfectly to stabilize the soil next to Ricanau Mofo. Unfortunately, the Parwa tree didn't gain much favor among the locals due to its branches causing inconveniences for activities like washing and laundry. It required a lot of maintenance to keep these mangroves in shape. Locals did not prefer this. The Mosiri was creating too much shadow and blocking fresh air entering the village and was thus not preferred by the locals. Finally, the Bugrumaka tree would fit well in this area, but this tree grows spines. Because the shore is also used by children as a playground, the Bugrumaka tree was not considered a good option.

Results

Taking into account the opinions of the local people and the availability in the area, we decided to plant new Podosiri trees (figure 37). These trees grow in the area, allowing us to harvest them nearby and plant them along the shoreline. Where the Podosiri trees are replanted, the top soil is moist (muddy) and contaminated due plastic waste. The question is if the Podosiri trees will sustain these kinds of environments, compared to the drier and less contaminated soil it usually grows in.

Figure 37: Results planting podosiri

Discussion

Despite the implementation of short-term solutions, there are still unanticipated risks that remain unresolved. The extension of the sewer pipe didn't go according to our plan. Together with three residents of Ricanaumofo, each with different opinions, we tried to construct the sewage pipe extension. This resulted in a difficult collaboration between us and the local people. As a result, the first sewer pipe has not been installed in the way we wanted to. To make sure the sewer pipe would not stick into the mud, the sewer pipe has been extended along the riverbed. Something that should be considered is that sediment can accumulate in the sewer pipe. Also, a large majority of the time, the end of the pipe is submerged underwater. This can cause scents of the septic tank which cannot escape through the pipe and cause a dirty smell in people's houses. Both the accumulation of sediment in the pipe and unclean scents are consequences we will discover over time.

Something else to mention is that the vegetation we have planted in the soil may not take root into the soil. There are multiple reasons plants don't thrive in the soil they're planted in. The most common reason is a planting shock: the plants have been removed from their previous environment and their root system is destroyed and planted in a different soil with different circumstances. Another common reason is the chance of root rot in clay soils (Spengler, 2022). When the roots of the plant are too wet, root rot may occur and the plant will die. The ground we subtracted the plants from was a lot dryer than the new ground it is planted in. If the plants die of shock, it is an idea to be more careful while planting them. If the reason is root rot, a reason has to be found to drain the soil or they have to be planted at a different location or find better vegetation alternatives for this specific type of soil.

Currently, there is a lot of waste located near the shore. Placing nets will prevent waste flowing from the Cottica river to the shore, but will not prevent the accumulation of waste caused by the people in the village. Unfortunately the latter is the main reason for this waste problem.Therefore it is important to tackle the problem at its origin and change the mindset of people. Providing enough bins next to the shore can lower the threshold of throwing away your trash in the bin.

Long term development

Future plans are also described to develop a more improved sheet pile wall and to tackle the current problems, described in the evaluation paragraph.

The current sheet pile wall has been well received by the residents. As mentioned in paragraph 1, the sheet pile wall resulted in multiple advantages but also some disadvantages. The disadvantages that have yet to be resolved are the swamp preventing and sediment retention. In this paragraph, new design possibilities are described which aren't implemented yet. First there will be looked into the swamp preventing, secondly there will be looked into the sediment retention.

Swamp preventing

Preventing the shore from becoming a swamp is of great importance. Therefore, water-flow is needed every few hours to prevent standing water in the form of puddles. There are a few options to create water flows through the sheet pile wall, while still retaining the sediment. Non feasible solutions, like a small water pump, are not taken into account as there is no budget available and the investment is not worth it.

1. Creating holes in the sheet pile wall on different places

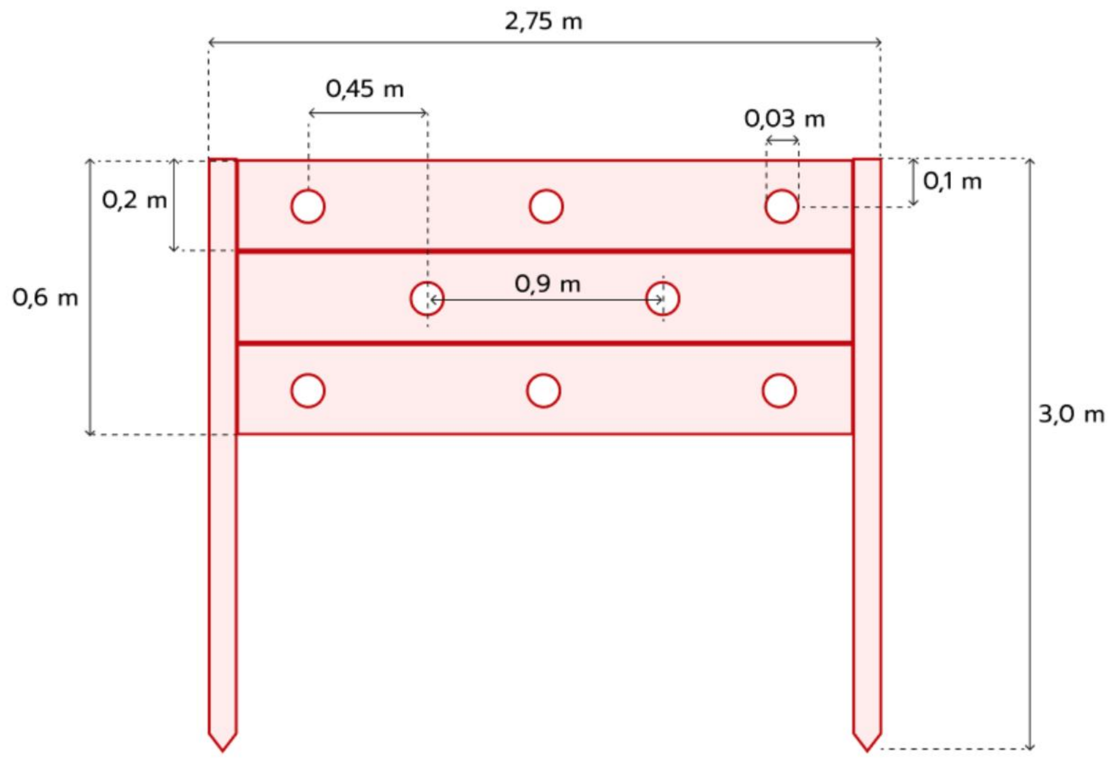


Figure 38: Holes in sheet pile wall

In the sketch in figure 38, holes are added to the sheet pile wall. Sediment is flowing through these holes if it starts raining. Therefore it is important to close the holes when a certain sediment level is reached. Otherwise, sediment will only retain until a certain level, i.e. the level of the drilled holes. By closing the holes, a normal wooden sheet pile wall is created., which will retain the sediment. The goal of creating holes is to stimulate water flows between high and low tide and thereby prevent negative effects of the sheet pile wall like standing water, creating a swamp and creating a breeding ground for mosquitoes. For this solution, it is important to maintain the holes and close them on time. Without this effort, it would be useless to create these holes, because seepage will rise during heavy rainfalls.

2. Creating gaps between the boards including filters

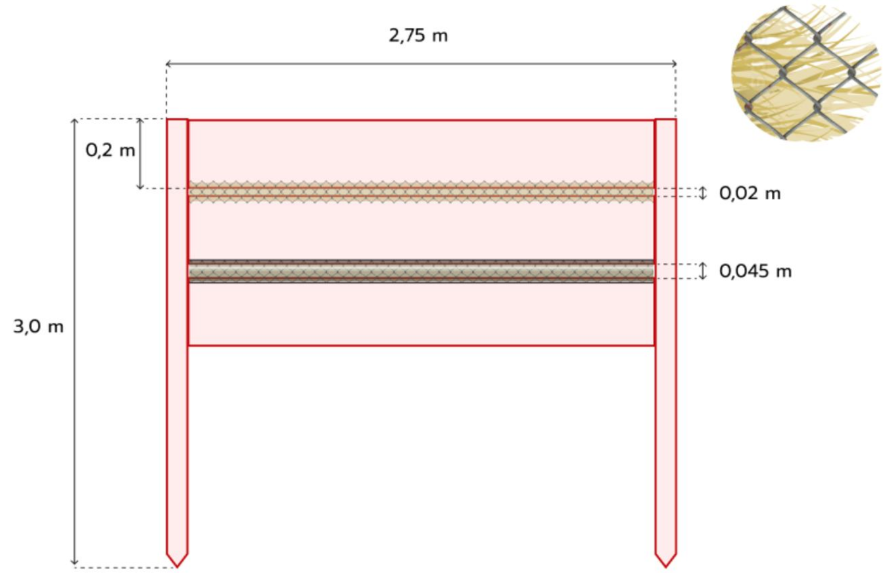


Figure 39: Gaps in sheet pile wall

In figure 39 gaps are created between the boards. There are a few options to create a filter between those gaps to retain sediment but keep the water flowing. The first option is to place a filter, created with dried grass, woven through a mesh filter. This solution can be carried out in two options. The first option is to create a flat filter and the second option is to place tubes, filled with dried grass, between the gaps. The dried grass can be used from local areas. When the filters are fully saturated with clay, the filters can be replaced by new ones. On the other hand, it may be no problem if the filter is saturated, because that means that the sediment level is rising.

For this solution, the space between the boards is an important parameter. If the gaps are too big, sediment will not be retained. If the gaps are too small, the water will not flow through the gaps. The most recent design of this solution uses gaps of 1-2 cm to place a flat filter between the boards and 4-5 cm to put the grass filled tube filters between the boards.

Sediment retention

The main function of the sheet pile wall is sediment retention. At times of heavy rainfall, a lot of sediment flows from the village into the river. This is already well retained by the current sheet pile wall, but in some places you can see a lot of sediment flowing along (figure 40), underneath (right figure) or through (left figure) the sheet pile wall. It is not possible to retain all the sediment using this wooden construction, but some improvements could stimulate this retention.

Figure 40: Sediment seepage through sheet pile wall

To prevent the sediment of flowing underneath or along the sheet pile wall, the following improvements are considered.

1. Placing an extra wooden plank underneath the sheet pile wall (seepage)

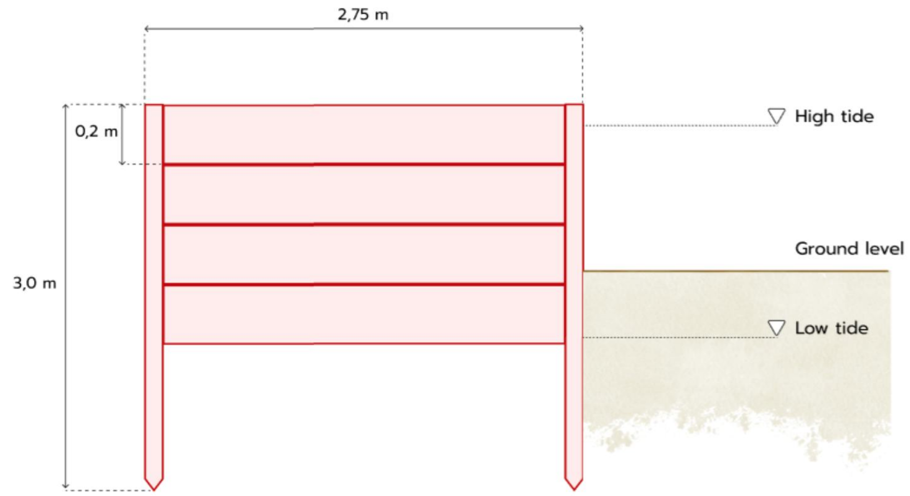


Figure 41: Wooden plank underneath sheet pile wall

In figure 41, placing an extra wooden plank underneath the sheet pile wall will prevent the water from flowing beneath the wall. However, during the rainy season the water pressure will be very high. At this moment, the sheet pile hasn't experienced these huge amounts of water flows yet. The question is if one extra plank will withstand this water pressure or that it creates too much pressure on the wall. A risk could be that the complete wall will collapse due to the high pressure.

2. Preventing seepage by placing an extra filter underneath the current sheet pile wall.

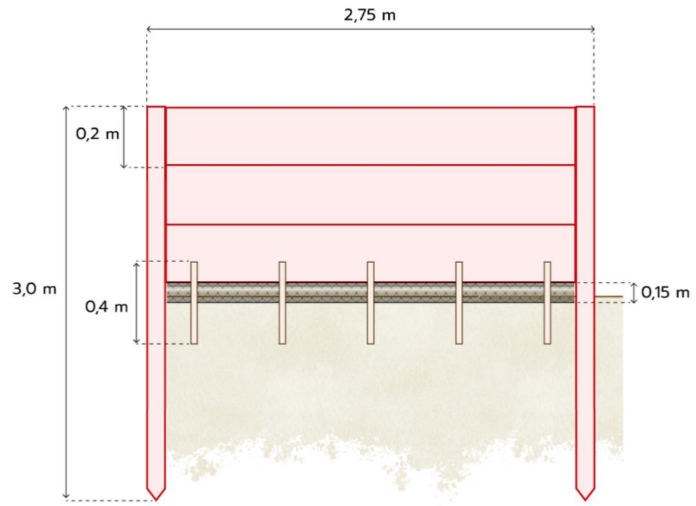


Figure 42: Wooden plank underneath sheet pile wall

Instead of placing a wooden plank, there could be placed filters underneath the sheet pile wall (figure 42). There are different types of filters which are possible to prevent seepage of sediment through the wall. This could be a geotextile filter, using stones, or placing a natural filter with dried grass or other vegetation.

Geotextile is a textile type which is permeable to water but does not allow sediment to pass through. However, the permeability is very small so the water will pass through it very slowly. In addition, it is not a sustainable solution. Therefore the natural materials, which are available in the area, are also considered.

Stones can be placed to strengthen the soil around the sheet pile wall. Depending on the size of the stones, they can hold sediment, but unfortunately clay is too small to be retained by placing stones.

Dried grass could be a possibility to work as a filter (figure 43). This is handmade by cutting long grass, drying it in the sun and putting it in a net. The advantage of this technique is that water is still able to flow through the wall, but the sediment will still be retained by the dried grass. A huge advantage of this option is that it is free, made of natural material and the residents of Ricanaumofo can make it themselves. One downside of this option is the use of iron mesh. Due to its contact with water and air, it will rust. Therefore, maintenance is necessary.

Figure 43: Dried grass as a filter

3. Placing dividers between the shore and the sheet pile wall to create small boxes and prevent sediment from flowing away alongside the wall.

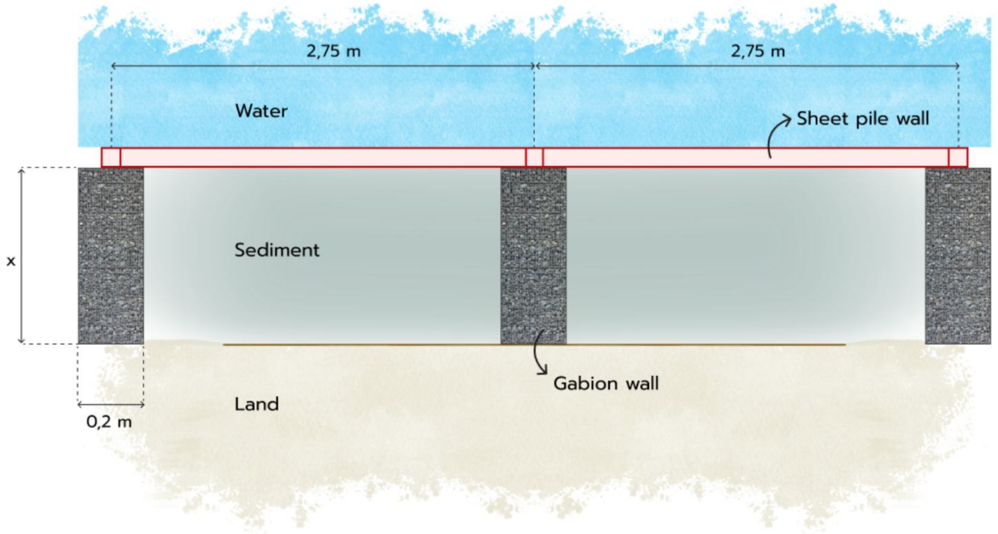


Figure 44: Gabion wall construction as seen from above

With this solution, smaller boxes of sediment are created behind the wall using (figure 44) . By creating these boxes, the process of sediment retention will be more efficient. These smaller boxes are created using gabion walls: these gabion walls which will still allow for water flow along the wall, but will also help stabilize the ground and retain most of the sediment particles. The chance of swamping increases, because this intervention slows down the water flow when it becomes low tide, so this intervention should be combined with a swamp preventing intervention.

Decision making

Based on the availability of materials, a filter is chosen for the natural one with dried grass. This filter will be built as a tube, filled with the grass. It will be placed underneath the wall and between the planks as shown in figure 30 and 31. This solution will probably prevent the area of becoming a swamp, but still retains the clay sediments.

To speed up the process there is also chosen to place gabion walls perpendicular to the wall. This holds the sediment but can permeate water.

Results

The final solution is based on the earlier mentioned interventions, combining them to create balance between sediment retention and water flow (figure 45). This balance is important to prevent swampy areas, while retaining the sediment. The filters between the wooden planks will improve the retention of clay, but also allow water flows. The Gabion walls have the same effect, but then horizontally behind the sheet pile wall. Together, these interventions will tackle the problems of the existing sheet pile wall and improve the soil quality behind the wall to stimulate vegetation growth.

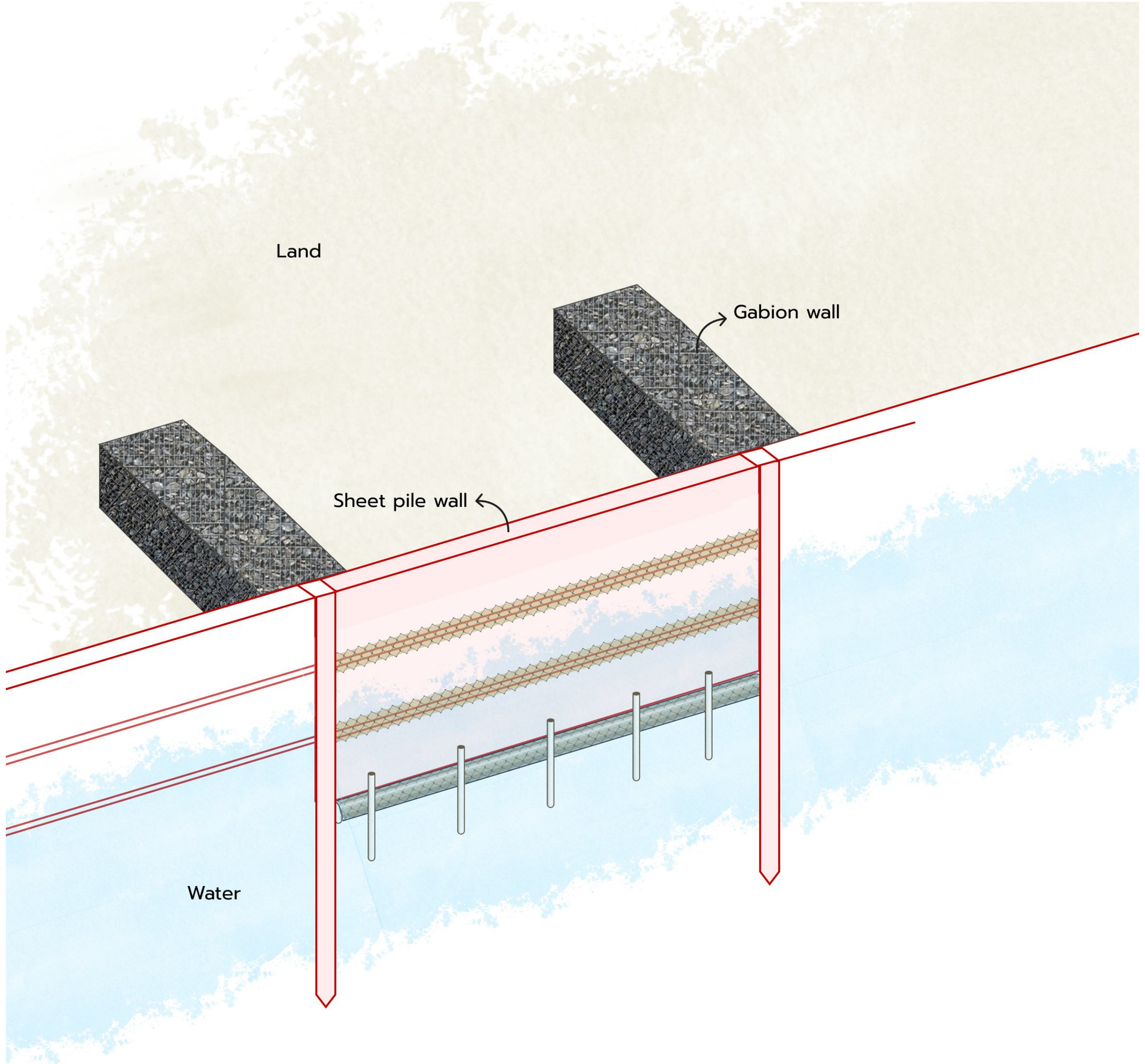


Figure 45: Final solution sheet pile wall

The wall will have an impact on the environmental system in Ricanau Mofo. This will be highlighted in the next paragraph.

Impact sheet pile wall

In the ideal situation, the sedimentation behind the wall will increase and the planted vegetation will grow. In a few years the roots of the Podosiri will be big enough to hold the sediment. The wall isn't necessary anymore and the vegetation is a natural protection for the embankment. What will happen in detail with the wall, vegetation and sedimentation, and how that will influence the system in which the wall is placed, is described in this paragraph.

Lifespan of sheet pile wall

The sheet pile wall consists of so-called Locsi wood and has a finite life. The wood is sensitive to moisture and in this situation the wood is submerged in water half the time, due to the tides. The wood can expand and contract, which can cause deformation. If wood remains damp for long periods, it increases the likelihood of fungal attack (DBNL, 54). Based on this, the lifetime of the wood is assumed to be 5 years. The vegetation should grow enough roots within these 5 years to stabilize itself.

Sedimentation

In four months of dry time, the sediment layer has risen an average of 5 centimeters. During the rainy period there will be more rainfall which will cause the sediment to become looser, but there will also be more sediment influx from the village because of the eroding soil. Because a functioning dam wall with good filters should stop all the sediment, it is assumed that sedimentation during the rainy period will be one and a half times greater than during the dry period. Therefore it is assumed that the sedimentation continues. The remaining four months consist of dry and wet periods. It is estimated that the rise of the sediment in five years will be 0.4 meters. The precondition for this is that the sheet piling is sealed along its entire length and there are no spots where the sediment can seep out.

Vegetation growth

According to villagers, the Podosiri trees will grow three meters within five years. They grow in groves of about 5 trunks. At that point the roots should then be large enough to partially hold the soil which has settled behind the sheet pile wall. At this point, the trees take over the function of the wall.

When the sheet pile wall is gone after five years (assuming this as the lifespan) and rain periods become more intense, as a result of climate change, the erosion will increase again.

However, it will be slower due to the grown vegetation than at the time of no sheet pile wall. However, sea level rise and more extreme weather conditions will also negatively affect the rate of erosion.

Even though the sheet pile wall is meant to hold the sediment, some sedimentation will take place. This process should last as long as possible so that the vegetation has time to grow. When the sheet pile wall loses its function, the vegetation must hold the soil itself. The roots of the Podosiri will not be able to hold all the soil, but it will hold more soil after a rainfall than when no vegetation is planted.

Risks

Within every construction project, risk management is of great importance. Even in smaller-scale projects, identifying potential risks and assessing their potential impact on the project is crucial. For each identified risk, mitigation measures are made up to lower the likelihood and/or the impact of the risk. Table 6 outlines the risks and corresponding mitigation measures.

Table 6: Risks of the sheet pile wall and their corresponding mitigation measures

Nr.	Category	Risk Description			
		Cause (must be a fact)	**Risk Event** (something that might happen)	**Consequence** (impact on one or more of the project's objectives)	**Risk/issue Response** (category **and** description)
1	Social	The Cottica is used for transporting goods via Korjaals (small boat)	A Korjaal hits the sheet pile wall and the board of the wall breaks	Holes or gaps in the sheet pile wall that decrease the sediment retention	Place bumpers at critical corners of the sheet pile wall. Also place bumpers at the tip of the ship. Of course, it is still possible to hit the wall, but by creating awareness, people can sail more carefully
2	Social	A lot of people do their daily activities next to the sheet pile wall	The planted vegetation is not accepted by the local people, so they will remove or poison the vegetation	The roots of the plants and/or trees will no longer grow and no longer retain the sediment	Teach people to take good care of the plants and limit growth by pruning them in time
3	Environmental	Mosquitos like to breed in swampy areas	As a result of possible standing water, the arised soil can be seen as breeding location	Musquitoes can become a local plague and spread diseases	Prevent swampy areas by creating water flows behind the sheet pile wall
4	Environmental	Algae like to grow in swampy areas	As a result of possible standing water, algae can grow in the arised soil	Algae compete with other plants for sunlight and nutrients, hindering their growth	Prevent swampy areas by creating water flows behind the sheet pile wall
5	Environmental	The vegetation adjacent to the coast is frequently submerged in water	The vegetation dies due to flooding and oxygen deprivation in the soil	The roots of the plants and/or trees will no longer grow and no longer retain the sediment	Only plant the best suitable vegetation, so that the chance of success is the highest
6	Environmental	The coastal area has highly contaminated soil	The vegetation is unable to thrive in such contaminated conditions and dies	The roots of the plants and/or trees will no longer grow and no longer retain the sediment	Clean the soil before planting new vegetation. Add fresh soil (sand or dirt) at the coastline
7	Technical	The sheet pile is situated within loose soil	Uneven loads on wall caused by changes or inequalities in soil conditions	The sheet pile wall can break due to changed forces on the construction	Add extra sand to stregthen the soil around the piles
8	Technical	A sheet pile wall needs to be maintained to lenghten its lifespan and functionality	People do not see the purpose of maintenance	The lifespan of the sheet pile wall will decrease	Create awareness and help the local people by working out a long term maintenance plan

Discussion

To make sure the sheet pile wall can fulfill its destiny as well as possible, the sheet pile wall has to be maintained by the residents of Ricanaumofo. At the moment, two residents take care of the wall. They make sure there is no accumulation of waste and fill up holes that appear at the bottom of the wall, so the sediment does not escape. When new sheet pile walls are built, it is necessary that there will be other residents that feel responsible for the wall. If the wall is properly maintained and kept tidy, there will be stable and fertile soil for the growth of vegetation. When the vegetation has established a robust root system, it will make the soil more firm. More firm soil will be able to withstand the force of the water when the sheet pile wall eventually reaches the end of its lifespan.

To prevent the area between the shore and the wall from becoming a swamp, several options are proposed. However, it may always happen that small puddles begin to exist. We assume that the vegetation will grow, allowing for more water absorption. If the vegetation does not grow, the chance of puddle formation and thus stagnant water is increased.

Because the idea of sediment retention and land reclamation with minimal resources is not very common, this project may give valuable insights and lessons. There is a chance that the grass filter will decompose rapidly or the netting may rust. For further research, the filter has to be tested over time: will it hold sediment and will it sustain the tropical circumstances of Surinam?

For now, an assumption is made about the sediment retention over time. This is something that also has to be explored in the future. Only a few months have passed since the construction of the wall and more time is needed to make an accurate assumption. There have also been holes at the bottom of the wall, which have allowed unwanted sediment transport to the river.

5.5 Solution B1: Quay wall

Based on the Multi-Criteria Analysis discussed in chapter X, the quay wall came forward as the best option for a bank protection despite its high costs, but with high benefits. Hence, it is an interesting alternative to analyze.

Two different designs of a quay wall will be given. First of all, a wall which prevents only riverbank erosion of the coastline will be investigated. This means that the height of the coastline stays the same and no additional measures will be taken. Secondly, a quay wall which also has a water retaining function will be investigated. Although a water retaining function is outside the scope of the project, there was a great demand from various stakeholders to explore this as well. Therefore, everything that applies to the erosion-resistant one is also valid for the water retaining quay wall.

In this chapter different sections will be considered. First the conditions in which a quay wall will be designed are given in paragraph 1: 'boundary conditions'. Secondly, a possible basic design will be given. Several possibilities exist, yet there is chosen to design in a conservative way. The influence of the environment will be explained in paragraph 3 'Impact in system'. In the 4th paragraph, different challenges are highlighted. After that, the construction method and a rough indication of the costs will be given in paragraph 5. Finally, the risks are explained in paragraph 7: 'Risks'. The same structure holds for both different quay wall designs, the design of only the erosion resisting wall and the water retaining quay wall.

Boundary conditions

To make a realistic design, the boundary conditions should be determined. In the best case scenario, recent data is collected and analyses will be performed based on this data. However, there isn't much data available in Ricanau Mofo and therefore several assumptions were made. The assumptions are listed below.

- **The soil consists completely of clay**. This is based on the CPT from 1958, taken at location A in the figure. The CPT was made 65 years ago. Because there has been a lot of erosion in the village, it can be assumed that the cone penetration test is not entirely accurate anymore.
- According to villagers, **1.5 meters of soil has been eroded in 30 years**. Assuming a linear trend, it can be concluded that over these 65 years 3 meters of soil has eroded. Therefore, the CPT reading begins at a depth of 3 meters from the point where the soil started in 1958. The CPT is shown in appendix x.
- **The soil is horizontally over the riverbed and the coast.** For simplicity it is assumed that the soil layers are horizontal on the surface. In reality there is a river bed slope.
- **The soil is a dense soil**. When it has rained the water does not penetrate the soil, but immediately flows away. Therefore it is assumed that water cannot penetrate and the soil is dense.
- **There is no additional settlement.** Because nothing has been built on the shore for many years, there are no additional loads to consider. Therefore it can be assumed that there has not been additional settlement compared to the year when the cone penetration test is made.
- **The soil is saturated.** Ricanau Mofo lies next to the river where the tides cause a high water level. Because of this high water level directly next to the shore, it can be assumed that the soil is saturated.
- **The sheet pile wall falls under the safety guideline CUR 166, class II.** In the Netherlands, this guideline is used for designing sheet pile walls. Since there are no readily accessible guidelines in Suriname, CUR 166 is used as a directive. Additionally, CUR 166 is integrated into D-Sheet Piling, the software that is used for the project. This facilitates easier calculations.
- **The quay wall will be 110 meters long**. This is based on the location given in paragraph 2.3.
- **The height between the riverbed and the bank is assumed to be 2 meters.** In figure 46, a schematized version of a sheet pile wall is given. The height of the bank is measured with a pile and rope, set spirit level, from the spring low tide. This was measured at 1.7 meters. Next to this, the difference between low and high tide is 1.8 meters. The measurement is coarse, therefore with safety precautions h is assumed to be 2 meters.

- **The most critical situation is assumed.** The critical situation is the most unfavorable one where the resulting forces of the ground are the highest. This means that the soil is completely saturated and the water level is 2 meters below the coastline. This is conservative but may occur when it has rained during the dry season and there is low tide.

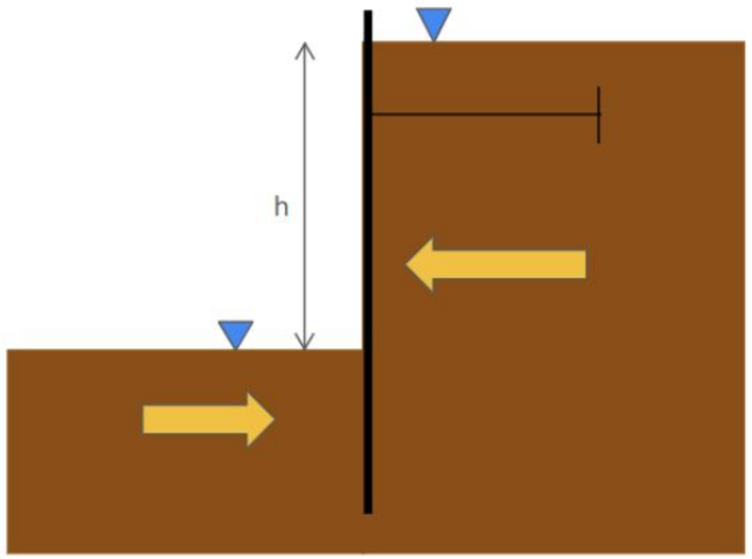


Figure 46: Critical case

Boundary conditions

A quay wall must be designed to be stable and sturdy in many different situations. However, no unnecessary costs should be incurred by over-dimensioning. The quay wall will consist of steel and a basic design is made in Deltares' D-Sheet piling program. D-Sheet piling models the sheet piling as a beam on a foundation of springs, which represents the soil.
The soil acting on the sheet pile creates forces. The force that presses the pile is called the active side, the force that is pressed by the pile is called the passive side. The water pressure also creates forces that act on the pile (Verruijt, 2010). Figure 47 shows the schematized basic design, dimensions are not determined yet. The right side is the landside, the left side is the waterside.

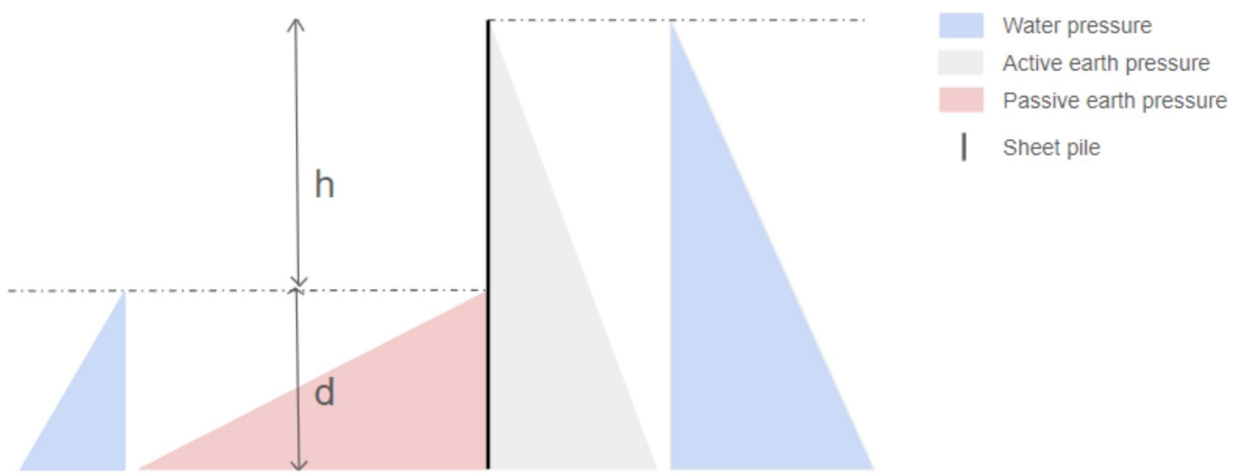


Figure 47: Schematized basic design

Method of calculation
To determine the dimensions of the sheet pile wall, the design is tested on different failure mechanisms. These are the critical length of the sheet pile, the structural integrity of the wall and the overall stability. All aspects are checked according to guideline CUR 166, which is a guideline for sheet pile constructions in the Netherlands that can easily be specified in D-sheet piling.

To determine the structural safety, the resisting bending moment and shear force are checked with the applied forces created by the soil and water in the ground. The critical length is determined by reducing the length step-by-step until instability occurs. To create a margin in safety, certain partial safety factors according to CUR 166, which are already incorporated in D-Sheet piling, are applied. Lastly, the overall stability is checked based on a Bishop calculation, a common method to ensure overall stability.

To perform the safety checks, D-sheet piling has two different models to determine the resulting forces from the ground. The so-called Ka, K0, KP model and the c, phi, delta method can be used. The first method assumes the same earth pressure coefficients over depth in all ground layers, when in reality the earth pressure changes over depth. The model is also limited to a horizontal surface and uniform loads. The c, ϕ, delta method is more accurate, because it is based on the real ground parameters, but cannot be performed when the friction angle ϕ is more than 15 degrees (Deltares systems, 2014). Because ϕ is assumed to be 20 degrees, which will be given later, the Ka, K0, KP model is preferred in this situation.

To ensure a construction is safe, there will be a safety check, expressed in the so-called safety factor. This factor indicates the safety of the structure, dividing the maximum resisting moment or force by the resulting maximum moment or force acting on the wall. A safety check of 1 indicates that a structure is considered safe but without any margin of safety. Therefore, it is recommended to aim for a safety factor of 1,3 or higher to provide a greater margin of safety.

Properties:
To calculate the forces acting and resisting on the wall, the properties of the soil and wall are necessary. The design is conservative, this means that for each choice the most disadvantageous option was assumed.

Soil properties

The soil properties consist of the unit weight, saturated and unsaturated, the cohesion and the friction angle. For soft and dense clay, the friction angle ϕ is 20 degrees and the unit weight of clay γsat is 19 kN/m^3 (ABG Geosynthetics, 2021). The unit weight of water γwat is 10 kN/m^3.

In table 7, a summary of the obtained values is given. The passive and active earth pressure coefficients are determined by D-Sheet piling which assumes a straight slip surface. A specified overview of the soil parameter inputs are given in appendix x.

Table 7: Soil properties clay

Parameter	**Value**
Friction angle, ϕ	20 degrees
Unit weight saturated clay, γ_{sat}	19 kN/m^3
Unit weight unsaturated clay, γ_{dry}	16 kN/m^3
Unit weight water, γ_{wat}	10 kN/m^3
Cohesion	10 kN/m^2

Sheet pile properties

The safety depends on the dimensions and properties of the sheet pile. There are a lot of different sheet pile walls. To have a conservative calculation, the AZ 13 sheet pile is chosen, which consists of steel. The sheet pile AZ 13 has the following properties

Table 8: Sheet pile properties

Properties sheet pile AZ 13*	Value
Length	6,5 [m]
Elastic stiffness; EI	4,1 E4 [kNm^2/m]
Maximum allowable moment; $M_{r;\,d;\,el}$	312,00 [kNm/m]
Elastic section modulus; W_e	1,3 E-3 [m^3/m]$_l$
Section area	137 [cm^2/m]

Results
D-sheet piling calculates whether the construction is safe for all failure mechanisms. Iterative designing gives a basic design as given in figure 48.

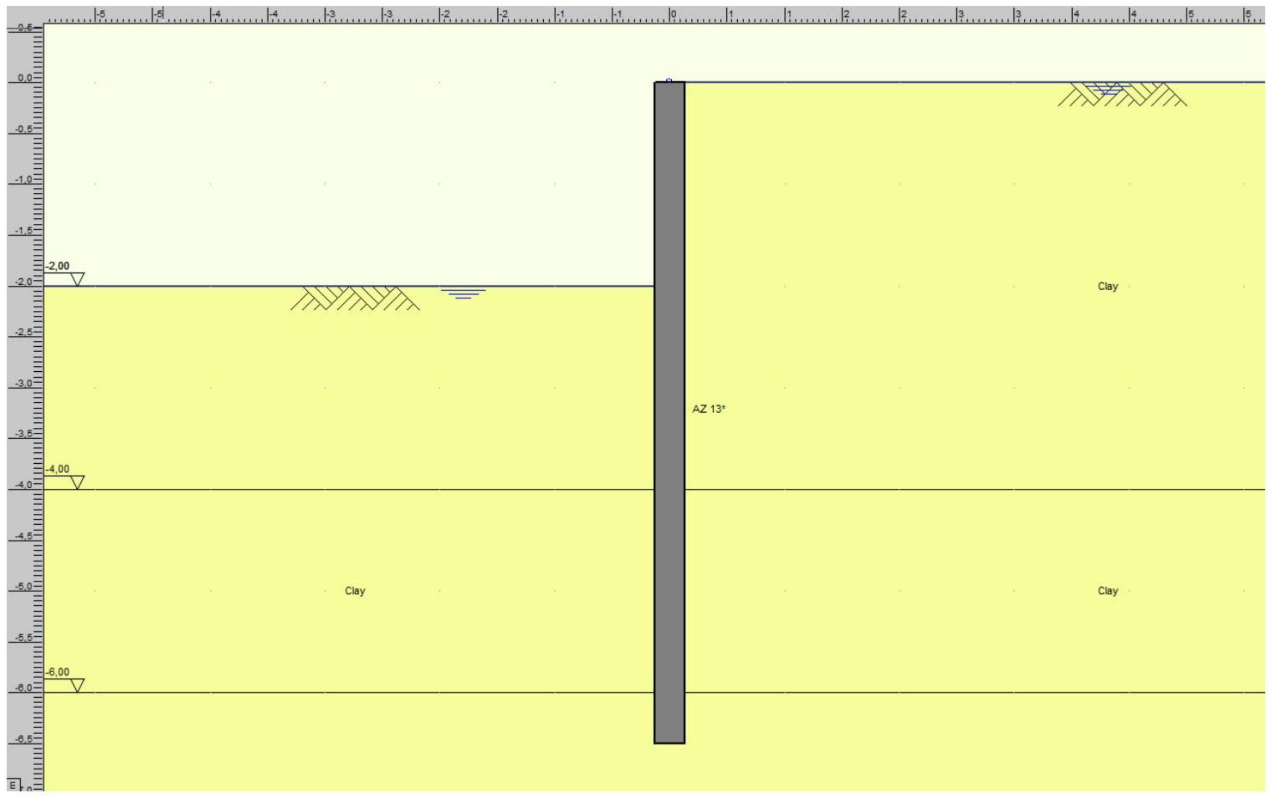


Figure 48: Basic design sheet pile

Critical length

The critical length according to D-Sheet piling, following the guidelines of CUR 166, gives 4,5 meters. To reduce the displacement of the pile, it is chosen for a length of 6,5 meters. For the specific calculation, see appendix A.2.

Moment and shear force

Since the material and soil properties are known, the calculation can be run. The soil acts as a force, resulting in a moment and shear force acting on the sheet pile and a deflection of the sheet pile. This results in the following maximum values, given in figure 49.

Stage nr.	Stage name	Displace-ment [mm]	Moment [kNm]	Shear force [kN]	Mob. perc. moment [%]	Mob. perc. resistance [%]	Status
1	Sheet piling	**-26,2**	**26,01**	**19,62**	**0,0**	**37,0**	
Max		**-26,2**	**26,01**	**19,62**	**0,0**	**37,0**	

Stage nr.	Stage name	Vertical balance
1	Sheet piling	Upwards
Summary		Upwards/Sufficient

Figure 49: moment and shear force

The moment and shear line over the whole depth can be found in appendix x.

The maximum applied moment is 26,01 kNm, this is way lower than the sheet pile can resist, 312,00 kNm. The safety factor is 12,00 [-], this is high but can be explained by the fact that it is chosen for a larger length of the sheet pile than necessary to reduce the horizontal displacement. Besides this, the calculation of the critical length in D-Sheet piling is based on the CUR guideline which has already a safety factor incorporated. This expresses itself in the way that in reality the sheet pile becomes unstable sooner than 4.5 meters.

Overall stability

The force of the ground on the pile can create a slip plane of a big part of the soil. This is called the overall stability. The stability factor, which ensures safety when it is higher than 1, is calculated by D-Sheet piling. The stability factor is 2.42 which is convenient (figure 50).

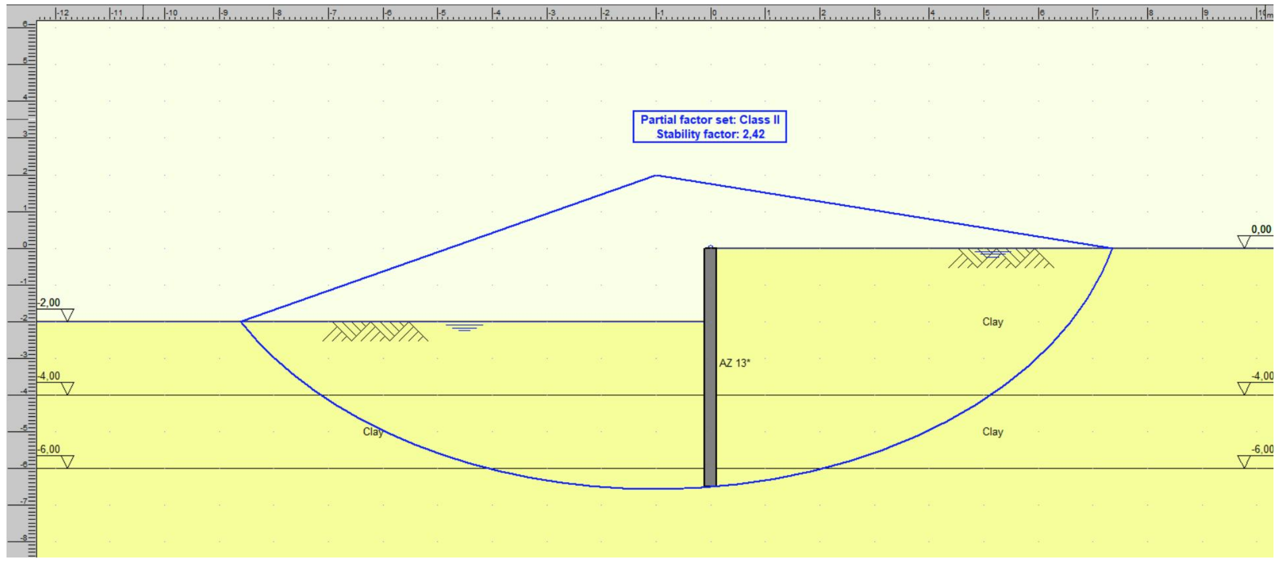


Figure 50: Stability factor by D-Sheet piling

Impact in system

In this paragraph, the consequences of building a quay wall along the shore of Ricanau Mofo are described.

The sheet pile wall is designed to prevent river bank erosion caused by the meandering river, thereby extending the lifespan of the village. The shoreline will be stabilized, which enables residents to continue living in their current location. However, it's important to note that the wall alone cannot address overflow issues during rainy seasons, especially with the increasing impact of climate change. Without a well-planned drainage system, excess water may accumulate behind the wall, potentially transforming the village into a swampy basin.

From the viewpoint of the local people, the impact of a sheet pile wall could be totally different. The presence of a shore, being a sheet pile wall, changes how people in the village use the water for activities like swimming, washing and doing the laundry. They will have to find new spots along the river or at the Cottica creek for these daily activities. Building jetties along the riverside could help, but excavating the soil too much could make the water too deep for kids to bathe safely with their parents. While laundry could still be done from the jetties, washing might need a new location. These changes to daily habits could cause resistance against this solution.

An advantage for people living near the coast is that constructing a sheet pile wall prevents trash from accumulating in the village, resulting in a cleaner and more appealing shoreline. At this moment, with no wall, the trash accumulates at the shore of Ricanau Mofo. Preventing this not only enhances the beauty of the coast but also creates a healthier environment.

Challenges

Different challenges come with the implementation of a quay wall. First of all, the quay wall will be a sheet pile wall that protects the shore against river bank erosion. The sheet pile wall will hold the sediment on the land side and prevent bank erosion, but the wall will not prevent land erosion. Therefore, it is important to strengthen the soil on the landside, by for example planting vegetation. Also the groundwater cannot flow away anymore. Therefore a functioning drainage system needs to be placed. It must be able to drain the large amounts of water which occur during the heavy rain period.

Besides this it is important that the finishing of the ends of the quay wall are done carefully. One needs to prevent a funnel from being created and erosion occurs.

Finally, because the quay wall doesn't have a water retaining function, the land will still overflow. When there isn't a functioning drainage system, land erosion will still occur. In this way, sediment can disappear behind the wall and a bathtub can occur. This will only make the situation worse and needs to be prevented.

Construction method

The implementation of a quay wall requires a certain construction method. This method (figure 51) is based on the area conditions and boundaries. Describing this method is essential to guide the necessary activities and their order. There are several ways to install steel sheet piles into the ground. The main parameters to consider are: soil conditions, sheet pile section and length, driving equipment, permanent vs. temporary wall, visible wall (coatings for aesthetics), installation tolerances (vertical, position), accessibility of the site, interlock sealing systems used and external environmental factors of the area (Arcelormittal, 2019). The construction of the sheet pile wall is divided into separate phases. For the installation of a non-retaining wall, anchoring is not needed. Therefore, phase 3 is not considered in section B1, but added in section B2.

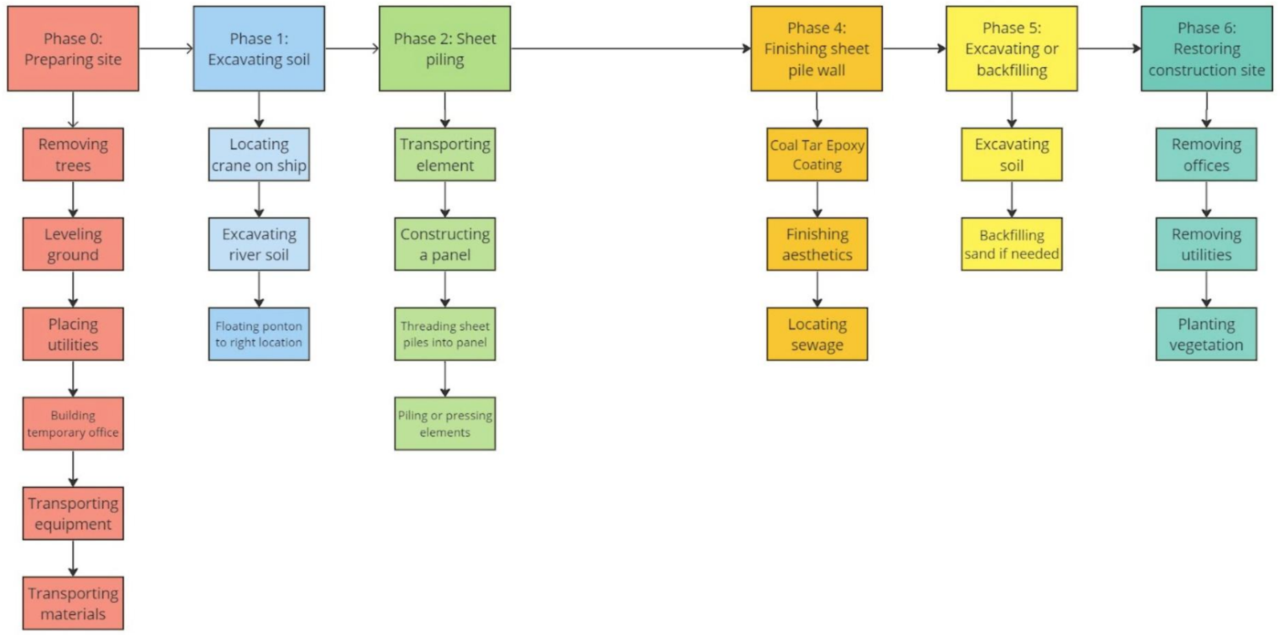


Figure 51: Construction method phases

Phase 0: Preparing site

During the preparation phase, the site needs to be prepared for use during the construction activities. It is important to choose the location wisely, as it is important to minimize the effect on nature and also minimize the transportation of equipment and materials from the site to the construction activities. As the Cottica river is meandering and the south side of the river is the outside bend, it is important not to damage the nature on this side, because this will result in less solid soil. Therefore the location on the north side is considered to be the most suitable location to create the site. On site, utilities need to be placed and a temporary office needs to be built. When the site is leveled and safe, the equipment and the materials should be transported to this area. After these activities, the construction of the sheet pile wall can start.

Figure 52: Phase 0 steps

Phase 1: Excavating

Before the sheet piling phase can start, it is important to create access to the shore. By using a crane on a ship, the soil next to the shore will be excavated. Not the complete soil needs to be excavated, otherwise a collapsing risk is created for the shore. It is important to gain knowledge about the riverbed in this location. Together with the information of the riverbed and the dimensions of the floating pontoon, there should be calculated how much soil needs to be excavated. After the excavation of the soil, the pontoon can be floated to the right location to start the sheet piling.

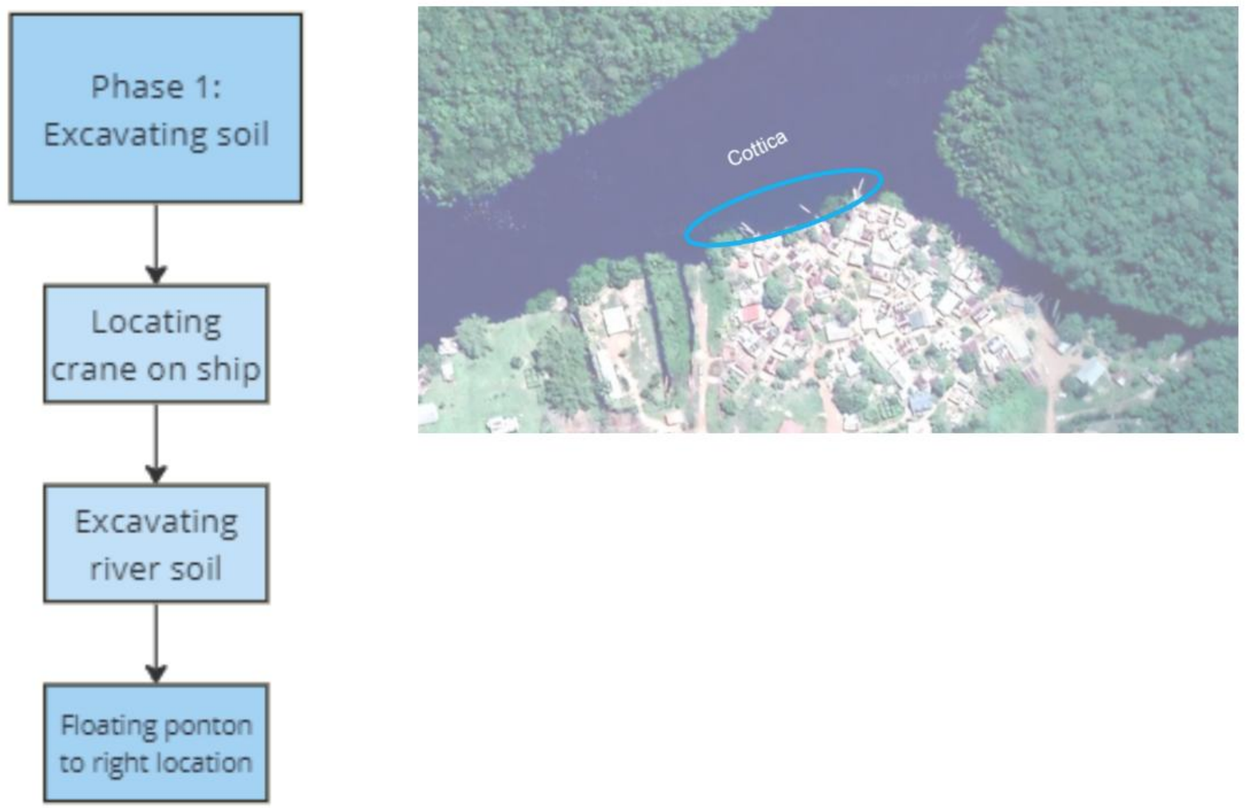


Figure 53: Phase 1 steps

Phase 2: Sheet piling

The sheet piling phase consists of building a panel, threading the piles into the panel and piling the elements into the ground. First, it is important to figure out which type of installation method fits the best for this location. The three standard installation methods are panel driving, staggered panel driving and the pitch and drive method. For this location, the most suitable installation method is panel driving. This method is recommended for constructing permanent walls, when installation tolerances are quite important and soils where leaning is predicted (soft soils). As mentioned in earlier paragraphs, it is assumed that the soil consists of clay. Therefore, the prevention of leaning is very important. A disadvantage of this method is the long installation time compared to pitch and drive, but this time investment is worth it. Also this procedure needs a longer crane boom for lifting the piles. Staggered driving is recommended if the soil turns out to be very compact. Making a CPT is therefore of great importance. The pitch and drive method is not recommended for this location. This method is used when installing temporary walls, for example for building construction pits.

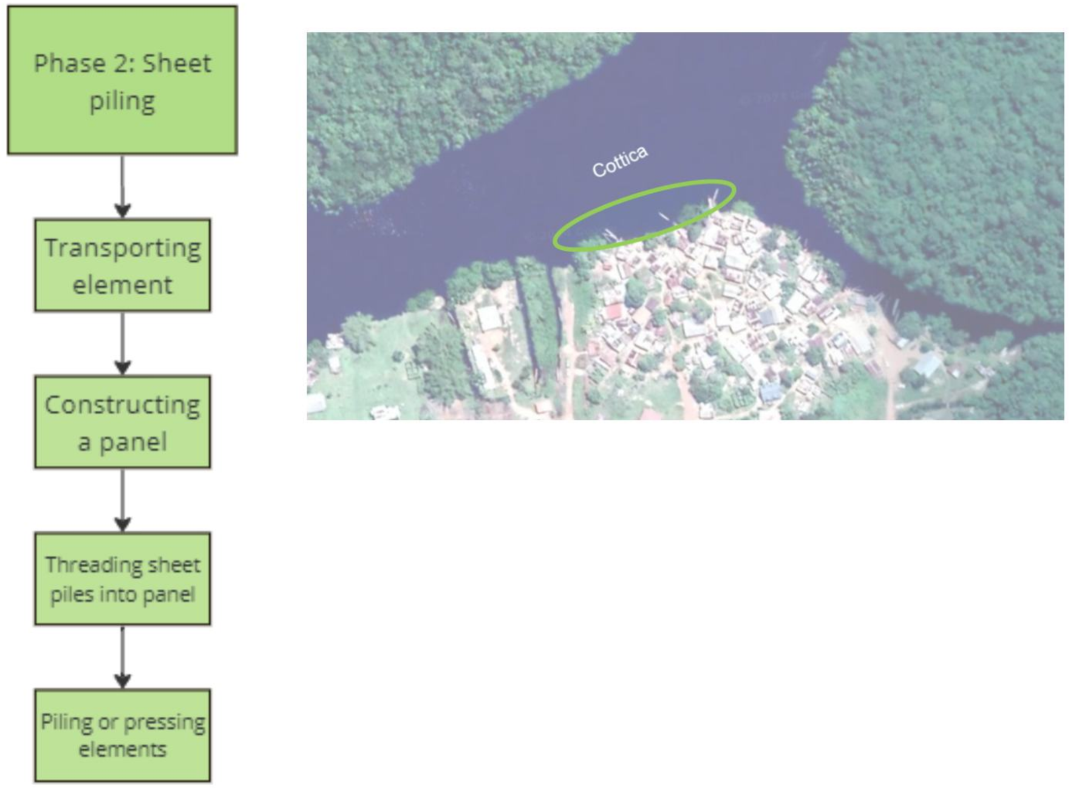


Figure 54: Phase 2 steps

Phase 4: Finishing sheet pile wall

After the sheet piling and the anchoring of the wall, there are some finishing works to be carried out. A Coal Tar Epoxy Coating can be applied to lengthen the lifespan of the wall. Also the aesthetics are very important and therefore it should be discussed with the local people how the top of the sheet pile wall should look like and how many cubic meters of sand should be added to the shore. Also, think about adding jetties next to the sheet pile wall for better access to the river. It's important for everyday tasks like washing, doing laundry, or getting into your boat.

Figure 55: Phase 4 steps

Phase 5: Excavating or backfilling

Once the construction of the sheet pile wall is complete, ensure that the riverbed is properly adjusted. Depending on the use of the quay wall, more soil needs to be excavated. By excavating the soil, the accessibility will be improved for larger boats. This could be intriguing if Ricanau Mofo aims to serve as a hub for the region. Additionally, it's worth considering sand backfilling to create a nature-based solution to provide extra riverbank protection.

Figure 56: Phase 5 steps

Phase 6: Restoring construction site

Finally, it's crucial to restore the construction site. Firstly, remove the utilities and offices. Secondly, restore the damaged natural environment by planting new vegetation to heal the scars in the forest.

Figure 57: Phase 6 steps

Costs

There are several aspects to consider for the cost. There is an overview of what kind of costs are involved in constructing a quay wall. These include;

- Engineering costs
- Equipment costs
- Labor costs
- Transportation costs
- Restoring nature costs
- Material costs
- Unforeseen costs

For this report only the material costs are calculated. This is because it is hard to make an inventory of the other costs and it falls out of the scope of this project. With a depth of 6,5 meters and 110 meters long, the material costs are about € 100.000,00. See appendix A.3 for a more detailed calculation.

Risks

A risk that needs to be taken into account is the effect a quay wall has on the ecosystem. It can lead to the loss of natural habitats. Natural habitats are of great importance for animals and plants. Fish can disappear and thus affect the villagers' diet.

Another risk that can occur is that the drainage system can silt up. Proper maintenance is necessary to prevent the occurrence of a bathtub in the village.

5.6 Solution B2: Quay wall with water retaining function

Everything said in the quay wall for 2 meters height also fulfills the water retaining function. However, more comes into account because the height of the wall needs to be increased and the land needs to be filled up. This chapter can be seen as an addition to the previous one. The boundary conditions stay the same but the basic design changes and consists of multiple construction stages. In this situation the quay wall is designed for a future situation, where Ricanau Mofo can become a hub for the surrounding villages. Therefore, besides heightening, a promenade is placed.

Boundary conditions

The same conditions are assumed as in the quay wall with no water retaining function. Only height h changes. Instead of the height assumed to be 2 meters high, the wall needs to have a water retaining function which needs to be higher. For this project, it is assumed that the ground will be heightened up 1 meter with respect to the current situation. This is based on the stories of the residents which said that the water level during the heavy rain period comes above the knees. Besides this the floodline on the houses is 0.6 meters (figure 58). To be conservative, and taking into account the sea level rise, 1 meter of heightening is considered.

Figure 58: Floodline of houses

Recommendations

To make a better assumption for the height that the soil needs to be heightened up, one needs to determine the water design level. This is based on the maximum tide, the storm surge, the local wind set up, the seiches, the peak river discharge and the sea level rise. This is the design water level (DWL).

DWL = Htide max + {Surge + local wind set up + seiches + peak river discharge} + sea level rise

The maximum tide, Htide max, is the maximum height of the water reached during spring tide. The storm surge can be approached by formula (1) (Jonkman et al, 2021). Therefore one needs the wind speed, the fetch length and the angle of incidence. To be accurate the wind speed needs to be determined for the lifetime of the structure. This needs further research.

$dh = 0.5 * k * u^2 / (gh) * F * \cos(\phi)$ (1)

The same holds for the peak river discharge. The discharge needs to be measured, and based on enough data the peak river discharge for a certain design life time can be determined.

Next to this the sea-level rise needs to be taken into account which can be based on the values of the IPPC rapport.

Basic design

For the basic design it is assumed that the soil is heightened up with one meter. In this way higher forces are created. To ensure stability also an anchor is applied. Figure 59 shows the new schematized basic design with an anchor, dimensions are not determined yet.

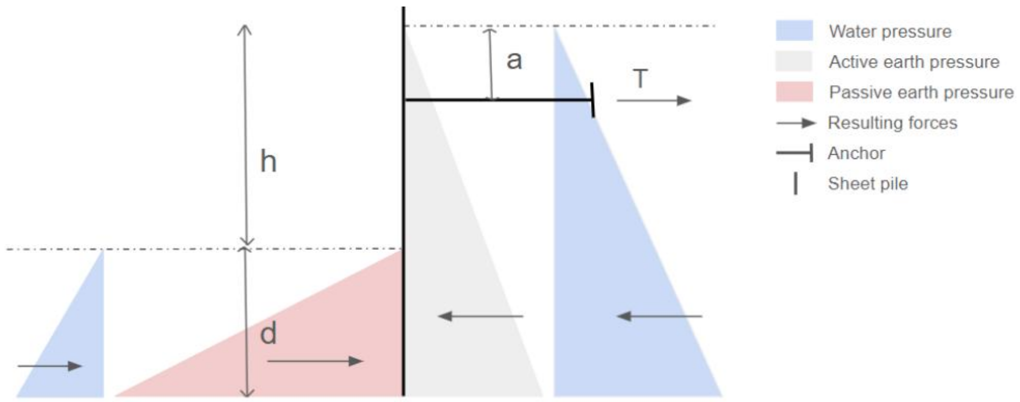


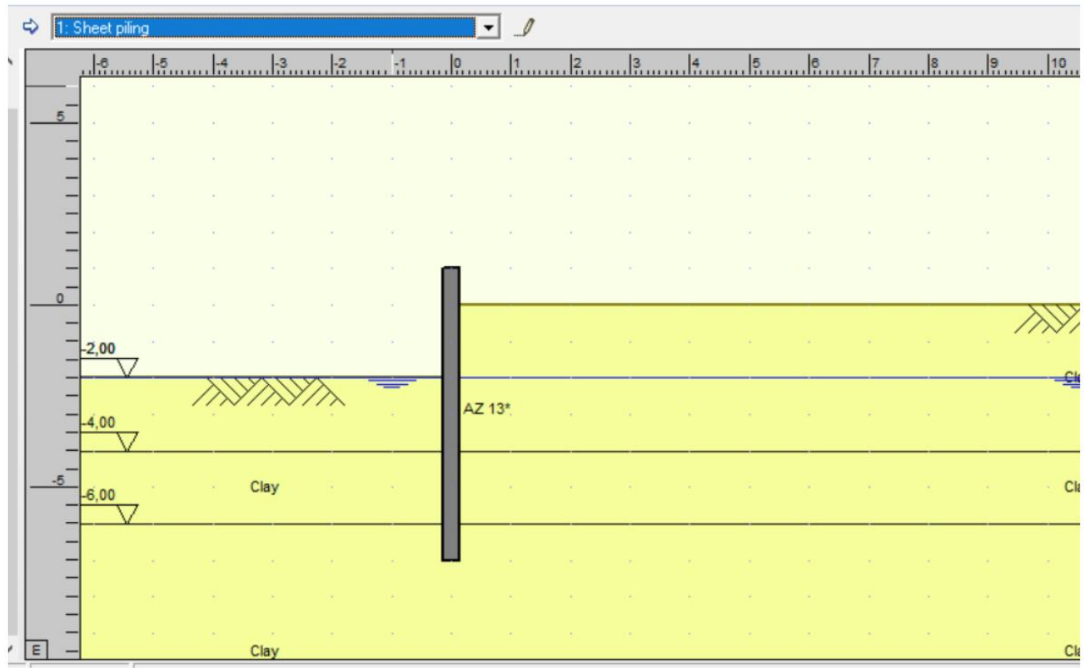
Figure 59: Basic design with an anchor

The design is tested on different failure mechanisms during different phases of the construction. Besides the critical length of the sheet pile, the structural integrity of the wall and the overall stability, also the anchor stability is tested. Just as in the first case, all aspects are checked according to CUR 166.

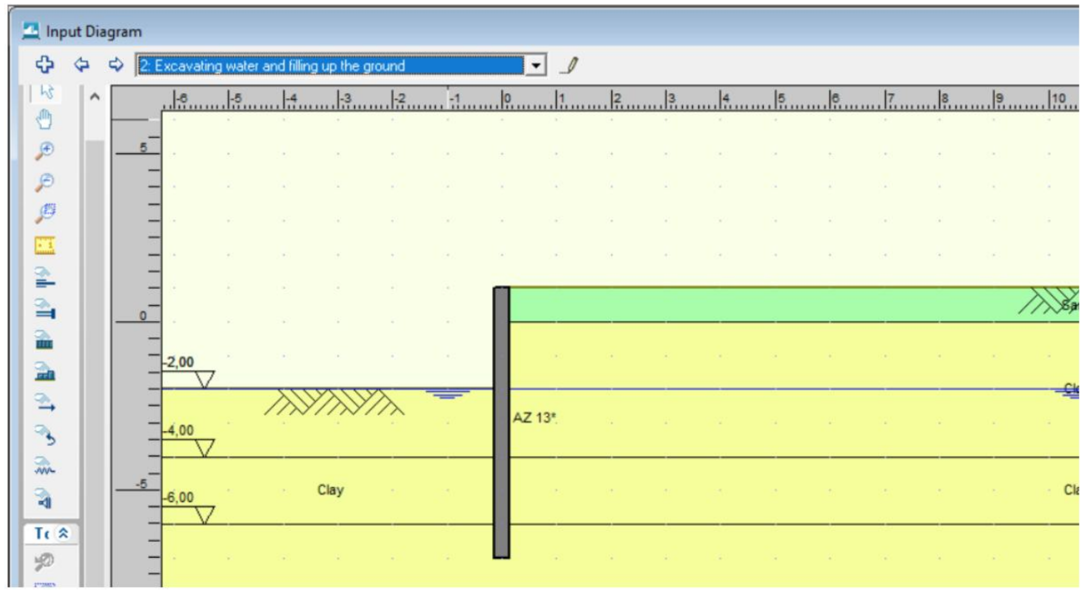
Unlike the previous design, different stages occur during construction. To ensure stability, all the stages need to be checked for all the different failure mechanisms.

The different stages that occur during construction are shown below;

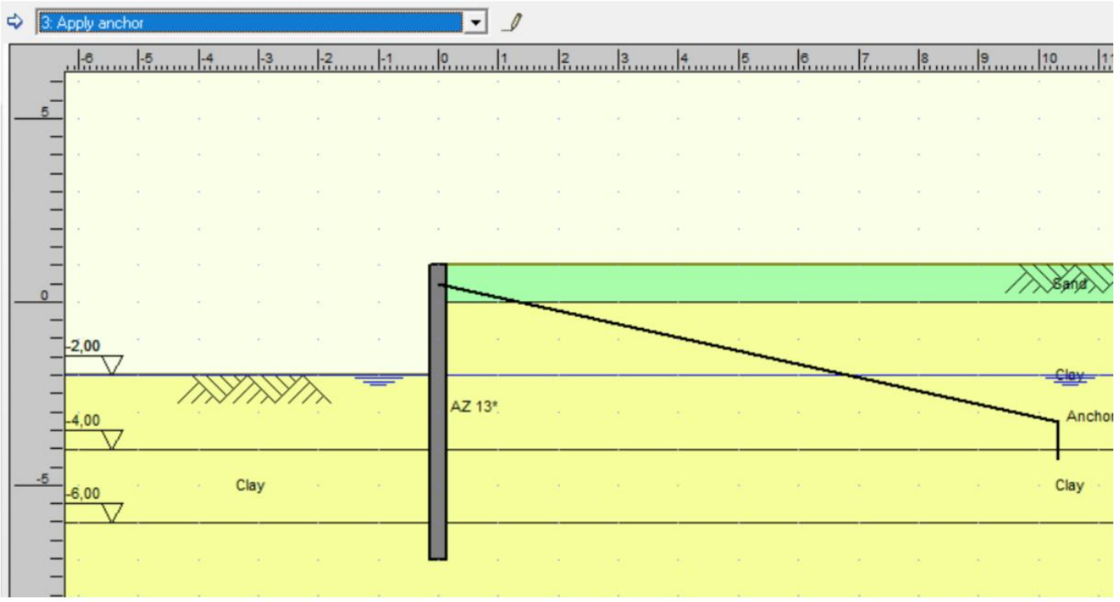
1. Vibration of sheet piling in the ground



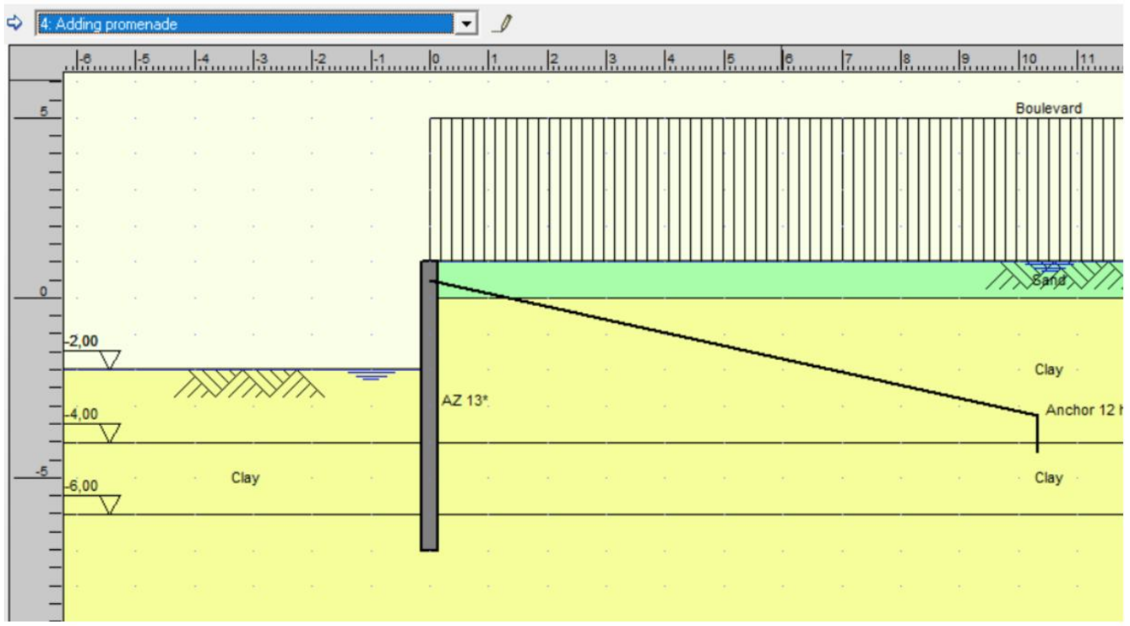
2. Excavating water and filling up the ground with sand



3. Placing the anchor



4. Placing a promenade. A weight of 10 kN/m^2 for the promenade is assumed.



The final basic design for different stages looks as shown in the last construction stage.

The structural safety, overall stability and critical length of the sheet pile wall are determined in the same way as the first design for every stage. The sheet pile and soil properties are the same, given in table 7 and 8 of the previous section. The anchor properties and safety checks for the length and stability are added.

Properties

The anchor properties are chosen to be the following, given in table 9.

Table 9: Anchor properties

Properties anchor	Value
Length	11 [m]
Angle	-20 degrees
E-modulus	2,1E8 [kN/m^2]
Cross section	4,00E-4 [m^2/m]
Yield force	240 [kN/m]

Results

Critical length sheet pile

The critical length according to D-Sheet piling, following the guidelines of CUR 166, gives 5 meters. To be conservative and design for a longer period, a length of 8 meters is adopted. For the calculation, see appendix A.2.

Moment and shear force

The model is run in the same way as in the previous situation. However now there are four different stages where safety needs to be assured. For every stage the maximum moment, shear force and displacement is calculated. These are shown in figure 60.

Stage nr.	Stage	Displacement [mm]	Moment [kNm]	Shear force [kN]	Mob. perc. moment [%]	Mob. perc. resistance [%]	Vertical balance
1	Sheet piling	-7,3	3,03	3,48	0,0	32,9	Sufficient
2	Excavating wate...	-14,7	10,93	8,15	0,0	42,6	Sufficient
3	Apply anchor	-8,9	-22,66	-54,02	41,6	42,7	Sufficient
4	Adding promena...	-15,3	**-46,19**	**-65,45**	**58,5**	**61,1**	Sufficient
Max			**-46,19**	**-65,45**	**58,5**	**61,1**	Sufficient

Figure 60: Displacement

The moment and shear line across the depth are given in appendix x.

The maximum applied moment is 46,19 kNm, during the final stage. The sheet pile can resist a moment of 312 kNm. In this situation this gives a safety factor of 6,75.

Overall stability

Because of the multiple stages, there are multiple stability factors, they are given in table 10.

Table 10: Stability factors per stage

Stage name	**Stability factor [-]**
Excavation water side and applying sheet pile	2,42
Filling up sand +2m	1,88
Applying anchor	1,88
Adding boulevard	1,28

The stage of adding a boulevard is critical. This stage has a stability factor of 1,28. The slipping plane looks as given in figure 61.

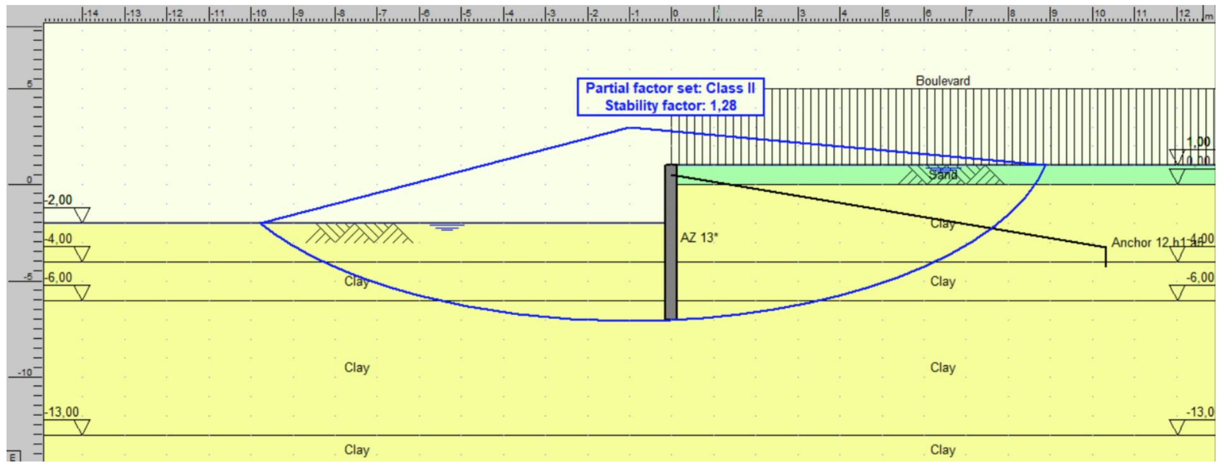


Figure 61: Stability factor

Anchor stability

Based on the forces on the sheet pile and the forces working on the anchor, the safety is determined by the Kranz calculation, this is the method used in D-sheet piling which calculates the anchor stability. The anchor stability is determined for the two last stages, the stability factors are given in table 11.

Table 11: Anchor stability factors per stage

Stage	**Anchor strength**	**Anchor force**	**Stability factor**
3	190,00	144,00	1,31
4	165,00	162,00	1,02

Impact in system, idealistic situation

The quay wall will stretch along the riverbank. It protects the village from erosion and provides a foundation for the boulevard that will be built on top of it. The boulevard can be wide and beautifully landscaped, with attractive paving and lighting.

In the idealistic situation, along the boulevard, there will be benches, flower beds, and possibly artworks reflecting the local culture. The boulevard will also benefit the economy, serving as a hub of economic activity with small shops and restaurants selling local products and in this way attracting tourists.

In addition to the quay wall and boulevard, Ricanay Mofo can develop and a harbor will be constructed, creating a hub for trade and transport. This will enable the village to improve its economic potential. For these reasons, Ricanau Mofo can become a popular tourist destination. Tourists will come not only for the natural beauty and cultural experiences but also for tourist activities such as riverboat trips, walks along the boulevard, and visits to local markets. The village will evolve into a sustainable tourist destination, with the preservation of the natural environment and cultural integrity at its core.

Challenges

Building a quay wall in a village like Ricanau Mofo is a challenge. It is hard to reach, the soil is compacted so water flows off immediately or is collected in the village after construction and houses are situated next to the coastline which means that people will live in the construction site during construction.

To accomplish the building of the quay wall including the raising of the ground through which a flood control function is achieved, people will have to move in the parts next to the coastline. This will be done 20 meters inland, shown in figure 62. In the figure around nine houses are visible however, four of them are uninhabited which means that five households need to move.

People are attached to their living space and their families have lived there forever. Besides this, people do understand that there is a problem of eroding soil and underflowing land, however they have problems with understanding solutions. It is of great importance that they understand the solution that will be provided and that they concur with this, otherwise they will not be willing to move.

Figure 62: Critical area in the coastline

Another challenge that people need to take into account is the flooding of the land. At this moment, water flows away on all sides of the coastline and is absorbed by the soil. When land is heightened up and a quay wall is placed, water cannot flow away anymore, a bathtub will arise. Because of this it is important that in the quay wall a drainage system will be placed and water can be pumped out of the lower parts in the village. This will cost a lot of money and maintenance is required. Because of the large rainfall during the big rainy season further research is required to check whether the construction of a quay wall is feasible.

Construction method

To construct a water-retaining wall, anchors need to be drilled in the ground. Therefore, a construction phase, including the anchoring process, should be added to the construction method. This is shown as phase 3: Anchoring.

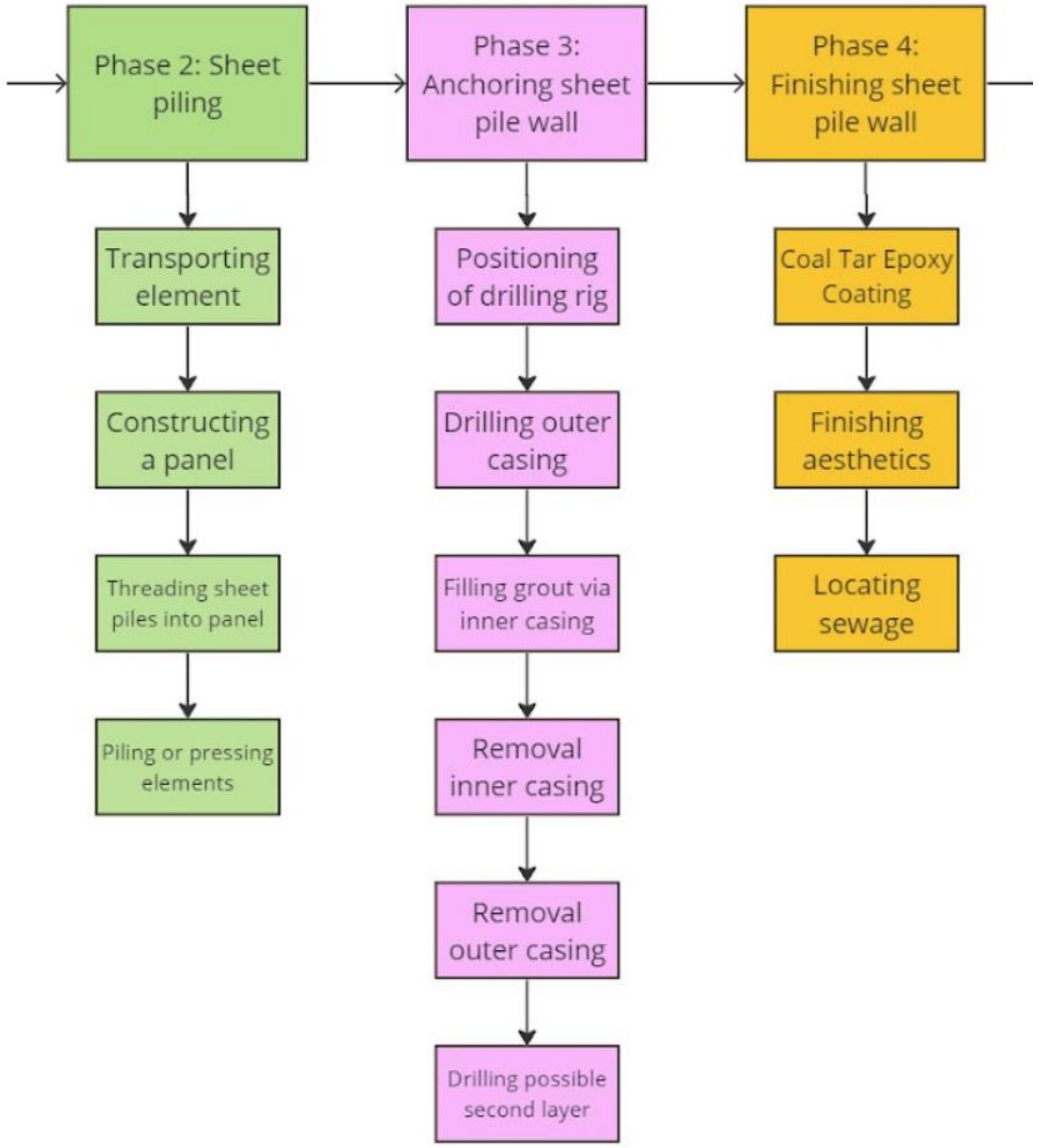


Figure 63: Construction method with phase 3 included

Phase 3: Anchoring

Without anchoring the sheet pile wall, the ground pressure together with the water pressure will push away the sheet pile wall when constructing a water-retaining wall in a soft clay soil. In appendix A.3, the calculations for the dimensions of the sheet pile wall and the anchors are shown. The first step of anchoring is the positioning of the drilling rig in front of the shore. The next step is to drill an outer casing in the ground. Within the outer casing, there is an inner casing. Via the inner casing the anchor will be filled with grout. After removing the inner and outer casings, the anchoring is done. Depending on the calculations, a second layer could be drilled. The difference between the method in B1 and this one is that the pressure is different on the land side. Also the level of backfilling sand is different, which results in a different pressure and other challenges and risks that should be taken into account.

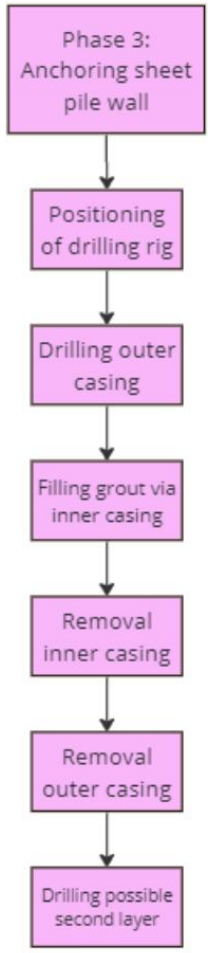


Figure 64: Phase 3 steps

Costs

The same costs are made as in the first case. The material costs include the sheet piles, the anchors, and the sand for filling up the coast. The total costs for a sheet pile length of 110 meters and a depth of 8 meters with an anchor of 11 meters amounts to € 260.000,00. The calculations are given in Appendix A.3.

Risks

By building a quay wall with a water retaining function, different extra risks need to be taken into account.

First, there is a reasonable assumption that people do not want to leave their house. To prevent this, there is a need to work well with and get residents behind the solution. Effort needs to go to the engagement of the people living in Ricanau Mofo.

Secondly, heightening up of the coastline can create a gradient in the village. Further research is required to know to what extent and where the gradient will occur. Because the lowest places of the village will change, water will flow over there and a displacement of the water problem will occur. It is important that this will be taken into account and the drainage system is in line with this.

This leads to the next risk, the drainage system can silt up. This requires a lot of maintenance and money to keep this feasible. When the drainage system doesn't fulfill its function, the problems in Ricanau Mofo can only get worse because the water will not flow away at all. Because of the situation where the residents of the villagers also cannot trust on the garbage collection service, is it doubtable whether the maintenance will be done in time.
Another risk that can occur when a quay wall is constructed is the disappearance of sand behind the wall due to heavy rainfall. When this happens, water will collect behind the wall at the time of a rainy period and the flood control function will be lost and instead worsened. The water can no longer drain away.

5.7 Discussion and recommendation

First of all, the assumptions made for the boundary conditions of the quay wall need to be verified. Therefore, data collection is necessary to determine the design parameters of the sheet pile wall. Methods to obtain these data are given below.

Cone Penetration Test (CPT)
First of all, the soil on the specific location should be investigated. The soil in this area in Suriname consists mostly of clay and a few sand layers. A CPT, carried out in 1958, showed data of one sand layer and a lot of clay. Unfortunately, this CPT is not reliable as the CPT was taken in 1958 which is very long ago and therefore no longer reliable. Besides this, the precise location of the CPT is not clear, and the soil can be changed over time. Therefore it is important to carry out a CPT to collect updated data about the soil near the shore. This CPT can be carried out by Baitali Pavement Testing & Technologies N.V. (BPTT). It is valuable to take the CPT test at multiple locations to get as much insight as possible in the soil composition.

River bed screening
To calculate the forces on the sheet pile wall accurately, gathering data on the river bed is crucial. The slope of the river bed directly influences the strength of the sheet pile wall, making this information essential for determining boundary conditions. The Maritime Autoriteit Suriname (MAS) has already created a depth map of the Cottica river next to Ricanau Mofo, but this analysis should be carried out in more detail to use the data for the boundary condition calculations.

Hydrological data
The rainfall data of the neighborhood of Ricanau Mofo and the water levels in the Cottica River are outdated. Additionally, updating the high and low tide data would enhance the accuracy of water pressure calculations and improve boundary conditions. Also, historical weather data for the region should be gathered to discover fluctuations in rainfall, wind and temperature. This information is necessary in determining a design water level (DWL).

In addition to collecting data, consideration must be given to the design lifetime of the village of Ricanau Mofo. The design lifetime is necessary to design the quay wall with water retaining function. With collected data the design water level can be set and a proper design can be made. The design lifetime should take into account the size of the village, its economic value and its potential for the future. It can be set higher than one might initially think, looking at the 8.5 million road that was built towards Ricanau Mofo. The design lifetime was omitted in this design and the water retaining height was assumed. It is then up to the client of the project whether the cost of the project to construct a quay wall outweighs the benefits.

Furthermore, the designs are conservatively designed which in reality need not be. More iterative designs can be made taking other types of steel into consideration for the wall and the anchors. It is also important to do good research in the area to see what materials are widely available in the area to save costs. This can have a huge impact on the costs of the design.

5.8 Conclusion

The erosion along the shoreline of Ricanau Mofo presents a pressing threat to the community's stability and well-being, impacting homes and daily activities. To address this problem, some interventions, from structural to natural solutions, have been proposed and evaluated through a multi-criteria analysis. These assessments have identified the construction of a sheet pile wall and a quay wall with and without water retaining function.

The sheet pile wall is a way of implementing a nature based solution where vegetation must ensure that the water flow rate should decrease and erosion slows down. Time is required to let the vegetation grow and it is important that the population fully supports the solutions.

The quay wall without water retaining function is a protection for the shore against erosion caused by factors like river flow and wave impact. The quay wall with water retaining function is also a protection against the flooding. Besides this it has community benefits where the promenade can become a focal point for recreational activities, tourism and economic growth.

However, there are some challenges and risks to take into account. Community involvement is crucial and a proper drainage system must be carefully applied to prevent Ricanau Mofo from becoming a bath tube. Ongoing monitoring and maintenance, along with data collection and refinement of design parameters, are essential for the long-term. Besides this there are a lot of costs for building the quay wall, including the construction of a construction site. One needs to consider whether it’s worth it given what it yields.

6

Water drainage

This chapter addresses soil erosion challenges in Ricanau Mofo's old center, primarily caused by heavy rainfall and the lack of existing drainage measures. To assess the situation, a hydrological analysis was conducted, simulating a 50 mm/hour rainfall event. This analysis incorporated field measurements and observations alongside existing scientific reports. The analysis enabled the categorization of distinct flow areas based on factors including clay content, vegetation cover, discharge, and slope.

Informed by this data, various intervention strategies were explored and finally, through a multi-criteria-analysis, an integrated system of solutions is proposed.

6.1 Research questions

1. **Problem analysis**

2. **Understanding stormwater drainage**

3. **Understanding the hydrological catchment area in the centre of Ricanau Mofo**

- What are the quantities and flows of rainwater in Ricanau Mofo?
- How is the drainage system of Ricanau Mofo organised?
- What are the current interventions implemented?
- Which areas are most at risk to erosion?

4. **Evaluation of erosion prevention concepts**

- Which concepts are evaluated?
- How are the concepts evaluated?
- How and where can the concepts be implemented?

6.2 Problem definition

During heavy rainfall the old centre of Ricanau Mofo experiences heavy soil erosion due to stormwater not being properly drained. There is no stormwater drainage system in place, and most roofs do not have gutters. Water is concentrated in ridges in the sloped corrugated sheet and falls directly next to the house. This splash erosion causes deep ridges in the ground, laying the foundation bare and vulnerable.

Due to the high density of buildings in the village, there is little room for the water to find a natural way to the river. Therefore the water is concentrated in gullies in between houses, resulting in certain pathways where water is concentrated. There are no pavements or hardened gullies in the village, but instead most of the floor consists of compacted clay. Bare roots and foundations show that runoff from rainwater has resulted in the loss of soil and fast erosion of foundations of properties.

The current drainage infrastructure is woefully inadequate, This lack of infrastructure is often the case in developing countries, as urbanisation has taken place without adequate investment in infrastructure and local institutional capacity (Cohen, 2006). However, the situation in Ricanau Mofo can be considered worse than in other urban slums described in research for several reasons.

Physically, the village is almost at level with the river, resulting in floods during rainy seasons. Apart from that, the lack of slope in large parts of the village deter water from naturally flowing off and make implementation of hardened channels more difficult. Apart from that, the clay ground is mostly impermeable and erodes easily with runoff. Logistically, the village is not only built without any apparent pattern or street organisation, but the implementation of the new water supplying system of SWM and the root network and root networks of the big trees form a subground maze which makes building channels extra difficult. Apart from that, no official maps of Ricanau Mofo are in existence.

The village has been connected with Moengo with an asphalted road in 2024 which is supposed to bring more economic opportunities. Ricanau Mofo is indeed spreading at its edges with new, well-built, houses. However, the old centre is slowly washing away and needs structural improvement in order to cope with the increasing extreme weather due to the changing climate.

6.3 Preliminary studies

Although the field of urban drainage is mature and a lot of research has been conducted into drainage of stormwater in urban areas and erosion resulting from urban development, there seems to be no information available about drainage projects undertaken to tackle erosion in rural villages in tropical environments. As mentioned in the problem definition, combating erosion in Ricanau Mofo is a hairy problem with specific challenges. In this chapter, the basics of urban drainage will be explored based on the main books written on the matter, 'Urban Drainage' by Butler & Davies (2000) and 'Urban drainage in tropical environments' by Tucci & Maksimovic (2001). After that, work from the previous groups in Ricanau Mofo will be further explored.

To deal with erosion problems, the first step is to diagnose where erosion is already taking place and identify terrain that is more susceptible to erosive processes. After that, preventive and corrective control measures can be established (Tucci & Maksimovic, 2001). To describe this on a geographical map, this map has to be available which is not the case for Ricanau Mofo. Previous groups from the University of Antwerp have made a fairly specific map depicting the houses of Ricanau Mofo (Vandermeeren, 2023; Goossens et al., 2023). Building on this map, several more specific maps had been made with additional information, e.g. inhabitants per house, economic functions and terraces (Vandermeeren, 2023). As the researchers had not added a source for the map and neither described how the map was conducted, the map had to be revised, both with online geographic information software and through physical surveys.

Surinam governmental policy

Drainage works in Surinam are in the portofolio of the Ministry of Public Works (OW). In 2021, the minister of OW stated that drainage is the most prone problem in Suriname (Ramcharan, 2021).

There does not seem to be a general plan for improving drainage in Surinam. Instead, the ministry focuses on individual projects. A big problem for structural improvement in Surinam is the weak economy and uncertain political situation. During the road opening to Ricanau Mofo, the minister of OW, Ronny Brunswijk (the VP) and the DC all emphasised how important it was to only start projects which can be finished within one administration so that projects do not stop unfinished due to a change in policy or stop of funding.

In order to get support from governmental organisations it is therefore important to emphasise what the project could mean for them in terms of success within their administration period. The news feed from the ministry shows that projects are more personal showpieces of the ministers, than cohesive steps within an integral water policy (Saktoe, 2024a; Saktoe, 2023).

A positive development from the ministry has been the expansion of activities outside of Paramaribo. Its policy was criticised for its mostly centralised focus on the capital, which has been refuted by hiring more people in other districts and making public works more visible (Saktoe, 2024b). Some people are hired in district committees for drainage works, in Marowijne this committee does not seem to exist. What is visible is the dozens of people in Moengo and Ricanau Mofo responsible for cleaning the public area of weeds and trash. They are paid by the ministry for keeping the lands clean. The task of maintenance of drainage works would therefore fall under their responsibility.

6.4 Understanding hydrological dynamics in the old centre of Ricanau Mofo

What are the quantities and flows of rainwater in Ricanau Mofo?

To get a better understanding of the requirements of the measures against flooding and erosion the expected rainfall has to be quantified.

Surinam has a Tropical Monsoon climate, which means there is a large variance in the amount of rainfall in Suriname over the year. Yearly there is an average rainfall of 2200mm (World Bank Climate Change Knowledge Portal, z.d.). This is not spread evenly over the year but falls mostly during the two rainy seasons. During the big rain season, daily rainfall can exceed 100 mm as can be from figure 65. The intensity of the rainfall asks for larger drainage systems than would be calculated using monthly or daily averages due to the high peak flows (Tucci & Maksimovic, 2001).

To estimate the maximum amount of water which can be expected to fall within an hour, different approaches can be taken:

1. Measurements from the Surinam Meteorological Institute which describe daily rainfall can be used to estimate the maximum amount of rain for an hour
2. A maximum amount of rain can be chosen using publicly available data about hourly rainfall in the tropics. Choosing a conservative number will result in a safe estimation.
3. Data could be derived from experiments. Measurements of rainfall can be made at the author's home in Moengo. Although not representative for the most extreme situations this data can be used to estimate rain quantities during smaller amounts of time.

For the first approach, data from Paramaribo has been analysed. It is mentioned that this data is applicable for Paramaribo and the surrounding coastal areas. As the distance between Paramaribo and Ricanau Mofo is only 83 km, they are both next to a river and fairly close to the sea, and relief is roughly the same we assume rainfall patterns will not be too different.

Analysis of daily precipitation data shows the maximum daily rainfall in the past 20 years was 80mm on average. The highest recorded value is 114 mm. It has to be noted that the data comes from Zanderij, which is 20 km inland from Paramaribo.

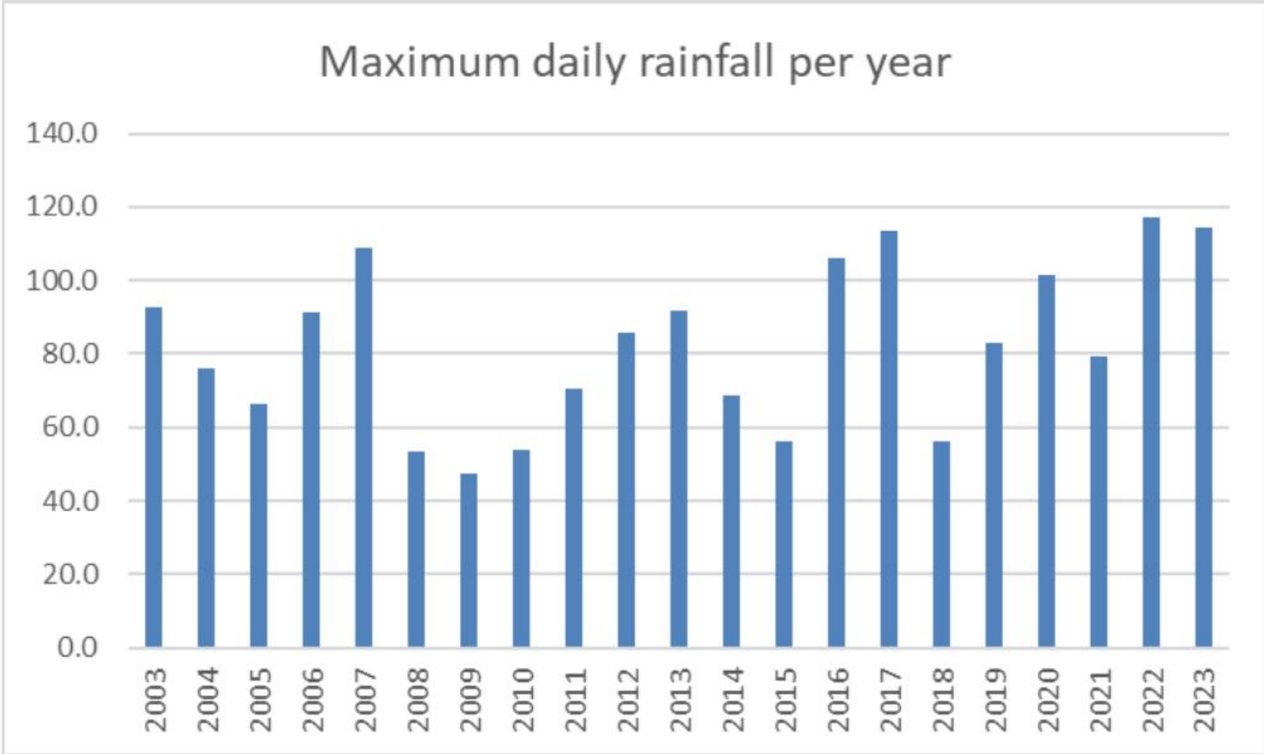


Figure 65: Maximum daily rainfall per year (2003-2023) (World Bank Group, 2017)

After communication with Lorenso Kasmani from the 'Meteorologische Dienst Suriname' (Suriname Meteorological Service) it was concluded that a value of 50 mm/hour could be used as the maximum rainfall in Suriname in calculations (L. Kasmani, personal communication, 18 March 2024). This is the maximum the Meteorological institute uses itself. This is the value that will be used from now on.

Further steps:

The best way to use maximum precipitation levels is by conducting an IDF. After an appropriate timespan is chosen, the corresponding precipitation levels can be read from the IDF. That way measures can be better adjusted to long and short term precipitation events.

It is quite time and data intensive to make an IDF. Contact with the meteorological institute proved unfruitful and no IDF seems to be publicly available for the Marowijne region. It is often that little information is available about rainfall intensities, in particular for the short durations needed for design of urban drainage systems in small urban catchments (Parkinson et al., 2007).

Climate change will have a big influence on the precipitation in the tropics. Both extreme droughts and rainfall events will increase. It is estimated that for every 1 degree (C*) of global temperature rise rainfall extremes in the tropics will be 10% heavier (O'Gorman, 2015). While we were in Suriname, it was already noticeable that it was unusually dry, while the year before there had been big floods. Climate change is already hitting the country, and it can be expected that rainfall levels will also be influenced. Further research on the impacts of climate change on precipitation would be helpful to mitigate the effects of climate change, by preparing for appropriate levels of rainfall.

Infiltration

In ecosystems, one of the main services provided by soils is water management (Adhikari & Hartemink, 2016). Urbanisation impacts the water regulating properties of soils through hardening, subsidisation and the removal of vegetation (Butler & Davies, 2000). These result in changes in water movement, soil permeability, hydraulic conductivity, and infiltration capacity (O'Loughlin et al., 1996).

In the modelling of the flow scheme of Ricanau Mofo, the area has been divided into 3 coverage types: rooftops, open ground and vegetation. Although simplified, this division aims to model the infiltration and runoff rate as accurately as possible through different infiltration and drainage factors.

Rooftops

Infiltration factor of either 0 or 1.0, depending on whether there is a working gutter with a rain barrel. If there is no barrel nearly 100% of the water flows to the ground, causing the splash erosion visible in the ground below the roof in the form of small gutters.

Clay ground

Water falling on the open ground will partly infiltrate. The amount of infiltration depends on the type of soil, saturation, slope (Butler & Davies, 2000) Unplanned and informal establishment of settlements result mostly impermeable surface and, consequently, local flooding (Abd-Elhamid et al., 2020). This is also the case in Ricanau Mofo, where large parts of the settlement area consists of compacted clay.

Usually, infiltration of water into the surface soil is the largest 'flow' of rainwater in natural areas (Pitt et al., 2003). However, due to compaction and urbanisation most water will not infiltrate but rather run-off.

The runoff rate is the excess of the rainfall intensity greater than the infiltration rate. For clayey soils, especially when they are compacted (as is the case in Ricanau Mofo), the infiltration rate is very low. This is graphically visualised in figure 66.

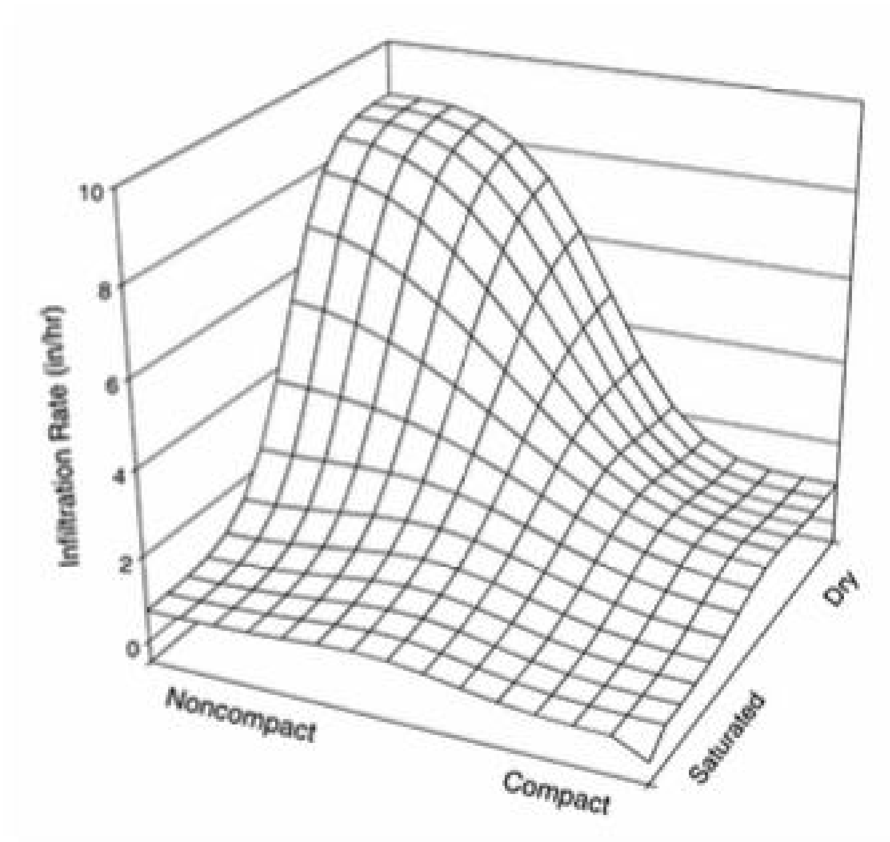


Figure 66: three dimensional plot of infiltration rates in clay (Pitt et al., 2003)

In the tests performed by Pitt et al. (2003), the average rate of infiltration in compacted clayey soils (with clay percentages between 30 and 98 percent) was 5 mm/h.
From the experiments from Kuok et al. (2023) in Sarawak, Malaysia, an even lower infiltration rate of 0.852 mm/h was found.
After communication with Tom Bogaard from the TU Delft it was concluded that for the case of Ricanau Mofo, a value of 5 mm/hour would be too high and should be chosen a factor 10 lower (T.A. Bogaard, personal communication, 8 April 2024). This leads to a value of 0.5 mm/hour, which is the value that is used in calculations from now on.

This number is very low compared with the tropical rainfall intensity, and this will thus quickly generate substantial runoff because the infiltration capacity at the upper soil surface is surpassed, even though the underlain soil might still be dry.

Vegetation

Both the infiltration rate as the maximum infiltration of vegetated patches are higher than those of bare ground (FAO, 2024). The roots create bioturbation macropores which allow small flow paths. Macropores can also increase the surface porosity and promote aeration of the soil (Gabet & Seabloom, 2003). Through these macropores, water infiltrates into the soil adjacent to pore walls (Gabet & Seabloom, 2003). Also, the vegetation transforms the soil from mostly clay-loam to a more mixed soil matrix. The soil beneath vegetated patches receives much larger organic matter input in the form of plant debris compared to bare soil. This helps to maintain a more active soil biotic system (Puigdefábregas 2005). This biological activity helps with building stable soil aggregates, which influence the soil structure and leads to increased water storage capacity and decreased soil erodibility.

The best protection for soils is a functioning forest ecosystem, with a functioning canopy and multiple layers of different trees, shrubs and grasses. However, experiments from Joshi & Tambe (2010) showed that just a grass cover already increases infiltration rates and reduces erosion by over 25%. A side benefit from vegetation is that the plant cover provides protection against the rain-drop impact and lessens the crusting effect (FAO, 2024).

Experiments by Nugroho & Hadi (2021) at the urban forest in Surabaya, Indonesia, showed that constant infiltration rates at compacted and vegetated clay soils were a lot higher than that of bare compacted clay soils, at 12.5 mm/h.

Urban Morphology Ricanau Mofo

Within the old centre of Ricanau Mofo it is not possible to understand the water flows without inclusion of urban morphology. Urban morphology includes the spatial analysis of urban structures, street patterns, open space and buildings (Kropf, 2017; Ravari and Mazloomi, 2015). The reasons are that the water flows in the centre are mostly influenced by the informal scattering of buildings and different area covers (rooftops, vegetation and hardened clay) have a big influence on infiltration and erosion rates.

The old centre of Ricanau Mofo and the current urban morphology is shown in figure 67.

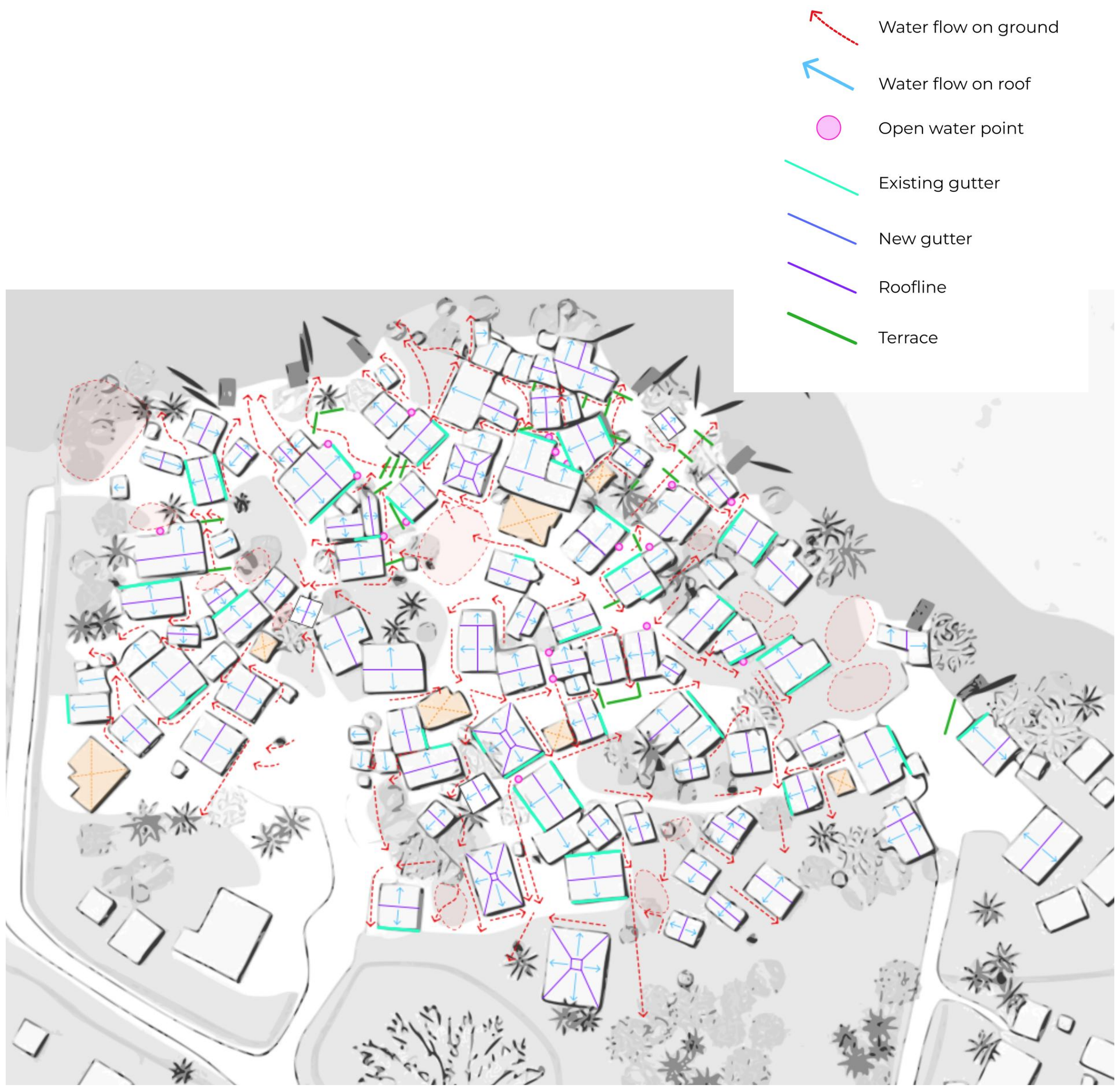


Figure 67: The old centre of Ricanau Mofo and its current morphology

What are the current interventions implemented?

The problem of erosion has not gone unnoticed to the people of Ricanau Mofo and they have applied a couple of different types of measures. They have noticed that vegetation traps the soil and therefore some people have been planting trees. Furthermore, they have put wooden planks in the ground in order to trap the soil in steep areas and some houses have roof gutters attached to their house.

Figure 68: current interventions against erosion in Ricanau Mofo

Vegetation

The vegetation in the village has not been intentionally placed as intervention against erosion. Rather, it is the result of ground not being occupied. An example can be seen in figure 69. Inhabitants of Ricanau Mofo usually remove any vegetation around their houses to combat pests and snakes. Apart from that, it was mentioned in interviews that there is a cultural belief that (most) plants such as grasses should be removed in order for the property to be properly maintained.

As explained before, effects are highly visible in erosion levels in the village. Most areas with vegetation have retained the soils while soil around it has eroded, leaving 'islands' of plant covered higher grounds.

Apart from the small plants, spread around the village are large trees. Some are tens of years old and have extensive root systems. Due to erosion much of these roots are laid bare. Apart from making erosion visible, these trees also stem further erosion and sediment disposal with roots often perpendicular to the runoff streams. These roots have to be taken into account when designing drainage systems.

Figure 69: example of vegetation

Terraces

In an attempt to stem soil erosion villagers have built improvised terraces from wooden planks as can be seen in figure 70. These seem to be quite effective as most retain their height in soil behind them. Some are in bad shape, and either deteriorating at the top or having visible scour at the bottom.

These terraces have been implemented by individuals and therefore lack planning or structure, and are made with different kinds of woods and sizes.

Having a proper structure in the terraces could help steer water flows to reduce erosion and water nuisance.

Figure 70: example of wooden plank terraces

Figure 71: example of a roof gutter

Gutters

Various houses have gutters but most are in bad shape. Interviews with villagers showed that the gutters with a connected rain barrel or water storage were implemented in many houses as the main source of fresh water besides the river. However, in 2019 the SWM has implemented a village wide fresh water network which has removed the need for rainwater as a freshwater source. The big rain barrels, which were bought with assistant finance from the Inter American Development Bank, are often not in use anymore (Vandermeeren, 2023). The water in these barrels was never used as drinking water but was used for washing and other uses.

A negative side effect from the connection to the SWM waternetwork is the decay of many of the gutter systems as they are not maintained. For other houses, the gutter system is still hanging but misses a connection to either a container or a proper drainage. Placement of rocks below the gutter exit helps reduce erosion at some houses, while at others soil is eroding at a hole shape below the gutter exit.

An example of a gutter attached to a roof can be seen in figure 71.

How is the drainage system of Ricanau Mofo organised?

In order to understand how the rainwater is behaving in Ricanau Mofo, it is important to know how the water is currently finding its way from the village to the river or the other drainage channels currently present. That is why in this chapter the hydrological dynamics in the old centre of Ricanau Mofo during a rainfall event of 50 mm/hour will be modelled. The schematised waterways including the flowareas based on figure 67 are shown in figure 72. The flow areas are based on the connected waterways where water flows in the same direction during rainfall. A more detailed explanation of how these flow areas were estimated can be found in appendix B.1.

Understanding the flow areas

Figure 72: Quantification of the flow areas in Ricanau Mofo

Open areas

To also take into account the water that does not fall on the roof, but rather falls on the ground, also the water intake on the ground is important. For this we classified the soil into two classes, clay and vegetation. For clay we took an intake of 0.5 mm/hour and for vegetation we took an intake of 12.5 mm/hour. The division per flow area can be seen in figure 73.

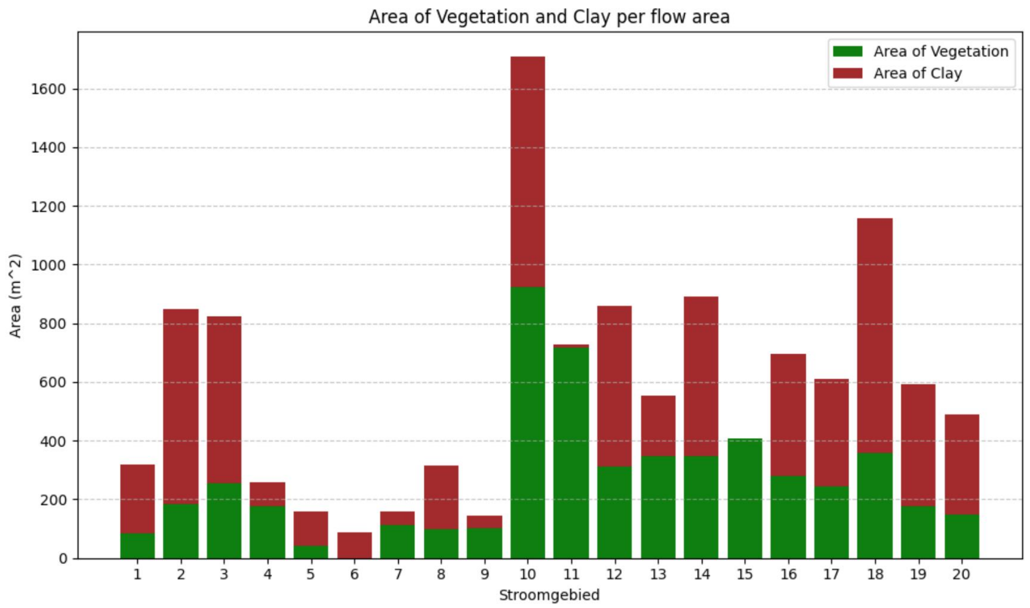


Figure 73: area of vegetation and clay per flow area

When knowing which open surfaces flow to which channels, figure 74 can be constructed, showing the intensity of waterways taking into account the whole old centre of Ricanau Mofo.

The different flow areas can be ordered by the maximum amount of water that flows through it. This is the amount of water that flows through the 'last' waterway before the water reaches either the river or another channel around the old centre. The barchart is shown in figure 75.

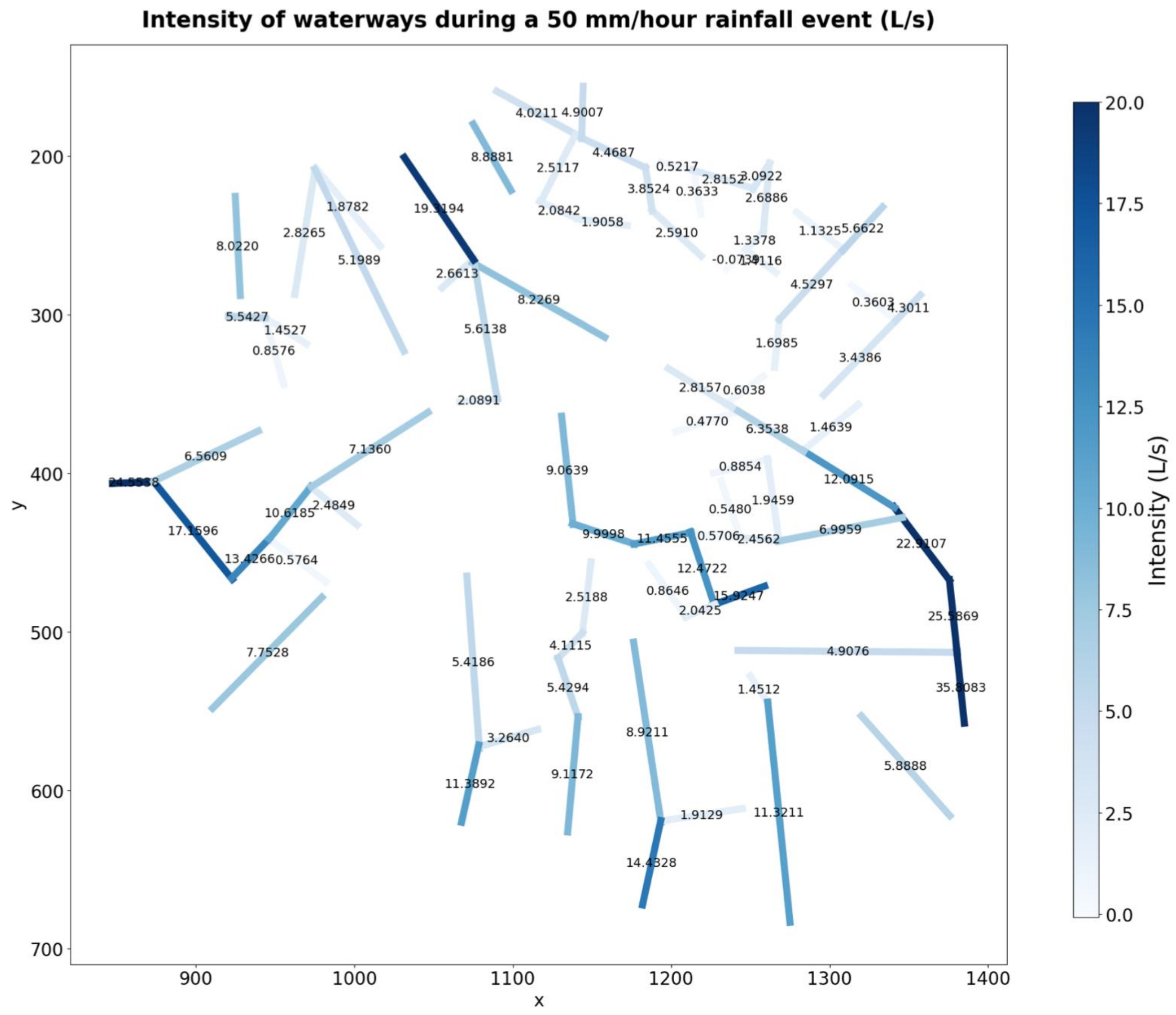


Figure 74: intensities of waterways during a 50 mm/hour rainfall event.

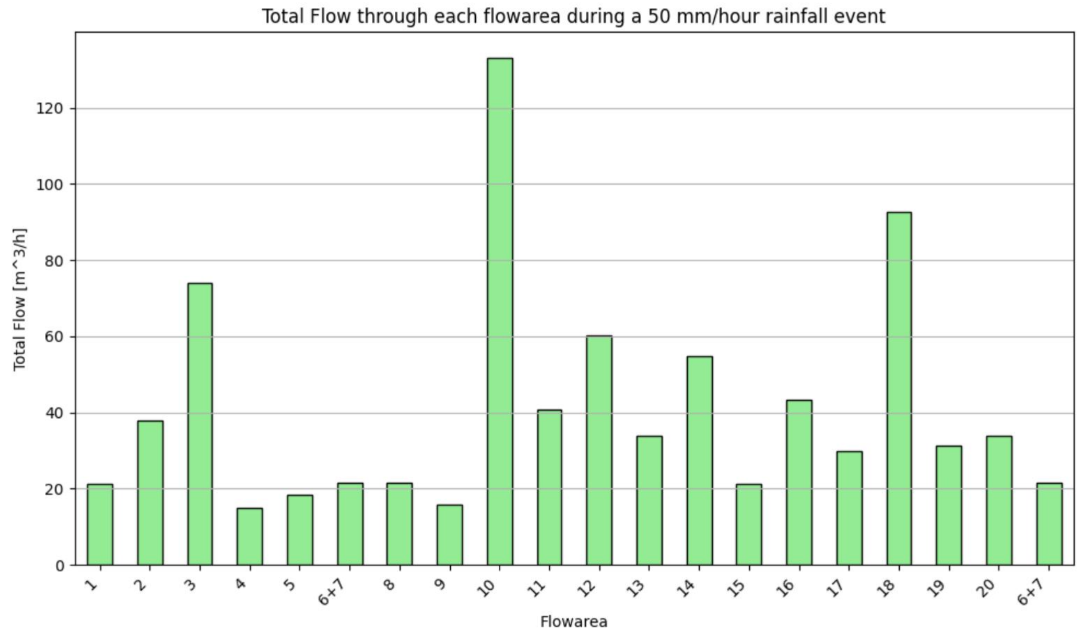


Figure 75: total flow per flow area during a 50 mm/hour rainfall event.

Slope

Another important factor that indicates whether erosion will take place is the slope of the waterways. In figure 76 the elevation map of Ricanau Mofo can be seen.

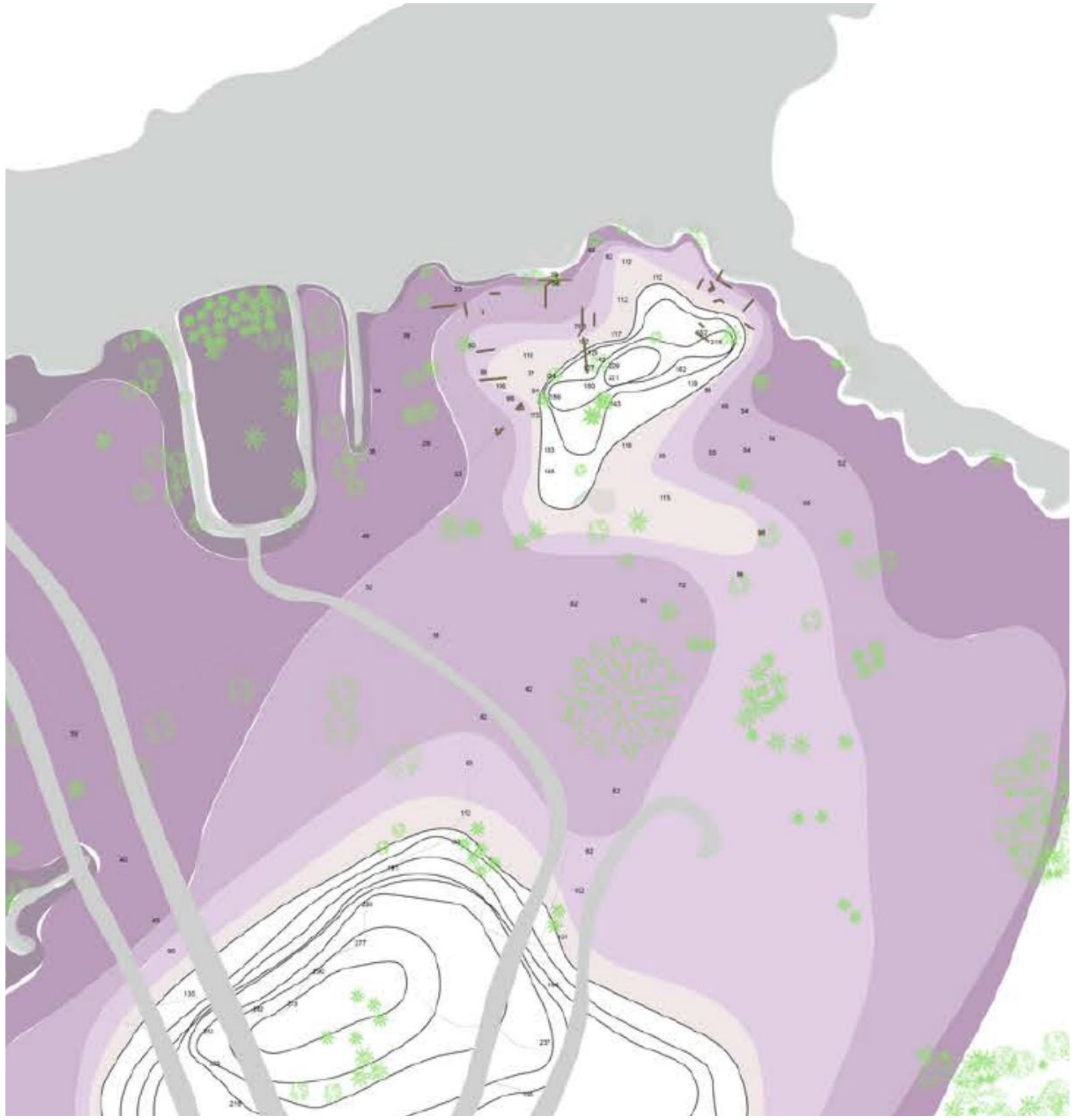


Figure 76: evelation map of Ricanau Mofo (Vandermeeren, 2023)

Based on this elevation map, the slope can be determined per waterway and figure 77 can be made.

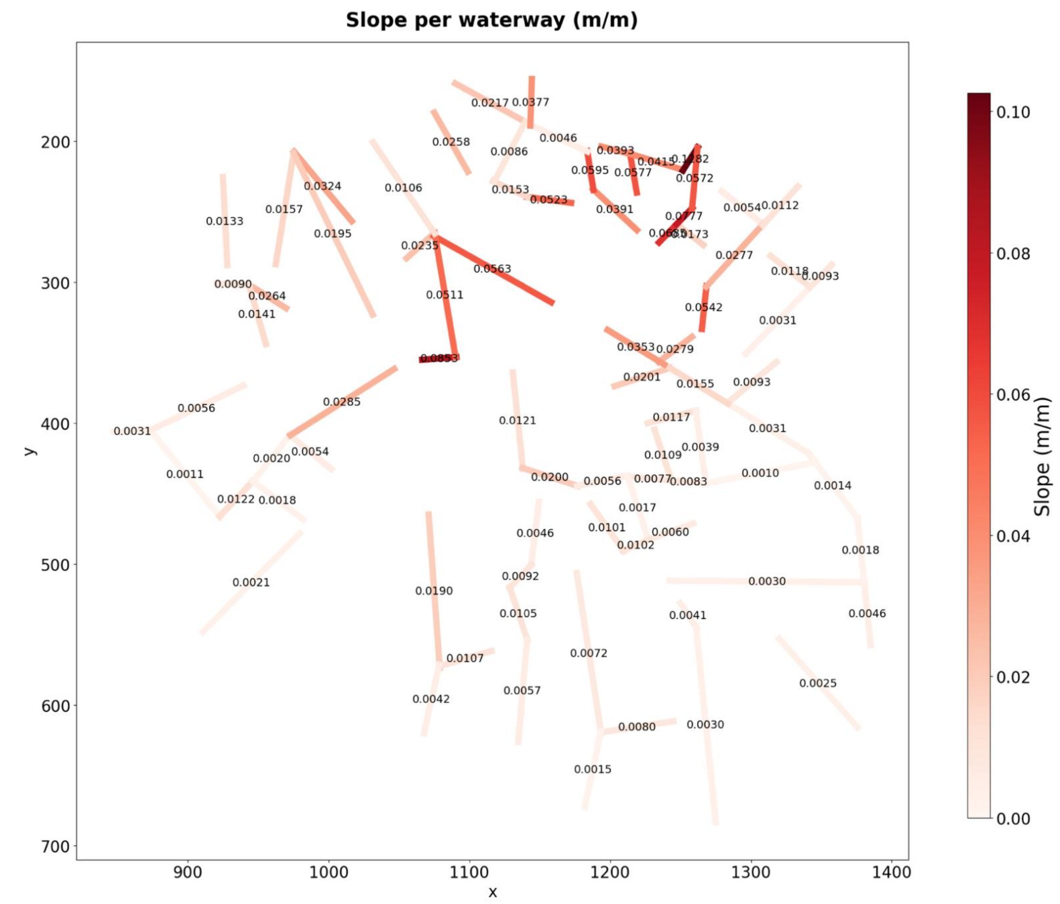


Figure 77: slope per waterway

In figure 78 the average slope per flow area is depicted. It can be noticed that especially the areas at the northern side of Ricanau Mofo, which are closer to the river, are steeper compared to the areas further away from the river.

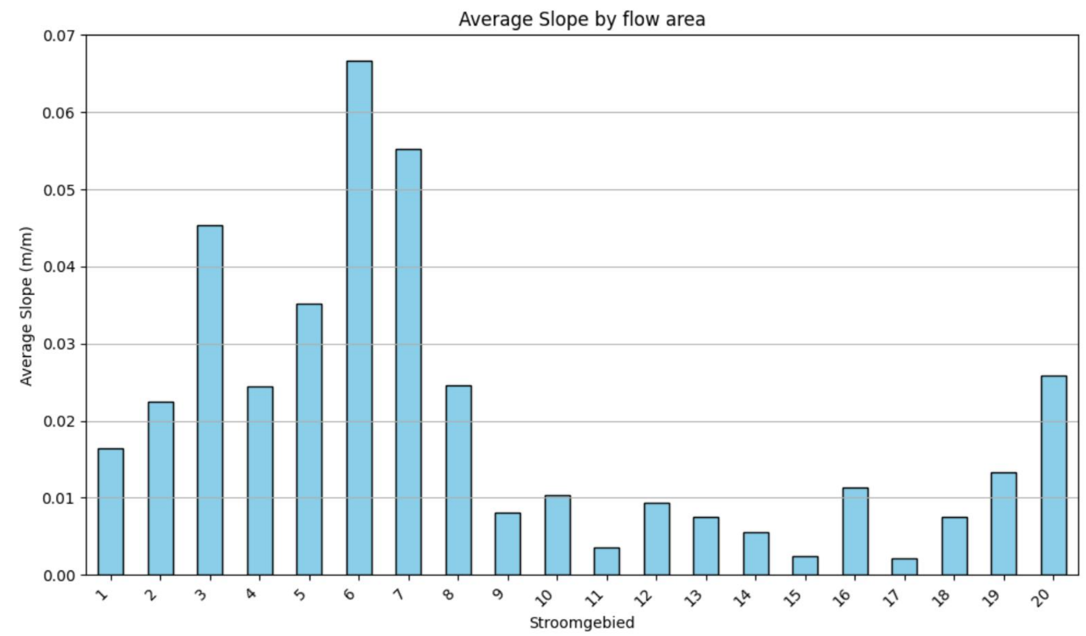


Figure 78: slope per flow area

Classification flow areas

Based on the amount of water flowing through each waterway, the ground classification of each flow area and the average slope of the flow area the different flow areas can be classified. The areas will be classified in the following categories: Areas with high average slope, areas with high clay percentage and areas with high discharge. These classes have been chosen as they all contribute to erosion. In Table 12, the areas are assigned to classes according to their specific percentages. In figure 79 the area classes have been visualised.

Table 12: Classification of flow areas

Flow Area	High slope	High clay %	High discharge
1		x	
2	x	x	
3	x	x	x
4	x		
5	x	x	
6	x	x	
7	x		
8	x	x	
9			
10			x
11			
12		x	x
13			
14		x	
15			
16		x	
17		x	
18		x	x
19		x	
20	x	x	

Areas with high average slope

One of the most important factors in soil erosion due to water is the flow velocity of the water. This is partly determined by the slope of the area and therefore it can be stated that areas with a higher average slope are more prone to soil erosion than areas who have a flatter ground surface due to the simultaneous increase in the amount and energy of surface runoff (Delgado et al., 2021).

Flow areas 2-8 and 20 all have an average slope larger than 0.02 m/m as can be seen in figure 78 and are therefore classified as areas with high average slope.

Areas with high clay percentage

Areas with more clay instead of vegetation are also more prone to erosion because the roots of the vegetation will stabilize the soil and keep it in place during high rain intensities. Furthermore, clay soil can take up less water compared to clay soils with vegetation. As can be deducted from figure 73, Areas 1-3, 5, 6, 8, 12, 14, 16-20 all have a percentage of clay that is above 60% and can therefore be classified as areas with high clay percentage.

Areas with high discharge

Areas with high discharge are also more prone to soil erosion. The total flow through an area depends on the rain conditions, but for this classification the total flow through an area during a rainfall event of 50 mm/hour as is depicted in figure 75 will be used. Flow areas 3, 10, 12, and 18 all have a discharge higher than 60 L/s and can therefore be classified as high discharge flow areas.

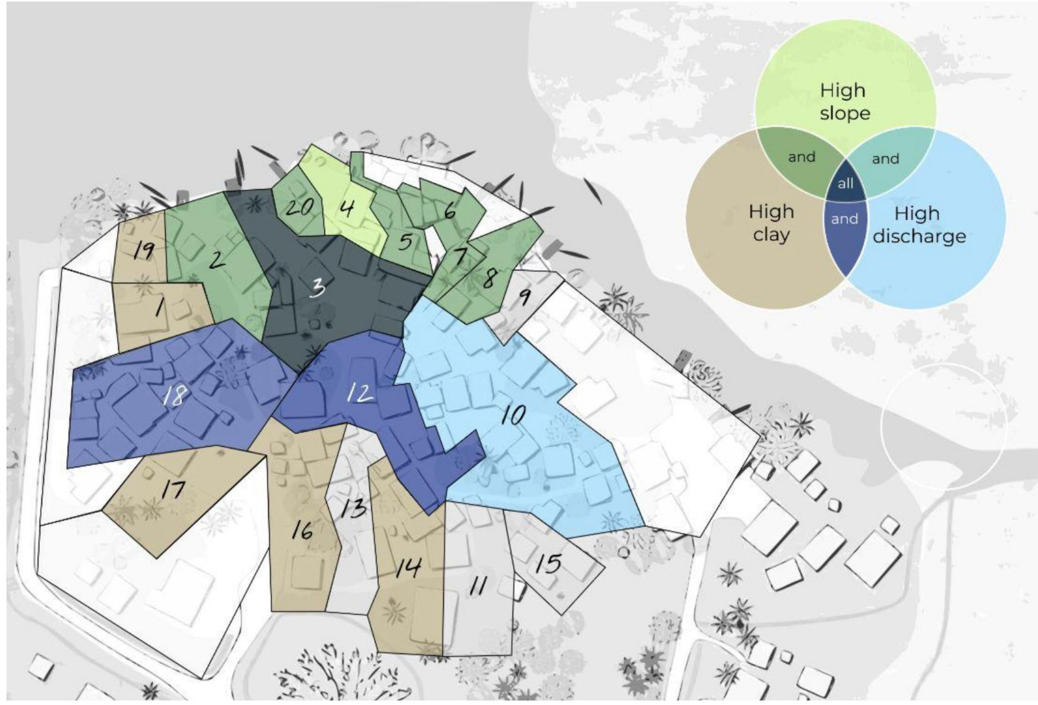


Figure 79: Classification of flow areas

Green areas indicate areas with a high slope, brown areas indicate areas that consist of mostly bare clay and blue areas indicate areas that have a high discharge.

On the northern side of the old centre of Ricanau Mofo, close to the river, the areas are steeper compared to the areas more far away from the river. These areas also mostly consist of bare clay instead of vegetation. Areas with a large surface also have a high maximum discharge, areas 10, 12, 18 and 3 are an example of this.

Which areas are most at risk to erosion?

Based on table 12 a couple of critical areas can be determined that are more vulnerable to erosion than other areas. These areas are: 2, 3, 6, 10, 12, 14, 18 and 20.

Flow area 2
High slope and high clay percentage
Total area: 874.5 m^2
Percentage clay: 67.7 %
Percentage vegetation: 32.3 %

Flow area 2 is the area close to the riverside and the water in this area finds its way to the river just left of the dam built by the previous group. Due to this high clay area the area is prone to erosion. This area comprises three small waterways finding the river at the same location.

Flow area 3
High slope, high clay percentage and high discharge
Total area: 1644.4 m^2
Percentage clay: 76 %
Percentage vegetation: 24 %

Flow area 3 is the area in the centre of the old village close to the riverside. The area is relatively large and the ground consists mostly of clay. Furthermore there is quite a steep slope, making the area vulnerable to erosion. This can also be seen in figures 80.

Figure 80: erosion in area 3.004

Flow area 5
High slope and high clay percentage
Total area: 342.6 m^2
Percentage clay: 73.7 %
Percentage vegetation: 26.3 %

Flow area 5 is a relatively small area with quite a steep slope and mainly clay. Because this area is relatively small, the amount of erosion taking place is also not excessive, however, erosion next to houses can significantly be seen. Area 5 is also less interesting because one of the main houses that experiences erosion next to its foundations due to the waterway in area 5 is deserted.

Flow area 6 & 7
High slope and high clay percentage
Total area: 488.5 m^2
Percentage clay: 61.6 %
Percentage vegetation: 38.4 %

Flow area 6 is also a relatively small area with a steep slope consisting of only clay. The area is combined with 7 because waterway 6 and 7 both find the river at the same location. Because of the high density of buildings in this area, water is concentrated in a small channel, causing erosion next to the houses (figure 90.1). Furthermore, the waterway in this area finds the Ricanau river at the same location as where the flow from area 7 finds the river, causing erosion at the terraces at the riverside (figure 90.2).

Flow area 10
High discharge
Total area: 2870 m^2
Percentage clay: 47 %
Percentage vegetation: 53 %

Flow area 10 is the largest flow area and therefore the total discharge at 10.001 is the highest. It comprises two waterways that come together in the waterway 10.004. In the areas 10.001 - 10.004 the ground is mostly flat, which is one of the reasons why this area has a low average slope. However, more upstream in this area, the slope increases quite significantly. In one of the waterways that joins in at waterway 10.004, consisting of 10.005, 10.009-10.013, the slope is substantially higher than in the rest of this flow area. Furthermore, the high discharge results in quite significant erosion downstream at 10.003 as can be seen in figure 91. However at 10.001, the erosion is less severe due to high levels of vegetation and a lower slope as can be seen in figure 91.2. This stream finally ends in a highly vegetated area as can be seen in figure 91.2.


Figure 90.1 and 90.2, erosion in area 6 along waterway 6.003 and 6.002 (90.1) and at the terraces at the riverside (90.2)


Figure 91.1, erosion at waterway 10.003
Figure 91.2,

Flow area 12
High discharge and high clay percentage
Total area: 1471.6 m^2
Percentage clay: 63.7 %
Percentage vegetation: 36.3 %

Flow area 12 is relatively a large area, resulting in a high discharge at 12.001. It is an interesting flow area because it is the only flow area where the rainwater does not flow to the outskirts of the village. Rather it flows to an area with high levels of vegetation as can be seen in figure 92.

Flow area 18
High discharge and high clay percentage
Total area: 2130.4 m^3
Percentage clay: 69 %
Percentage vegetation: 31 %

Flow area 18 is a large area at the western side of the old village. Because it is quite large, the discharge at 18.001 is also quite high, causing severe erosion at this point as can be seen in figure 93.1. Further upstream of this flow the slope increases causing erosion next to the houses in this densely populated area as can be seen in figure 93.2.

Flow area 20
High slope and high clay percentage.
Total area: 231.9 m^3
Percentage clay: 70 %
Percentage vegetation: 30%

Flow area 20 is a relatively small area close to the Cottica river. The small open area within this flow region is predominantly composed of clay. This, combined with a high slope, makes the area prone to erosion.

Figure 92: waterway 12.001 ending in an area with high levels of vegetation.

Figure 93.1, erosion at waterway 18.001.
Figure 93.2, erosion at waterway 18.008.

6.5 Exploring solutions

Possible interventions

As the problem of erosion is quite versatile, the solutions are also varied and diverse. Because of this, the solutions are grouped in three different categories. The first is roof water erosion, which includes interventions that mitigate erosion caused by water falling off the roofs directly next to the houses. The second category is erosion of open spaces, where the different interventions mitigating erosion of open places, such as public spaces will be discussed. The third category includes different possibilities for the channel system. Once the water is collected, it needs to be guided to the river or larger channel for which there are multiple different types of interventions.

Roof water erosion

Gutters

One of the possible solutions is to provide the whole city of Ricanau Mofo with gutters. Gutters are effective in preventing erosion as they prevent splash erosion next to the houses. This specific splash erosion is especially dangerous as it causes erosion next to the foundation of the houses.

Roof gutter

The most obvious type of gutters are roof gutters, widely applied in developed countries to catch the water from the roofs. The roof gutters prevent splash erosion next to the houses and need to be maintained regularly. Roof gutters typically have a lifetime of 20 years (Alexandre & Figueroa, 2024).

There are some houses where roof gutters are already applied. These can be seen in figure 94. These gutters have been applied by the citizens of Ricanau Mofo to catch the rainwater in large tanks for personal usage. However, since a couple of years, Ricanau Mofo has been connected to the SWM (Surinamese Water Company) water, making the storing of water unnecessary. A large part of the existing gutters are therefore not in excellent shape and would require maintenance to be fully functional.

In total, the old centre of Ricanau Mofo would need around 1800 m of roof gutters. In a rainfall event of 50 mm/hour, these would catch 43.2% of the water currently falling on the ground and causing erosion. These can be applied by the people themselves, or they could be helped by the government in the form of government subsidies.

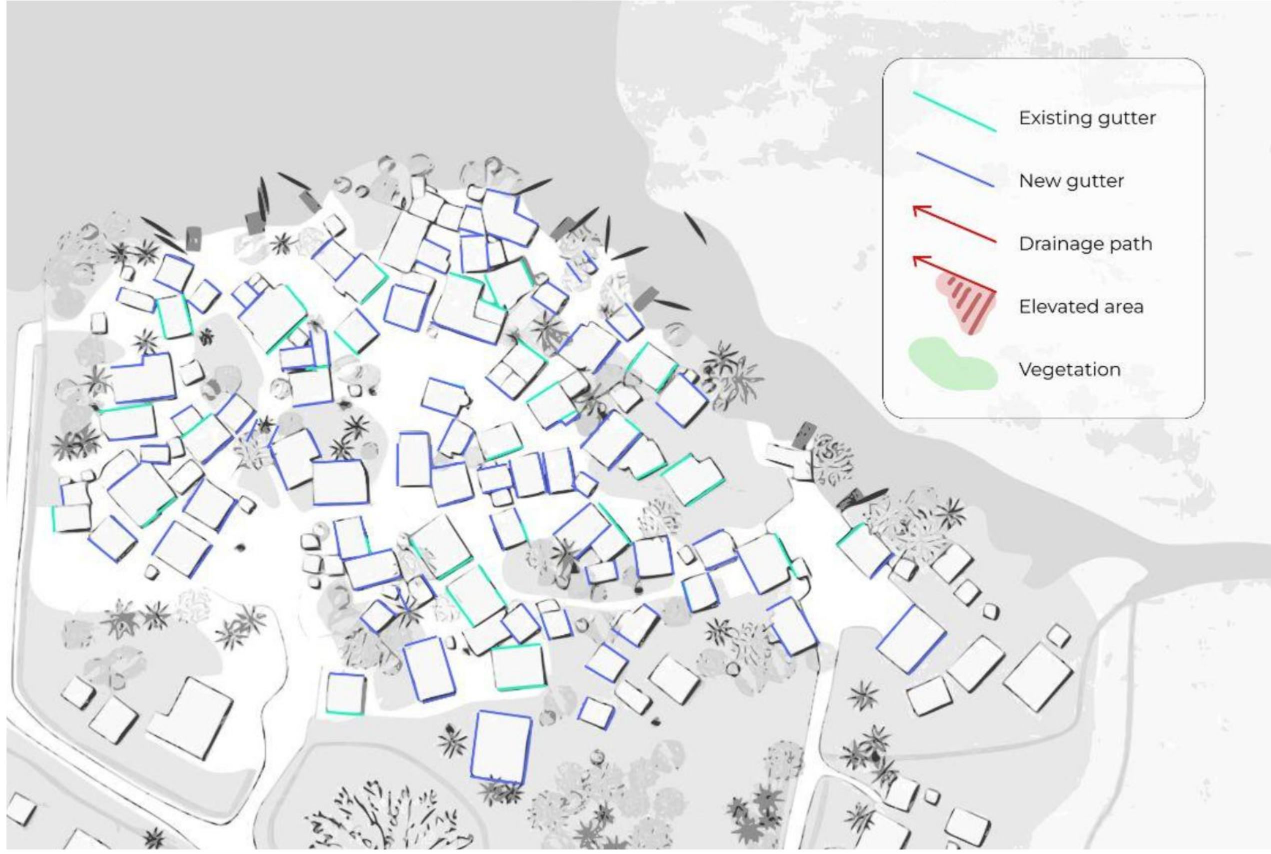


Figure 94, existing gutters and to be applied gutters.

Ground gutter

This solution consists of a (semi-)hard material placed on the ground at the spots where the water that is coming from the roof falls on the ground. It has as its main function the damping of the rainfall falling from the roof to prevent splash erosion right next to the foundation of the house.

The ground gutter could be placed in such a way that they are connected to a channel system guiding the water to the river. However, compared to the roof gutter, this system would not be as effective in letting the water runoff as water has a higher chance of escaping the gutter when falling down.

This system would also require regular maintenance. The lifetime, if applied correctly, can be stated to be comparable to the lifetime of the roof gutter.

Erosion of open spaces

Cocos sheets

Cocos sheets can be placed on the ground to hold the sediment in place and to provide a fertile soil for vegetation to flourish, which also counteracts erosion. In figure 95 an example of cocos sheets can be seen. Cocos sheets, if placed correctly, require little to no regular maintenance and are biodegradable. Furthermore, cocos sheets should be able to remain in place for a long time. Cocos sheets are not available in Surinam at the moment.

Figure 95, cocos sheets

Vegetation

For open areas, other solutions needed to be found to combat erosion. As discussed in chapter x, vegetation in clay ground can take more water compared to bare clay soils. When more vegetation is planted in the areas where the water intensities, as can be deduced from figure x, are high, more water will be taken up by the soil. Which will decrease the water which can contribute to erosion.

When planting plants or trees in the clay soil, it is recommended to plant them slightly elevated above ground level (Sierra Azul, 2022). This will improve drainage and survival rates for the plants.

This solution is mainly applicable in areas where there is not a lot of vegetation already and could offer a solution for areas that do not have a steep slope.

Terraces

Terraces are a familiar solution to the people of Ricanau Mofo. They have been applied at various places in the old centre as can be seen in figure 96. It can be noticed that they have mainly been applied in areas where the slope is significant. Terraces are most functional in areas where there is a significant slope (> 2%).

Figure 96, the currently present terraces are depicted in green.

Terraces also need some maintenance, as they lose their functionality when they are not properly maintained. An example of a broken terrace can be seen in figure 97. If maintained properly the lifetime is high.

Figure 97, broken terrace

Geogrid

Geogrid is a geosynthetic material used to reinforce soils and similar materials. It is widely used for roads and train tracks. An example can be seen in figure 98. It increases the shear resistance of the soil. It essentially traps the soil and it can therefore be used on open areas with a mild to steep slope to prevent erosion. It requires little to no maintenance and has a high life time.

Figure 98, geogrid

Semi-circular bund

Semi-circular bund are half moon shaped excavations that are meant to trap moisture (figure 99). By trapping moisture, they make a perfect breeding ground for vegetation. Furthermore, this also makes the soil more prone against erosion. Eyebrow terraces do need quite some space to be fully functional. According to Mekdaschi & Liniger (2013) they require a diameter of 2-8 metres and they are applied on slopes up to 15%, however earthen bunds are rarely used on slopes steeper than 5%, receiving more than 300 mm/y of rainfall. Surinam has on average 2200 mm/y, which makes them difficult to implement in Ricanau Mofo.

Figure 99, eyebrow terraces

Gabion wall

In tactical places in the villages gabion walls can be placed to create terraces. These terraces retain soil. In comparison with wooden terraces they are stronger and have a longer life span. Water can diffuse through the crevices while larger debris and sediment will retain in the wall. depending on the rock size in the cage the diffusion factor can be influenced. The gabion walls require little to no maintenance and should last a long time if placed correctly. In figure 100 an example of gabion walls can be seen.

Figure 100, gabion wall

The installation of gutters brings the necessity of effective drainage for the collected water. Therefore, as an integral component of the solution, a channel system must also be implemented.

To quantify how much water would be drained when gutters are placed figure x has been constructed. In this figure the intensity through the channels are shown when only taking into account the water falling on the roofs.

Channel system

The installation of gutters brings the necessity of effective drainage for the collected water. Therefore, as an integral component of the solution, a channel system must also be implemented.

To quantify how much water would be drained when gutters are placed figure 101 has been constructed. In this figure the intensity through the channels are shown when only taking into account the water falling on the roofs.

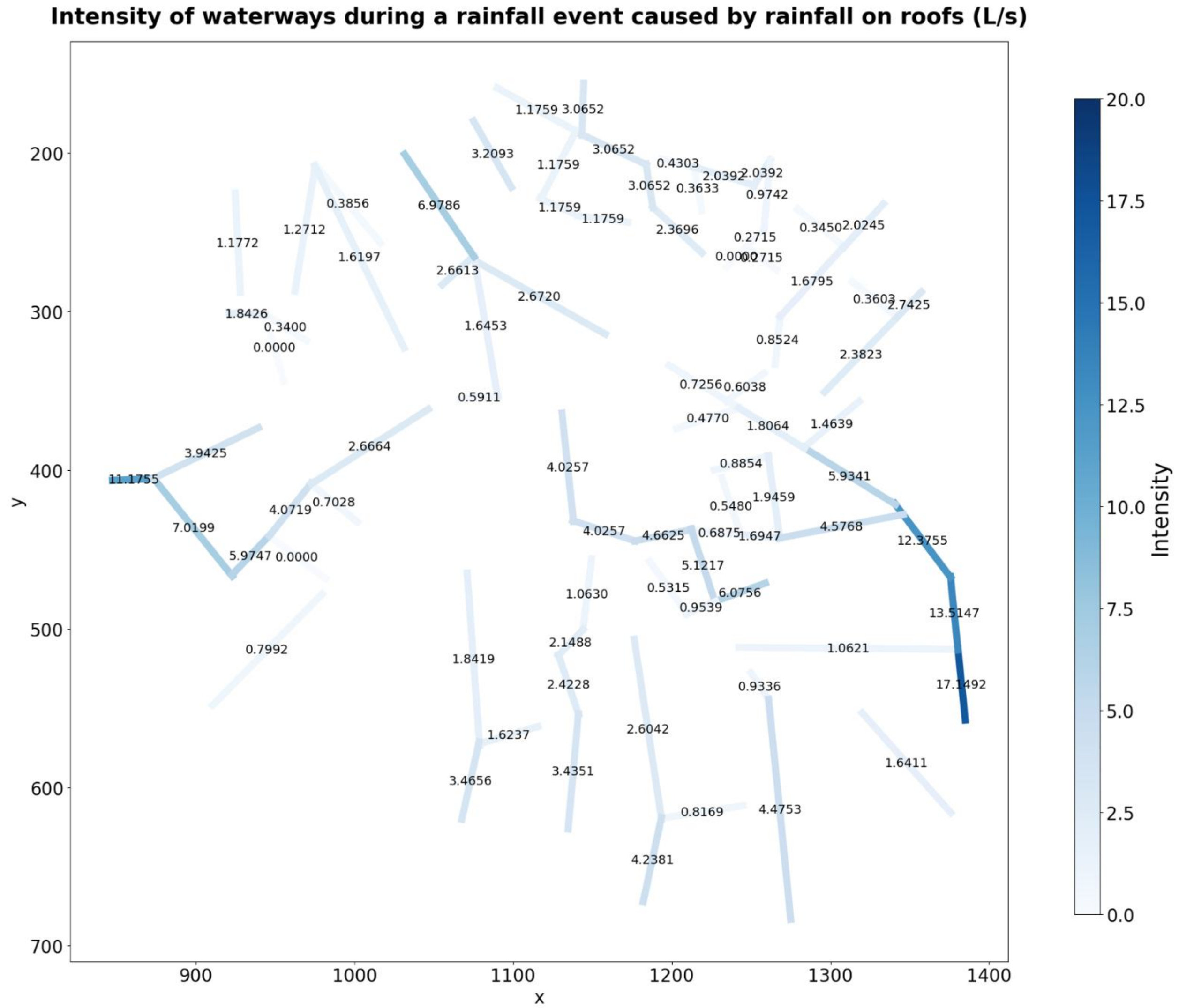


Figure 101, intensities of waterways during a 50 mm/hour rainfall event.

Because the water must be drained, a slope is required to encourage good flow to the river or the channels surrounding the old centre. A slope of approximately 2% is required to encourage good flow. The average slope of areas 1, 9-19 is below this 2%, meaning that in this area it is likely that a gutter system with trench drain is not possible. However since this is an average slope, this does not mean that for certain areas in a flow area a gutter system with trench drain is not possible.

For flow areas 2-8 and 20 the slope is above 2%, indicating that a gutter system with channels can be applied in these areas.

For the channels there are two main possibilities, hardened or unhardened channels.

Hardened channels

Hardened channels include channels made from u or v shaped concrete elements as can be seen in figure 102. These elements can be placed in the ground and should be put in connection with the gutters. The advantage of such a system is that there will be minimal erosion due. However, if the system is implemented incorrectly or fails over time and the water is not guided through the channels, it might lose its function completely.

Vegetated channels

The application of vegetated channels is a more nature-based solution (figure 103), involving the addition of vegetation to the dug-out channels. This vegetation keeps the ground together when high levels of water pass through. Furthermore, this vegetation increases the intake capacity of the soil which decreases the total discharge that runs through the channels.

This type of channel does require more space than the hardened channel. According to Harris et al. (2015) the vegetated channel will need to be around 25-50 centimetres deep and 1-2 metres wide. Due to the high density of houses in the old centre of Ricanau Mofo, this might be too wide for some parts of the area and might take up all the space for walking.

Figure 102, concrete u channel.

Figure 103, vegetated channel.

6.6 Multi-Criteria Analysis (MCA)

Selection criteria for solutions

In order to determine the most effective solutions to combat erosion in Ricanau Mofo a couple of selection criteria have been set up. These criteria will be used to create a multicriteria analysis based on which the different solutions will be tested. Aesthetics has not been selected as one of the criteria for these solutions like has been done in chapter X. This is because aesthetics is considered to be subjective and what the writers of this report consider as good looking might be completely different from what the people of Ricanau Mofo consider as good looking.

1. Effect on soil/sediment retention
The most important aspect of the possible solutions is its capability to combat erosion. It can do so in multiple ways, by decreasing water flow, by increasing permeability of the soil or by hardening of the soil.

2. Controlled water runoff
Controlled water runoff is another important aspect of a possible solution. Currently, the water flows naturally through the village from high to low, disregarding obstacles in its path. By implementing control measures, the flow of water can be directed to minimise disruption and reduce erosion.

3. Maintenance
Another important aspect of a possible solution is the degree of maintenance. As there is not a lot of materials and (technical) expertise available in the village itself, it is important that regular maintenance is minimised. If maintenance is required it should not be difficult and doable by the people of Ricanau Mofo themselves.

4. Life expectancy
Next to the functionality of the possible solution, the life expectancy is another important aspect. If the life expectancy is high, the solution will contribute to a future proof Ricanau Mofo.

5. (negative) Impact on community
This criteria takes into account the impact of the intervention on the people of Ricanau Mofo. A possible solution should minimise interference with the traditional life of the people in Ricanau Mofo. A solution that is familiar to them is therefore preferred.

6. Sustainability of materials
By prioritising sustainable materials practices, you can support both local communities and global efforts towards a greener, more sustainable planet.

Results MCA

For the multi-criteria analysis, each selection criterion of the section above has been assigned a weight score. These scores vary from 0 (not important at all) to 10 (very important) and can be found in table 13.

Table 13, weighted scores criteria

Effect on erosion	10
Controlled water runoff	6
Maintainability	8
Life expectancy	7
(negative) Impact on community	6
Sustainability of materials	2

Then, each intervention has been assigned a score for each selection criterion varying from 0 (does not meet the desired criteria) to 2 (meets desired criteria very well). In appendix B.3, a detailed breakdown and explanation of the weight scores assigned to the criteria are given and explained.

In the MCA, the score of the intervention per criterion is multiplied by the score of the importance of the criterion. The final score is the total score of the intervention on a scale of 0 to 2.

Table 14, multicriteria analysis

Intervention	Effect on erosion	Controlled water runoff	Maintenance	Life expectance	(negative) Impact on community	Sustainability of materials	Total score	Assigned overall score
Roof gutters	2	2	1	2	2	0	169,23	1,69
Ground gutter	1	1	1	2	1	1	117,95	1,18
Cocos sheets	1	0	2	2	1	2	128,21	1,28
Vegetation	1	0	2	2	2	2	143,59	1,44
Eyebrow terraces	0	0	2	2	1	2	102,56	1,03
Wooden plank terraces	1	1	1	1	2	2	120,51	1,21
Gabion Wall	1	0	1	2	0	1	87,18	0,87
Geo Grid	1	0	2	1	2	1	120,51	1,21
Vegetated channels	1	2	1	2	1	2	138,46	1,38
Hardened channels	2	2	1	1	0	0	120,51	1,21

As can be seen in the results of the multicriteria analysis in table 14, the intervention 'roof gutters' scores best on the posed criteria. This is mainly due to the ability of roof gutters to prevent erosion and control the water. They score better than ground gutters on these high weighting criteria.

When looking at erosion of open places, vegetation scores best because of the low maintenance and the long life expectancy. Cocos sheets also score quite high, but are unavailable in Surinam at the moment. Wooden plank terraces are also a feasible option because they can be applied quite easily. Geo grid would also be an option, but is not available in the region of Ricanau Mofo. Eyebrow terraces and Gabion walls score relatively low.

When considering the channel system, vegetated channels score higher than hardened channels because of their more positive impact on the community and their sustainability of materials. Whether vegetated channels are indeed the best option for the channel system is something that would require further research.

Elevating the ground

Another potential solution that has been explored is the elevation of the ground at specific places. This could be a solution for places in the village where the erosion around the foundation is reaching a critical stage and the chance of failure of the foundation is increasing. An example of this can be seen at flow area 6 in figure x.1 (Foto bij flow area 6). Areas like flow area 6 are also interesting for elevation of the ground because the area between these houses that has eroded away does not require a lot of material to be filled up. Other examples of this can be seen in flow area 3 and flow area 18.

Furthermore, the channel system can be taken into consideration when making the elevation design in such a way that a slope of approximately 2% is accomplished in order to encourage good flow.

Further research will need to be conducted to know which areas are most effective to be elevated. Also, information will need to be gathered about which material is best to be used.

Integrated solution

As stated previously, the erosion problem in Ricanau Mofo is quite versatile and requires a diverse solution consisting of different aspects of erosion prevention. Based on the multicriteria analysis and the different area classifications, in figure 104 a plan has been made including roof gutters, channels, vegetation and elevation of areas. In the steeper areas drainage paths are applied and vegetation is proposed for the areas that are less steep and where vegetation is lacking.

It should be noted that there are more options and that this is only one of the possible combinations of a solution.

Grade soil pathways

To create a better grading for a drainage system, soil can be deposited in certain areas of the village. There seems to be very limited information available about which type of soils are best used to create grading specifically. Therefore, information on soil types and drainage qualities can be used. Various local options are available in Ricanau Mofo are; gravel, laterite, sand, base course or clay.

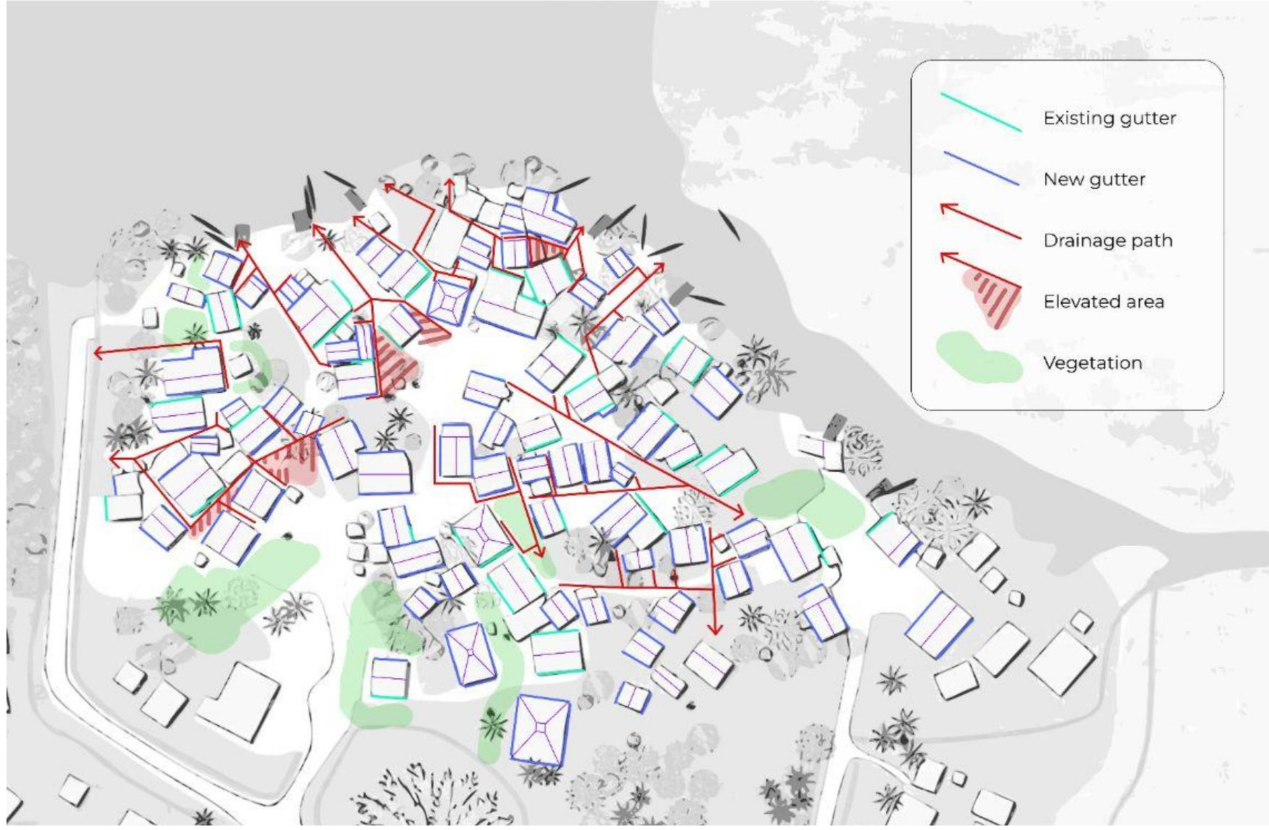


Figure 104, integrated solutions for the old centre of Ricanau Mofo.

6.7 Conclusion

The old centre of Ricanau Mofo is prone to soil erosion due to heavy rainfall and a lack of measurements against erosion. As there was very limited information available about the hydrology in this area, a hydrological analysis was performed in which a rainfall event of 50 mm/hour was modelled. For this, field measurements and observations were combined with existing scientific reports. This allowed us to categorise the different flow areas, which are based on percentage clay ground with respect to vegetation, discharge and slope.

Solutions were defined for the different areas. These were sourced from previous research in the area, literature research and workshops with Surinamese students. The solutions have been scored with a multi criteria analysis. The solutions that scored the best are roof gutters, vegetation and hardened channels for the different aspects of erosion. However, also solutions like wooden terraces or gabion walls, that scored less, could be valuable in order to prevent erosion.

These solutions have been combined in an integrated solution as can be seen in figure X. In this solution, roof gutters, vegetation and channels are introduced and combined. Furthermore, this solution includes areas where raising of the soil is proposed. This could be used to reverse the prior erosion, but also enable better discharge of water and adjust flow areas for better spreading or concentration of the water flows. This is something that should be further researched.

7

Waste management

n Ricanau Mofo, visible trash littering the village exposes a pressing issue: inadequate waste management. This chapter first delves into the problem and thereafter explores potential solutions for a more organized and effective waste management system in Ricanau Mofo.

7.1 Research questions

1. Understanding current waste management Ricanau Mofo

- How is the waste system of Ricanau Mofo organised?
- What are the flows of waste in Ricanau Mofo?
- How is the nationwide waste system organised?
- What are the current measures against displaced trash?

2. Steps forward towards a more sustainable system

- What are the steps forward towards a more sustainable waste system in Ricanau Mofo?
- Which actions should be prioritised?
- How can the actions be effectively communicated to the inhabitants of Ricanau Mofo?
- What are possible pathways towards a sustainable system-wide waste management?

Figure 105: Waste at the riverbank of Ricanau Mofo

7.2 Problem definition

When walking through Ricanau Mofo, the garbage lying around on the ground is immediately noticed as can be seen in figure 105. According to Goossens et al. (2023) this is a result of an inadequate waste management system of the past years. It was unclear when and how often the waste collection vehicle would come by, which is why villagers decide that to avoid smells in the village it's better to have the trash to be washed away by the river then to have it at their home. As of today there is garbage collection every week. However, there is no clear system in the village where inhabitants can drop their garbage bags, leading to garbage (bags) being dropped on the ground next to the road. These garbage bags on the ground attract pests and other unwanted animals and lead to an overall unhygienic living environment. To overcome these problems there is a need for a better organized and more reliable waste management system.

Municipal solid waste (MSW) collection and disposal is one of the major problems in urban environments worldwide (Abdel-Shafy & Mansour, 2018). MSW management solutions must be financially sustainable, technically feasible, socially, legally acceptable and environmentally friendly. Solid waste management issue is the biggest challenge to the authorities of both small and large cities'.

The waste problem also directly impacts the other two projects undertaken by the group. When evaluating the sheet pile wall it became clear that one of the reasons many plants could not grow was the deep layer of clothes and trash below the mud. Trash is one of the main reasons drainage works get cluttered and dysfunctional (Nepal & Bharadwaj, 2022). With the current levels of trash this is a serious risk to take into account when designing a drainage system.

7.3 Understanding current waste management in Ricanau Mofo

How is the waste system of Ricanau Mofo organized?

Officially, household waste is to be collected weekly by Moengos waste service. However, the accuracy of these pickups has been disputed both from inhabitants of Ricanau Mofo as from the district commissary. People from Ricanau Mofo have mentioned they felt less prioritised than Moengo, while the district commissary blamed a faulty waste truck.

There are no clear locations where people can drop their garbage bags. Keba, a leading figure in the village said that the solution for now is that people put their trash bag on the street on Thursday evening or Friday morning, where it will then be picked up. If the pickup service does not come, they will communicate that to certain people in the village so that people will not put their trash on the street.

After pickup, it is unclear what is the official plan for the trash which is picked up, as the last public report for Marowijne is from 2003 and is therefore not up to date to the current state (Pan American Health Organisation, 2003). It has been mentioned that a site near a former marron village close to Moengo is used now as an unofficial dump, lacking sanitary and safety measures. We have not been able to verify this information. However, it is certain that the waste is not properly managed as the ministry of spatial planning and environment itself states that 95% of waste in Suriname is not properly managed and ends up on unsanitary landfills (Ministerie van Ruimtelijke Ordening en Milieu, 2022).

There are hardly any public trash cans in Ricanau Mofo. Some people are hired by the Ministry of Public Works to keep the village clean and trash free. It was observed that, due to a lack of trashbags, the trash was swept up and dumped in the middle of the river. The current system of systematically dumping the trash in the river can be seen as the most unfavourable option for waste handling when seen from an environmental point of view. The tide and mangroves partly prohibit the waste from moving towards the sea which lead to the trash washing back ashore in the village and a buildup of trash on the river banks and in the mangroves over time. The trash which does make it to the sea will partly wash ashore on the coast west of the Marowijne river mouth due to the westward Guyana stream (SCF, 2022). All in all it is a very shortsighted 'solution' to the local waste problem.

What are the flows of waste in Ricanau Mofo?

A thorough analysis of waste was not possible within the project scope. Therefore it is assumed that trash laying around in the village and on the riverbank gives a fair representation of the average trash produced by the village. This is almost all coming from households and mostly consists of plastic bottles, containers, bags, cans and clothes.

A leading woman in the village said it is common to throw organic waste, such as leftovers and scraps, in the river for the fish to eat. This avoids smells and pests in the trash bags.

Apart from the general household trash, some environmentally harmful or toxic objects such as batteries, paint containers and electric appliances were found. There is no formal separation of toxic substances in Surinam, and as these batteries could be seen laying around for long times, some were partly deteriorated, it shows that people are not aware of the environmental and health risks of these products. Due to the lack of industry in the village, there does not seem to be a major source of trash apart from what households produce.

Figure 106: Waste from households floating in the Cottica river

7.4 How is the nationwide waste system of Surinam organized?

In Surinam, the Ministry of Public Works and Environment makes the policy for waste treatment, which is executed by the Ministry of Public Works (Dagblad Suriname 2024b). The DC (District Commissioner) is responsible for the waste collection in the districts.

The Surinam government is aware of the problems they are facing concerning waste management in the country. On the government's site it is stated that the country produces roughly 200.000 m^3 garbage per year and that the waste management in Suriname is not adequately regulated. Furthermore they state that if the waste is improperly managed, it can lead to the outbreak of deadly diseases such as malaria, dengue and yellow fever (Overheid van de Republiek Suriname, 2022). Currently, all collected waste in Suriname is dumped on large open dumps, of which Ornamibo, a large site south of Paramaribo, is the largest (Ministerie van Ruimtelijke Ordening en Milieu, 2022)). The government has been trying to improve the situation for decades, with plans to rearrange the dump going as far back as 2006 (Dagblad Suriname, 2022). However, as of 2024 little seems changed, except for the regular coverage with sand to avoid fires, as in the past years these had become frequent and they could often last weeks (Dagblad Suriname, 2022).

Figure 107: Ornamibo trash dump covered with sand. Photo: Dagblad Suriname (2022)

There is a plan for integrated waste management in Suriname ('Voorbereiding van een Geïntegreerd Afvalbeheer Plan voor Suriname') by the Ministry of Spatial Planning with a theoretical framework which steps should be prioritised and which ministries have responsibilities in taking action (Ministerie van Openbare Ordening en Milieu, 2022) .

Apart from that, the government was planning 60 furnaces to burn communal trash all over Suriname (Dagblad Suriname, 2024a). After the first 30 had been placed, the last 30 had considerable delays, which was questioned by an opposition member during a governmental meeting (Dagblad Suriname, 2024a). A week later the minister released a statement that the furnaces turned out to be costly and unsustainable, and the solution had to be sought in sanitary landfills (Dagblad Suriname, 2024b). The minister of Public Works told us that the costs and quantities of diesel necessary were underestimated which made the project not feasible to continue.

The sanitary landfills will be a joint project from the ministry of Public Works and the ministry of Spatial Planning. For a sanitary landfill a large hole is dug which is covered with a protective lining. The trash is compacted before it's put in the landfill, which should improve safety and capacity.

Figure 108: Clear Packaging and Recycling

The total amount of recycled materials is very low, as only 5% of waste is not landfilled or littered in the environment (Ministerie van Ruimtelijke Ordening en Milieu, 2022). Another problem is the necessity of export of materials that can be recycled. Only very little trash is recycled in Surinam itself, with over 84% of recycled materials exported in 2019 (Amreco, 2019).

7.5 Stakeholders

To visualise stakeholders and their mutual relations, a stakeholder diagram has been made (figure 109). Although a note has to be made that the stakeholder list is not completely exhaustive, it has helped to better comprehend the complexity of the problem.

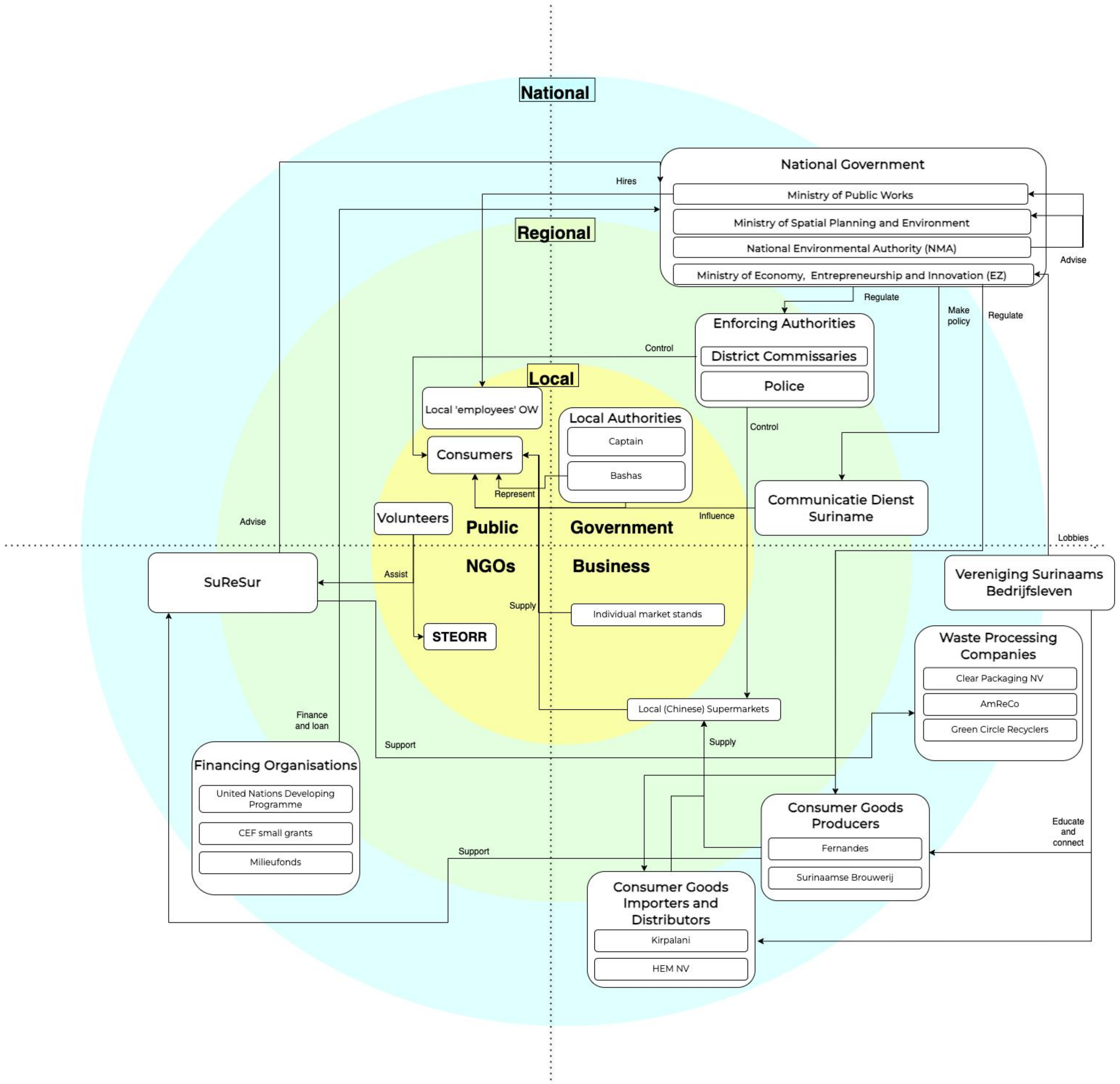


Figure 109: Stakeholder diagram

7.6 Prioritization of the problem

In solving this wicked problem it is impossible to solve the whole problem at once. A list of priorities is composed, so that it's possible to work towards intermediate goals. The goals have been inspired by the report for sustainable waste management as written by the Ministry of Spatial Planning and conversations with the DC and local villagers (Ministerie van Ruimtelijke Orde en Milieu, 2022). The goals are chosen to align with the roadmap of the ministry and expectations from villagers, as to make it easier to gain support during the process.

Figure 110: The goals for waste management in Ricanau Mofo

1. Redirection waste flows from the river to waste management

As long as there is a constant and intentional flow of waste towards the river this is the most important waste flow to address and change. As explained previously, having the trash dumped in the environment has such negative impacts it is important to avoid this as much as possible. It is low hanging fruit to address the current way of dumping as it happens on purpose and in one place, rather than that it happens accidentally somewhere along the chain.

Most important for the first goal is involvement of local villagers and the District Commissary. As mentioned before, this goal includes a stop to the systematic dumping of trash in the river by local workers. This requires a change in attitude, but also regular controls and support from the districts commissary.

Important is that a frequent and reliable waste pickup service from Moengo visits Ricanau Mofo, as the lack of this service was mentioned by many villagers as one of the reasons for not retaining their personal trash for the weekly pickup. Local attitudes concerning littering have to be changed, as the quick formation of new trash after the cleanup showed the frequent littering in public spaces.

A solution proposed by villagers was to place better public trash cans. Currently there is only one place in the centre where people can throw their trash, which is a trash bag tied to a tree. Public trash cans in the centre, as well as at the entry of Ricanau Mofo would make it easier to throw trash away responsibly without having to take it home.

2. Reduce the amount of waste

With increasing welfare, the amount of waste is also expected to increase. To reverse this trend, people in Ricanau Mofo (and Suriname) should move away from the usage of single-use plastics. The government has planned to ban plastic bags for a number of years but this ban is yet to be enforced. It is hard to define which plastic would fall under the single-use plastics ban as many products are packaged in plastic. Often the plastic is necessary to extend shelf life and, especially in the tropics, keep away insects and moisture. However, there is low hanging fruit such as the endless supply of bags at supermarkets or the plastic cups and sandwich bags used in abundance.

3. Separation of electronics and harmful substances

Currently, there is no separation of trash of any sorts in Ricanau Mofo. An important first step is to separate hazardous materials and electronics. As the village is modernising quickly, it imports products such as batteries or oil based paints and coatings. However, villagers are not yet aware of the toxicity of these materials to the environment and their own health when improperly managed. This problem is hard to tackle as it is not only present in the village, but the whole country lacks the infrastructure to handle these materials. It is of most importance that these objects do not end up in the environment. Further handling should be addressed by the government.

4. Sustainable household waste management

A next step in the waste management process would be to improve recycling of the remaining waste. Separation of waste is important to increase the quality and value of separate streams. A difficult factor is that for the whole of Suriname there is not yet a separate waste treatment, so if streams as paper are separated at the source now, they are bound to end up at the same dump as all other trash.

Support Recycling Suriname has placed a recycle bin in Moengo, separating various kinds of PET, HDPE and aluminum. Companies who advertise on the box pay for the maintenance and recycling of materials. A service could bring PET and cans from Ricanau to this bin. However, without any financial reward it might be difficult to incentivize people into undertaking the task.

5. Local waste-to-resource

A next step would be for locals to start using waste in a useful manner, which could even create value for local entrepreneurs. There are many examples globally of communities successfully transforming trash to value, such as compost or souvenirs (Soneva, n.d.). E.g. most organic waste is now thrown into a river, while a small composting facility could create much needed compost for the agricultural grounds. A minister was very enthusiastic about these ideas and said the ministry of tourism is currently undertaking a project to kick-off such projects along the upper-Surinam river.

Another solution to locally convert waste to something useful is a waste-to-fuel installation. Some small Pacific island nations have developed systems which are able to convert small quantities of plastic to gas which can be used as a fuel (Lower, 2024). We have contacted Frontline Waste, a small US based startup which builds a small scale Fluidized Bed Combustor which transforms waste to energy without additional fuel or emissions. Although inventive, the solution has only had 1000h of demo testing and would therefore be a risky investment as of now (Stein, R., personal communication, 8 april 2024).

7.7 Steps towards a nation wide sustainable waste management

A more holistic view on the waste management practises in Suriname shows that just having the trash picked up in Ricanau Mofo is not enough for the waste management to be called sustainable. The government is aware of the challenges it faces, and president Santokhi has composed a team to compose a pathway towards a sustainable waste system (Dagblad Suriname, 2023; Ministerie van Ruimtelijke Ordening en Milieu, 2022).

In this chapter, some propositions are made for steps which can be imposed on a larger scale, to build a system which manages the waste as good as possible within the current limitations of Suriname.

Plastic deposit system

Much of the litter seen on the streets and in the natural environment consists of bottles and cans (figure 111). A logical step would seem to implement deposit on these products, as is the case in many other countries, in order to add incentive to return these products. A study from CE Delft has shown that an implementation of a deposit on bottles and cans results in a 70-90% reduction in these products in litter (Bergsma et al., 2017). Apart from that, separation of PET and aluminium allows for better recycling, reducing the need for fossil ground materials (Koopmans, 2017).

Figure 111: a roadside in Suriname (Spaargaren, 2024)

Fernandes has investigated a deposit system with several (unnamed) actors in the fields of waste treatment and environmental issues, and concluded that they favour a system with a general waste fund over a specific deposit system (Fernandes, 2019). The main arguments given against such a system in Suriname are; the deficient infrastructure at shops, undetermined how the system should be financed, wrong consumers' attitude resulting in low return percentages, and the limited focus on PET (Fernandes, 2019).
The alternative given is a general waste fund which has placed 950 small recycling containers and focuses on awareness for customers. Another key initiative are 7 giant recycling containers, which allow for the separation of 3 sorts of PET, aluminium, and HDPE (Fernandes, 2021).

The issue is certainly more complicated due to the infrastructural and financial circumstances in Suriname than in European countries where deposit systems have already been imposed. Nevertheless, the argumentation of Fernandes against the deposit system does not match with the actions imposed afterwards. One of the main arguments against a deposit system is that customers do not bring back bottles to their supermarket to deposit money due to a wrong attitude. This has also been mentioned by the head of SuReSur (Ramdjan, G., personal communication, 10 april 2024). It is unclear why people would be willing to drive to one of the 7 recycling facilities in the country to recycle their bottles without any reward. And while augmenting that the deposit system is flawed for its limited view on PET and aluminium, these are the only products targeted with their own recycling plan.
They state that a door-to-door system as would be imposed with the trash fund would be more effective than a deposit system. This might be the case in Paramaribo, but in many of the smaller villages it is hard to imagine that such a system would be imposed as there is not even a general village wide collection imposed.

The ambitious 'Afvalfonds' (trashfund) which would be implemented instead of a deposit system was never seriously imposed and seems to be stuck in the pilot phase after its launch in 2020 (Fernandes, 2021). As of 2024, many of the giant separation containers seem to be in decay. Even if the tactic had good intentions, it falls in line with the greenwashing techniques used by many beverage companies worldwide (Bottlebill, 2020). Afraid of losing revenue due to customers unwilling to pay the initial extra or to be responsible for the cleaning costs, companies such as Coca Cola (Fernandes' mother company) have lobbied for years against deposit systems worldwide (Plastic Soup Foundation, 2017; De Feo, M., 2004), although positive environmental effects from deposit systems have been scientifically proven, along with the fact that deposit systems do not decrease sales (Gorgun et al, 2021).

A deposit system might face difficulties due to infrastructural and cultural challenges, it seems like an unavoidable step to prevent the current plastic epidemic in Suriname.

Support local recycling facilities

At the moment there are barely any local recycling facilities in Suriname. Subsidising these, or attracting foreign initiatives, can help in improving local recycling rates. The advantages are two sided, it is better for the environment and will retain more of the materials' value within the country. Currently much of the waste is seen as negatively priced, in such a way that it costs more money to collect and process than it yields in earnings. Having specialised companies and facilities where waste can be converted to valuable raw materials would not only decrease the waste problem, but at the same time make the country less dependent on imports.

Ban on single-use plastics

Single use plastics were planned to be banned in 2019, but as of 2024 this regulation has yet to be enforced (Gallant, 2022; Dagblad Suriname, 2023b). Although some of this plastic is hard to replace, there is some low hanging fruit which will immediately improve the litter situation. 200 million plastic bags are produced each year in Suriname (Dagblad Suriname, 2023b). With a population of only 620.000, this means an average of over 300 plastic bags are used per person per year (Worldbank, 2023). In the supermarkets it is noticeable how hard it is to avoid the usage of plastic bags, as personnel are not used to people bringing their own bags and often double-bag groceries.

A nationwide ban would decrease the amount of plastic thrown away, which would leave funds and personnel to tackle other sorts of waste. It would also decrease maintenance costs for the government as water works are currently heavily impacted by the amount of trash.

7.8 Which actions were taken to improve the situation in RicanauMofo?

After reading the previous reports the team had been made aware of the waste problem in Suriname. It is also hard to go unnoticed after arriving in the country, with trash lining the roads nearly everywhere. Although the problem was initially not within the scope of our project, it intrigued us to see how people could seemingly be so blind to the problem.
However, during one of the first village walks the group witnessed how two people took about an hour to collect all trash which had been stopped by the sheet pile wall, after which it was deliberately dumped in the river. As the river has a tidal movement it seemed not only bad for the environment but also a sisyphean task, as with high tide much trash would flow back to the shores of the village. Trash seemed to be one of the reasons why plants would not grow behind the sheet pile wall, and villagers mentioned the trash during the first workshop as one of their major concerns in the village, which is why it was decided to take on the trash problem as part of our project in Ricanau Mofo.

A first practical part was the organisation of a cleanup afternoon to clean the sheet pile wall and the river banks of any trash, as this had been a success with previous student groups and a good way to bond with the children and make them aware of the problem. Children from all over the village were indeed very enthusiastic to help, which might be due to the perspective on the cookies afterwards, and did a really good job on collecting all the litter in the bags we brought. Although we were happy that the cleanup was a success, it shocked us to see that since the last cleanup took place in November, over 25 60L bags full of garbage had accumulated on a 60m stretch of riverbank.
The cleanup also gave the idea for the implemented solution, as there was no place to bring these bags to so we just had to have them lined up next to the road where they would (probably) be picked up during the next pickup 5 days later, unprotected against rain, pests and dogs.

We were a bit lost on how to continue the project at first, which is why we decided we wanted to have a better scope of the problem. Conversations with villagers and local stakeholders, such as the DC, gave a better image of local perspectives.

Findings from the fieldwork in Ricanau Mofo

The solutions addressing the waste problem have to fit the local circumstances. The infrastructure and governmental budget of Ricanau Mofo are incomparable to any developed urban area. Therefore it is unwise to implement standard solutions which are common in urban areas without research in local response, as these might be quickly mismanaged which could actually worsen the problems. Some of the local characteristics will be further elaborated; funds, awareness, and local partnerships.

There are little funds available to address the waste problem in Ricanau Mofo. Local funds within the village seem not to exist, so all funds have to be applied for at the District Commissary, which is heavily underfunded and suffering under the bad economical state of Suriname. Conversations with the DC showed that she was aware of the fact that the pickup service is unreliable, but funds are not available to improve this situation at the moment.

As for local attitudes, we were positively surprised when talking to local people and hearing their thoughts about the waste problem. Although a large part of the problem is littering by individuals, a positive note is that in general people are not blind to the problem. In previous reports, the waste system and the littering has been continually named as one of the major problems in the village in participatory sessions (Vandermeeren, 2022; van Dongen, 2023).
Some people in the village are paid to keep the village tidy, which includes picking up litter and bringing public trash bags to the road. As previously explained, their work is now counterproductive as the litter gets thrown in the river. It was hard to find out what the exact motivation was for throwing the trash in the river due to a language barrier, as well as the fear of seeming pedantic when asking about the matter. It was mentioned that they considered trash bags too expensive at their own expense. After donation of some rolls of trash bags, it was visible that they indeed used these bags, which were tied to the trees next to the riverbank. These were used by some of the villagers, but still quite some trash could be seen laying around in the village and water. This results in an overall unhygienic living environment and a visible mess on the ground.

When properly educated and instructive, the workforce could become a force for good. The DC said that these could be picked up for free at the commissary and people should be aware of that. We have not been able to verify that they were indeed available, but this should be able to partly solve the problem. Two of the Bashas said they understood the problem and would hold a village meeting to speak about the littering and dumping attitudes. It will be a lot more effective once this comes from them in such a meeting, than if we, as external students, will tell them what to do.

As of now, there is little cooperation or communication with other villages. Ricanau Mofo is not the only community in Suriname dealing with the issue of waste. In other communities, much more remote than Ricanau Mofo, cost-effective and sustainable solutions are sought to handle the waste problem. In Galibi, a Carieben Indian village on the coast of the Marowijne river, people have designed and launched a waste management system to complement the incineration of garbage. This system is based around the incinerator donated by the Surinamese Government and consists of manuals and protocols for waste collection and treatment services within the reserve (Pact, 2022). We have not been able to get into contact with the people operating this system to verify the success, but if the system works this could be a good example for Ricanau Mofo.

Practical action during the project

After conversations with local villagers and the DC we decided it would be a good idea to fabricate a container where bags would be more protected until they would be picked up. A list of demands was composed as following:
The container must...

- Be easily accessible by workers from the garbage service
- Be nearby target audience who want to dispose trash bags
- Be at least 10 metres away from any house to avoid odor nuisance
- Protect trash bags against the sun and rain
- Have a life-span of at least 10 years
- Be build of material that is waterproof and easy to clean
- Be sturdy enough for improper usage, such as playing children
- Store the waste at at least 0.8m height to protect against flooding and dogs, and preferably not accessible by rats
- Cost a maximum price of 750 euros (as this was our remaining budget)

Using this list of demands multiple options were compared, which can be found in Annex 1. The final design is shown in figure 112

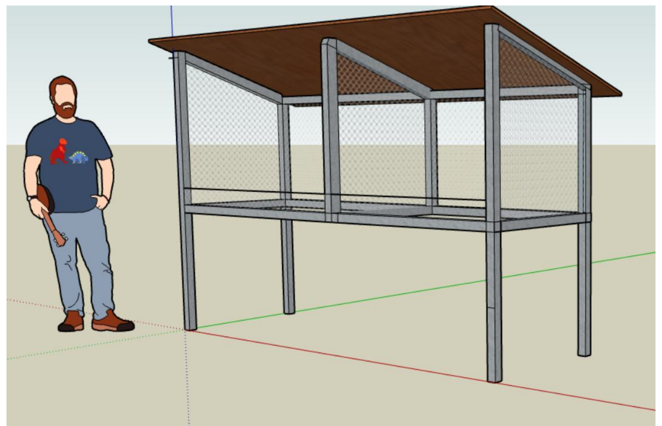


Figure 112: final design container

Figure 113: List of demands for the different designs

	Accessible	Protection against sun and rain	Lifespan >10 yrs	Waterproof material	Sturdy	Storage >0.8m height	<€750
Steel cage	✓	✓	✓	✓	✓	✓	✓
Upcycled cage	✓	✓	-	✓	-	✓	✓
Wooden frame	✓	✓	-	-	-	✓	✓
Plastic prefab	-	✓	-	✓	-	✓	-
Stone walled pit	✓	✓	✓	✓	✓	-	✓

A welder was found near the city of Albina, who went with us through the design and provided a range of options for the materials. After different options were provided for the thickness of the rods, a unity check was performed to determine the minimum dimensions.

During the final phase of the container project we experienced some problems due to unintentionally skipping some essential steps in the process. In order to gauge the support for the container, we had discussed it with the DC, and asked approval of the captain, who both were in favour. We had sent the plans to one of the Bashas through whatsapp and got no response, but as we already had two approvals and time was pressing we had decided to move on to production and paid the welder to buy materials.
A day later, we met one of the Bashas by coincidence, who casually mentioned she had spoken to a few villagers after which the consensus was that the container would not be necessary. She was in a hurry and had no time to elaborate further than that as far as the villagers were concerned having a more frequent pickup service would be the solution and the container would only bring more problems. This came as an unpleasant surprise, as we had a strong desire to improve the situation, and we had already spent a large part of our budget on materials. It turned out that a few years earlier some trash containers were placed by Public Works near the historic centre and villagers had had some bad experiences with these. As trash was sometimes not picked up for weeks, smells from the containers were a big problem in the village. Also, these containers were placed on the ground, attracting dogs and other pests. Lastly, the container was fairly small, causing people to leave their trash next to the container.
A quick brainstorm led to a new decision; the container could be placed next to the school, on the road to Moengo. There it could be used by the teacher, who was not always able to put the bags out on friday when they are picked up.

Besides, other people from Ricanau leaving before friday could leave their bags to be picked up. A last positive asset for this location would be the awareness created among the children of the school for proper waste management. The teacher agreed, and was enthusiastic about the idea to make signs during class to decorate the container later.
Apart from that, it became clear that the design did not came through as people were unable to open the PDF, and upon seeing the design (with the elevated placement of trash, roof, and protective mesh wiring) a relief and enthusiasm was visible, with people feeling confident that this container would perform better than the ones formerly placed.

The experience was very educational, as in hindsight we would have been able to avoid the problems experienced during the project. Better involvement and interaction with the villagers and the Bashas would have enabled us to better understand the problem, and create more ownership for the solution. Although having a pickup place for trash seemed overly logical from our mindset, understanding local fears and experiences made clear why villagers had not built these themselves yet. Although we as outsiders are sometimes able to better see and understand problems created (e.g. the practise of throwing plastic in the river), we are not the ones having to deal with the negative effects of solutions (e.g. smells from a trash container which has not been emptied for weeks).

In the end, we have received many positive opinions on the container and its location, and the fact that local stakeholders were explicitly against the option to make it (re)movable showed confidence in its effectiveness. Nevertheless, we would strongly advise forthcoming groups to tackle problems in such traditional villages during group meetings involving elders and leading villagers, as in such a way everybody is involved and more ownership is created.

To avoid problems faced in the past, we have tried our best to make the districts commissary aware of the importance of a frequent and reliable pickup service.

Communication tools used were a personal meeting with the DC, a letter, explicitly mentioning the issue during the water day in the village and during the end presentation. Lastly, the DC had explicitly asked for a recommendation plan after the project, in which this matter will again be explained.

Communication to the people of Ricanau Mofo

In Ricanau Mofo most communication still goes verbally, as villagers are constantly in contact with each other. The leading women of the village were very much aware of the littering problem, and wanted to plan a village meeting where the issue would be addressed.

One of the goals of the water day was to communicate the problems and solutions to the locals of Ricanau Mofo. As the turnup was not as we'd hoped, this goal was sadly not reached. However, officials from the village and the district were present and have received the information, which they will hopefully pass on to others.

Communication during the end presentation

The audience during the end presentation consisted of many employees from the ministry of public works, as well as representatives from the Dutch embassy, people from SuReSur and students from AdeK. We had therefore decided that it would be a good moment to raise awareness for the issue. The structure of the presentation was chosen as follows; first the magnitude of the problem would be highlighted by comparing Surinam to other countries, than the impacts and effects of the problem were highlighted, than the priorities for Ricanau Mofo were explained, as well as some suggestions for short- and long term actions which the government could take to assist the inhabitants. Lastly we told about our personal experiences and successes, which helped to end the presentation on a positive note.
Beforehand we were a little anxious that the presentation could be received as too confrontational, which can lead to a swift loss of attention. However, we were surprised by the overall attention and energy, as people were actively listening and wanting to discuss the matter afterwards.

8

Conclusion

In this chapter, a general conclusion of our Ricanau Mofo research project is presented.

During the Ricanau Mofo project, various challenges have been addressed, with a focus on water drainage, bank protection, and waste management. Each of these topics is described in this report, drawing on knowledge from diverse student disciplines, making it a multidisciplinary project.

The primary research question within the project scope was defined as follows: How can the erosion of the riverbank in Ricanau Mofo be mitigated? Reflecting on this research question, our project aimed to address it in two ways. Firstly, we explored soil erosion within the village, and secondly, we investigated erosion along the riverbank. Both types of erosion must be addressed to effectively slow down erosion in Ricanau Mofo.

First of all, the bank erosion is threatening the existence of the village. After information was gathered, various interventions, from structural to natural, were evaluated through a multi-criteria analysis. Proposed solutions include constructing a sheet pile wall and quay walls with or without water retaining function. The sheet pile wall is a nature-based solution, stimulating vegetation growth. This solution can be carried out with little resources. Therefore, people in the village or in other villages along the Cottica river can adopt this solution and apply it to their own shoreline. Quay walls, whether with or without water retaining function, protect against erosion and flooding, offering additional benefits like recreation and economic growth. However, this intervention requires a lot of resources. Also some additional challenges arise such as community involvement, drainage management, ongoing monitoring, and high construction costs, which must be addressed for long-term success of this solution.

Secondly, in Ricanau Mofo's old center, soil erosion is a significant problem. A hydrological analysis was conducted, combining field measurements, observations, and existing scientific reports. Different flow areas were categorized based on clay ground percentage, vegetation, discharge, and the slope. At the end, interventions were identified through previous research, literature review, and workshops with Surinamese students. These interventions were evaluated using a multi-criteria analysis, with the most effective ones being integrated into a combined solution. This solution addresses erosion prevention, water discharge improvements and adjusts flow areas for better spreading or concentration of the water flows.

In addition to the analysis on the process of erosion in Ricanau Mofo, this report highlights potential improvements in waste management, provides an overview of the current situation and describes the level of community engagement in tackling this problem. Together with local authorities and the villagers, more awareness is created and an extra waste bin is constructed near the primary school. This initiative aims to make waste disposal more accessible and thereby reduce littering in the village.

9

Future research

This chapter discusses the limitations of this research and proposes several possibilities for future research that build upon the foundation laid in this report. These projects explore unanswered questions, offering a better understanding of Ricanau Mofo's challenges. Also, as several interesting topics have not been addressed in this report, other directions for future research are suggested.

Future research

As mentioned in previous chapters, data on soil parameters and rainfall is missing to make a complete and thorough design for bank protection, as well as protection against ground erosion.

The current design of the shore protection is based on a lot of assumptions. For a thorough assessment of shore protection, data must be collected regarding the ground properties. A cone penetration test must be conducted for soil properties and it must be investigated if there are no large objects present in the ground, obstructing construction plans of a bank protection structure.
For the design of a quay wall, more research has to be done on drainage systems regarding the rainwater. This research could be combined with research for possible sewer systems.

In this paper, research has been done on a sheet pile wall and a quay wall. However, a system with groynes could be a very good protection system for the coast by deflecting currents. This could be a very cost-effective method, but first requires thorough research on its impact in the system; for example on the ecosystem in the river, on the daily activities of the villagers or on the route of passing boats. Next to impact on the system, research and calculations must be carried out on the dimensions, materials and application techniques of the groynes.

In the future, a drainage system must be designed for the town center. To be able to design this, data on the rainfall and water usage of the villagers must be collected to design for the drainage system dimensions. The most obvious design choice for a drainage system would be a subsurface sewer system. Next to a sewer system, it is useful to further investigate possibilities for leveling up the ground level of the old center. For leveling up the city center, research must be done on where exactly adding height contributes positively to an effective drainage of rainwater with as little erosion as possible as a result. Next to this, it is needed to investigate how much it must be leveled up and which material and building techniques can be used to achieve the desired result.

Regarding waste management, it is suggested that an analysis will be conducted on which waste is produced. This analysis can include where people dispose of their waste, at which moments and by who. The installation of the waste collection bin also presents an opportunity to investigate whether residents of Ricanau Mofo are more conscious about waste management when provided with convenient tools.

Next to quantitative and qualitative research, the importance of careful waste management must be communicated towards the community. In this current research, communication towards the community did not have the desired result as a large part of the community did not show more conscious waste disposal behavior and understanding. For future projects, it is recommended to investigate how the message can more effectively be communicated towards the community.

Other directions

Several topics have not been addressed in this research, but could provide an interesting project to future research groups. This would include a design for a port, a design for a restructured town or designs to protect the houses against floods.

An idea for a new project could be a design for the jetties at the shore. These jetties are subject to structural decay and require maintenance. However, instead of maintaining a jetty that is bound to fail in a couple of years, Ricanau Mofo could benefit from a port design due to its transitory function. For this design, not only flow velocities, possible materials and material dimensions have to be investigated, but also the impact on the community and the possible economic benefits.

The second new research idea is related to a new housing plan for the town. Right now, the floods already last a couple of weeks and are, with the rising sea levels, only expected to last longer. In this new housing plan, a plan must be made where people can move as effectively and cheaply as possible. This plan could include an overview of which people are recommended to move, where they should move and how they can rebuild their house. To make moving attractive for the villagers of Ricanau Mofo, the plan could also include sustainable ways to re-use materials of the previous houses and a plan for financial aid.

If the villagers refuse to move to a higher area as suggested in a new housing plan, protecting the houses against floods could be a temporary solution to keep the old town center a good place to live. This could be a design for existing houses, but also for newly built houses. For existing houses, solutions can be found to keep the water outside of the houses, protect valuable belongings or protect the house against structural decay. For newly built houses, an adaptive design to protect the house against high water levels could guide villagers to build for the future.

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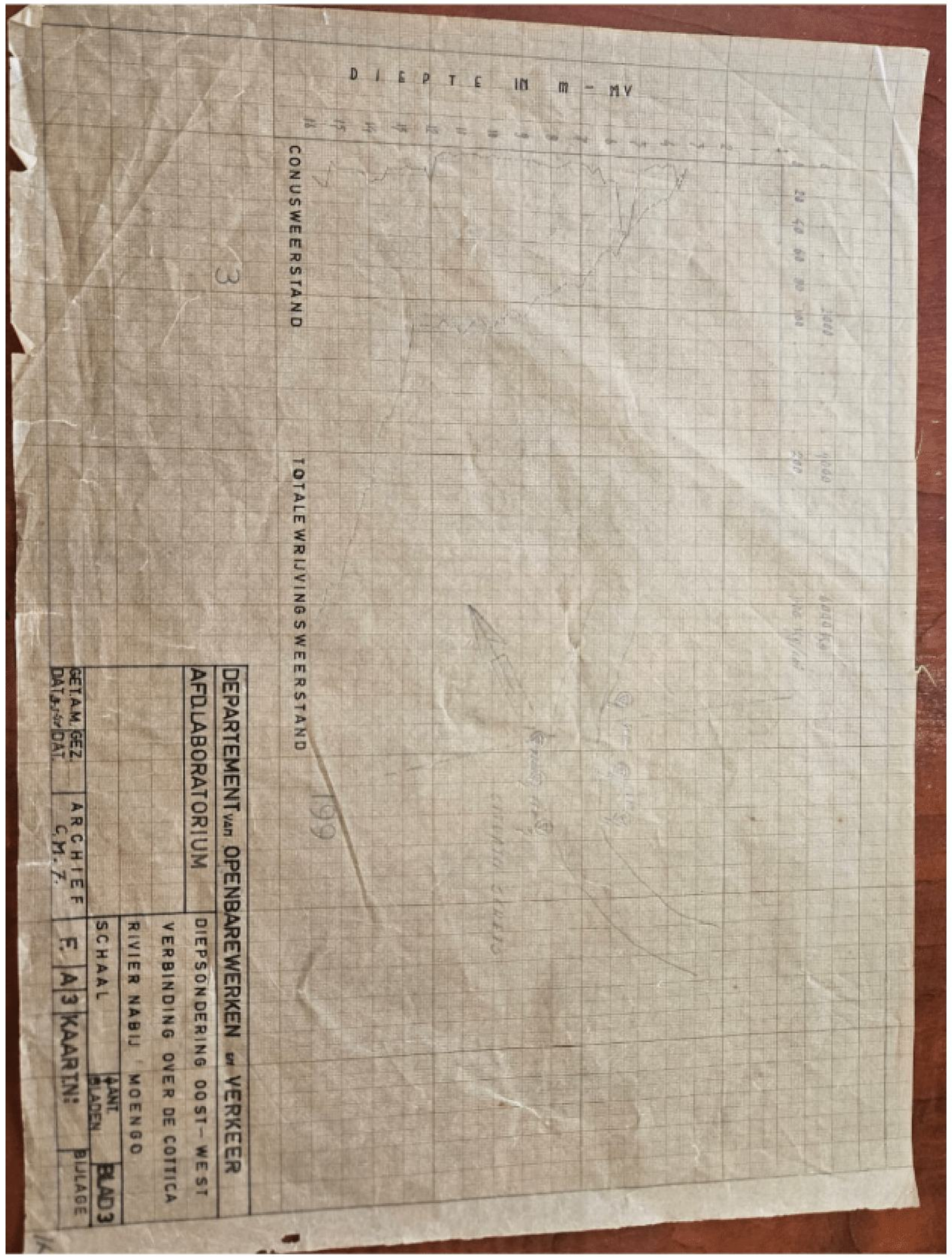
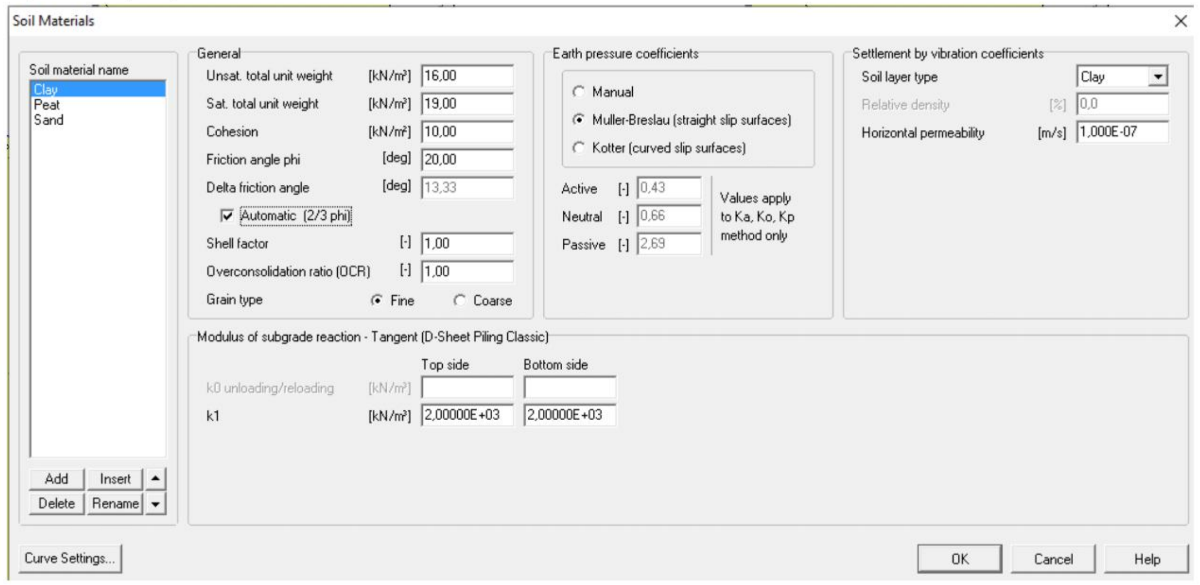
Appendix A.1 CPT

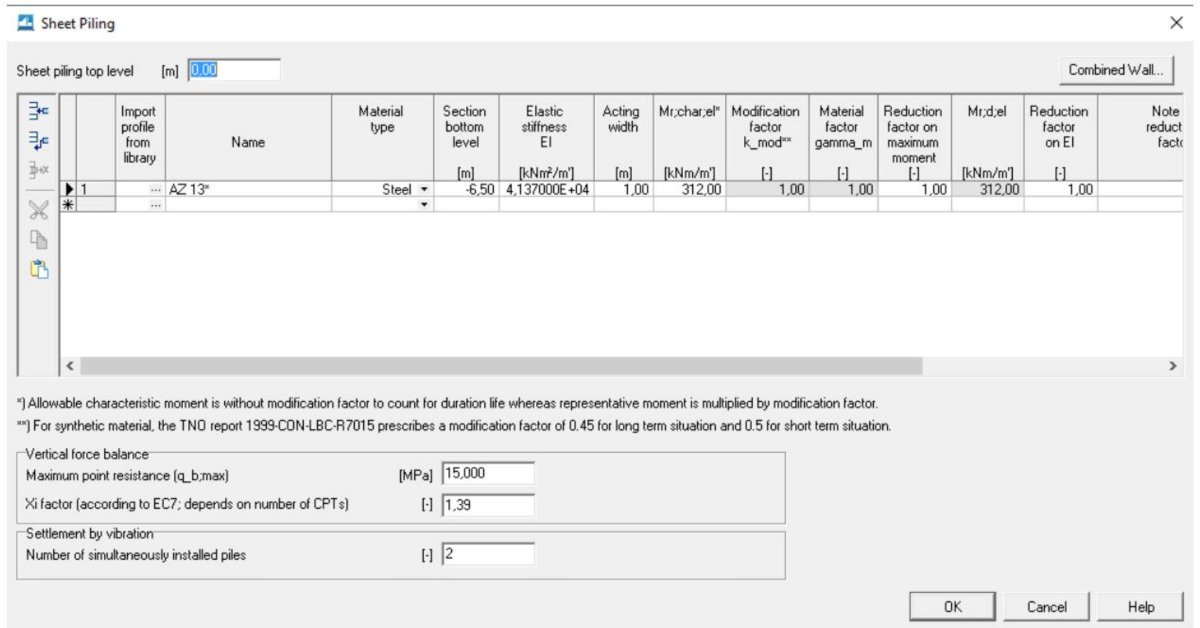


Appendix A.2 D-sheet piling inputs

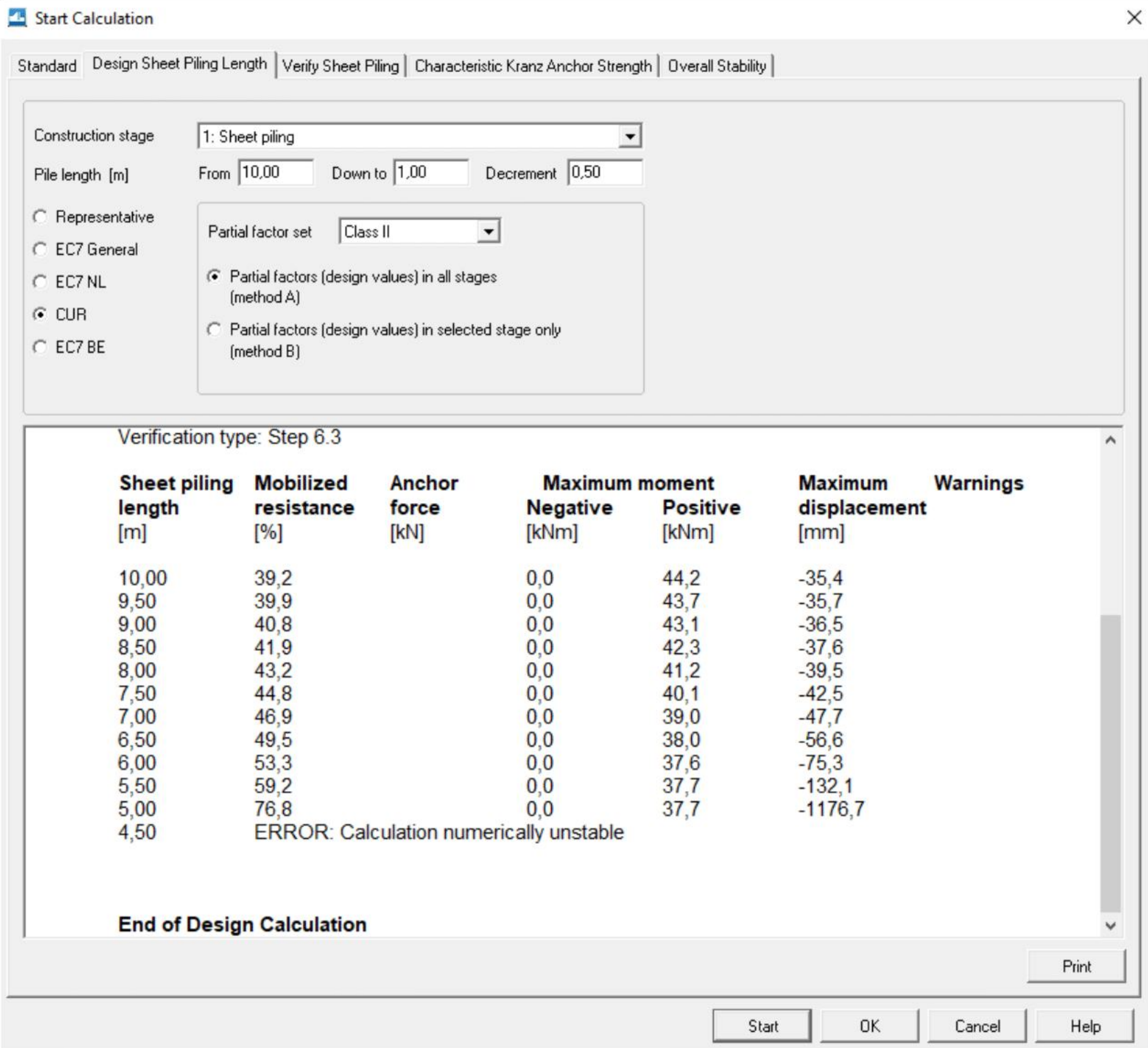
Input soil properties



Input sheet pile properties



Critical length calculation

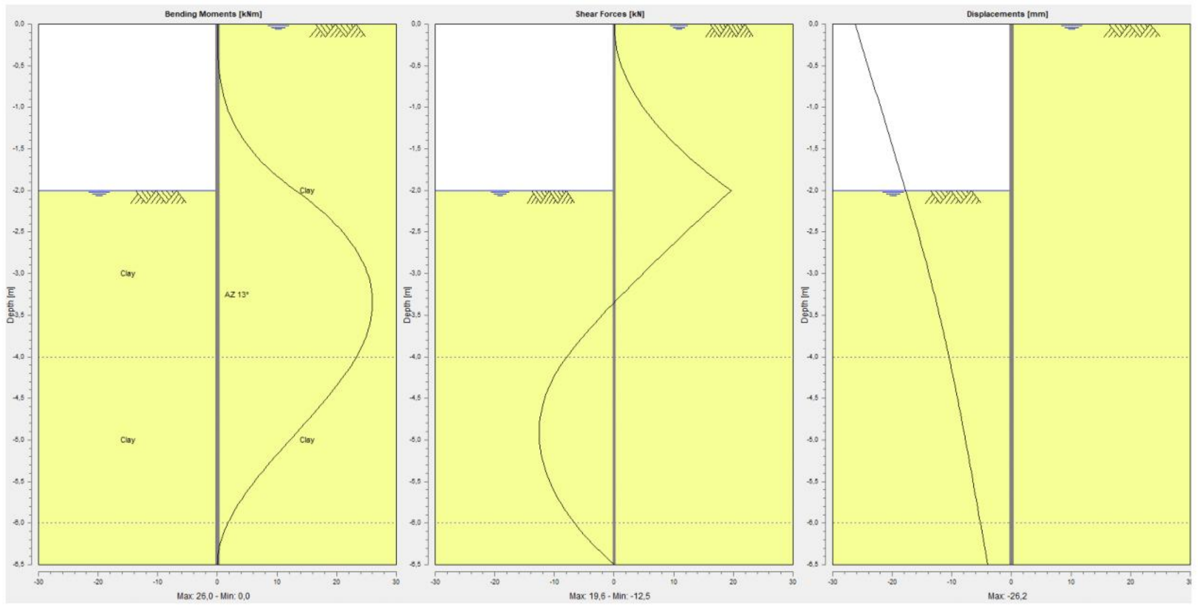


Verification type: Step 6.3

Sheet piling length [m]	Mobilized resistance [%]	Anchor force [kN]	Maximum moment Negative [kNm]	Maximum moment Positive [kNm]	Maximum displacement [mm]	Warnings
10,00	39,2		0,0	44,2	-35,4	
9,50	39,9		0,0	43,7	-35,7	
9,00	40,8		0,0	43,1	-36,5	
8,50	41,9		0,0	42,3	-37,6	
8,00	43,2		0,0	41,2	-39,5	
7,50	44,8		0,0	40,1	-42,5	
7,00	46,9		0,0	39,0	-47,7	
6,50	49,5		0,0	38,0	-56,6	
6,00	53,3		0,0	37,6	-75,3	
5,50	59,2		0,0	37,7	-132,1	
5,00	76,8		0,0	37,7	-1176,7	
4,50	ERROR: Calculation numerically unstable					

End of Design Calculation

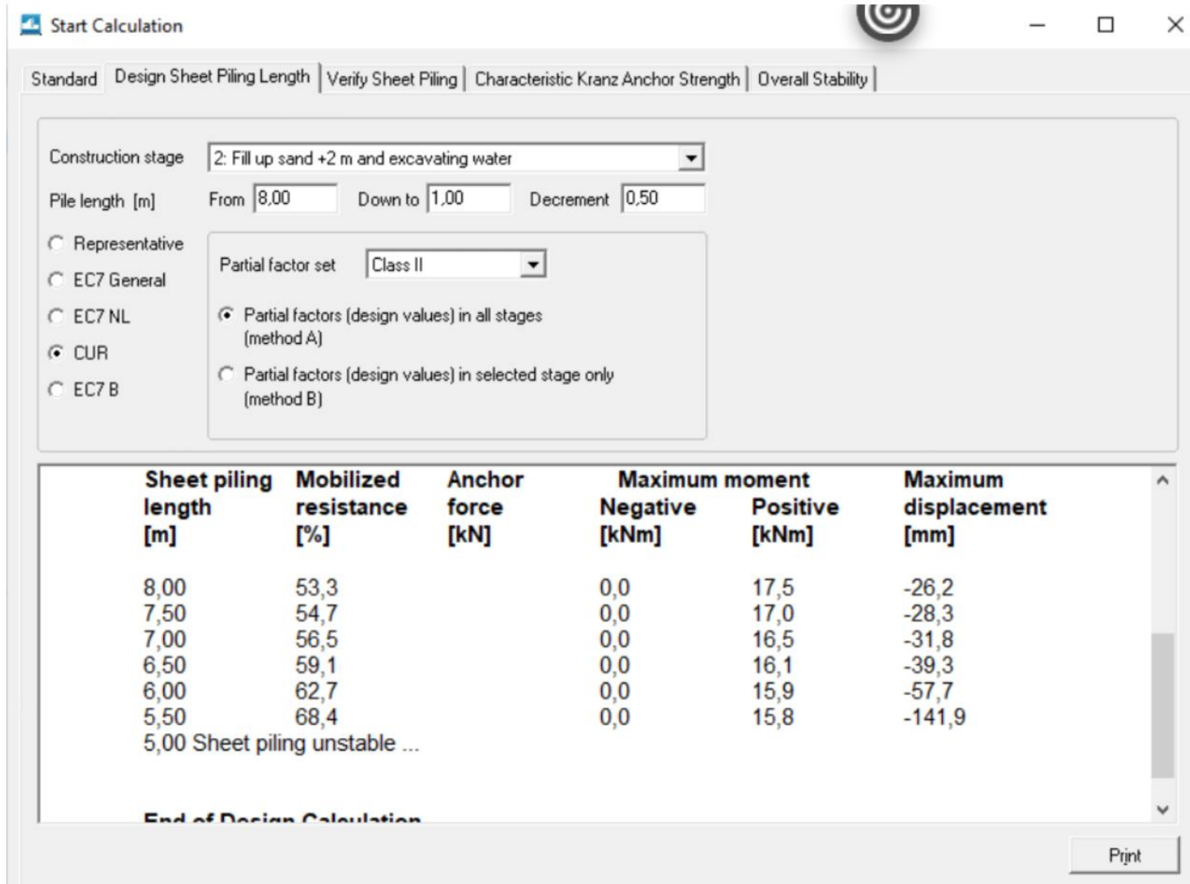
Moment, shear and displacement line



Costs sheet pile wall calculation

Sheet pile wall calculation	
Length sheet pile wall	110
Depth	6,5
Total m2	715
Costs per m2	€ 150,00
Total costs	€ 107.250,0

Appendix A.3 Inputs



Sheet piling length [m]	Mobilized resistance [%]	Anchor force [kN]	Maximum moment Negative [kNm]	Maximum moment Positive [kNm]	Maximum displacement [mm]
8,00	53,3		0,0	17,5	-26,2
7,50	54,7		0,0	17,0	-28,3
7,00	56,5		0,0	16,5	-31,8
6,50	59,1		0,0	16,1	-39,3
6,00	62,7		0,0	15,9	-57,7
5,50	68,4		0,0	15,8	-141,9
5,00 Sheet piling unstable ...					

End of Design Calculation

Start Calculation

Standard | Design Sheet Piling Length | Verify Sheet Piling | Characteristic Kranz Anchor Strength | Overall Stability

Construction stage: 3: Apply anchor

Anchor wall active	(Eo)	:	40,964	[kN]
Cohesion x length	(Ec)	:	103,366	[kN]
Factor due to angle	(Es)	:	0,953	[-]

Characteristic Kranz anchor strength
Rkr;k = (Ea - (Er + Eo) + Ec) / Es : 190,299 [kN]

Control of anchor (art. 9.7.2(a) NEN 9997-1:2016):

Characteristic Kranz anchor strength (Rkr;k)	:	190,299	[kN]
Actual anchor force CUR (1.5 * Pmax)	:	144,000	[kN]

MET according to CUR/EC7-NL

End of anchor force verification

Draw Results | Print

Start Calculation

Standard | Design Sheet Piling Length | Verify Sheet Piling | Characteristic Kranz Anchor Strength | Overall Stability

Construction stage: 4: Adding boulevard

Characteristic Kranz anchor strength
Rkr;k = (Ea - (Er + Eo) + Ec) / Es : 165,725 [kN]

WARNING: The characteristic Kranz anchor strength is calculated WITH loads.

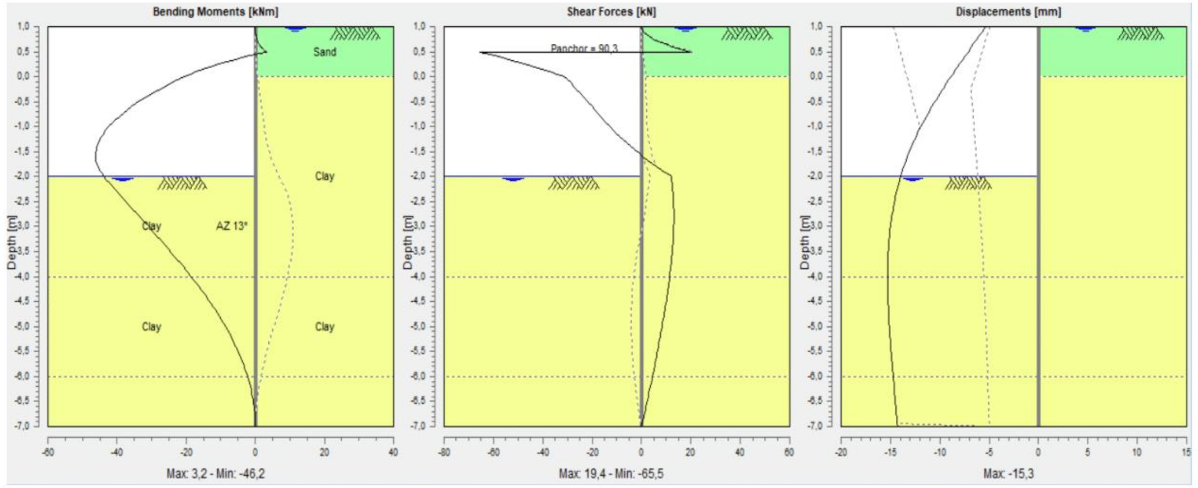
Control of anchor (art. 9.7.2(a) NEN 9997-1:2016):

Characteristic Kranz anchor strength (Rkr;k)	:	165,725	[kN]
Actual anchor force CUR (1.5 * Pmax)	:	162,549	[kN]

MET according to CUR/EC7-NL

End of anchor force verification

Draw Results | Print



Costs:

Sheet pile wall calculation		Anchoring calculation		Sand calculation	
Length sheet pile wall	110	Length sheet pile wall	110	Length sheet pile wall	110
Depth	8	Anchors per length (extra layer)	1	Depth landinside	20
Total m2	880	Total anchors	110	Height	1
		Length anchor	11,00	m3 zand	2200
				Kosten per m3 zand	€ 13,00
		Costs per anchor	€ 200,00	Aantal x vrachtwagens rijden	110
Costs per m2	€ 150,00	Costs per m anchor		kosten per vrachtwagen	€ 700,00
Total costs	€ 132.000,0	Total costs	€ 22.000,00	Total costs	€ 105.600
Total material costs	€ 259.600				

Appendix B.1 Map Making

There are some undetailed maps from the previous groups showing some information concerning water. These are limited to showing the main channels around the old city centre. A comprehensive map depicting the hydrological catchment areas or the total drainage system does not yet exist and needed to be made from the start. By analysing water flows within the village, which is done best during and right after a rainstorm, the natural flow directions between the houses could be determined.

Before conceptualising improvements, it has to be determined where erosion is already taking place and where the susceptibility to erosive processes is highest. This can be determined by survey assessment of damage to the physical environment, as well as soil types and vegetation. Without proper equipment available it is not possible to accurately map the relief in the village on a level of precision necessary to be useful for channel creation. Mapping this geographically can be used to determine which specific locations or categories of terrain are most susceptible to erosion processes.

Assessment of occurrences of erosion in the village can be used to review the flow-map, as well as add to the map by highlighting other places of interest.
The purpose of the file is to organise the information and evaluate the critical levels of erosion, and the map can be used to determine the priorities for implementation of measures, supplying scientific backbone to allocate resources to control urban erosions in the village.

The focus during the surveys was therefore:
-Revision of existing map composed by Vandermeeren (2023):
- Buildings
- Vegetation

Additional information:
- Height contours
- Gutters
- Roof Gutters
- Roof flow directions
- Water taps without drainage
- Open drainage pipes

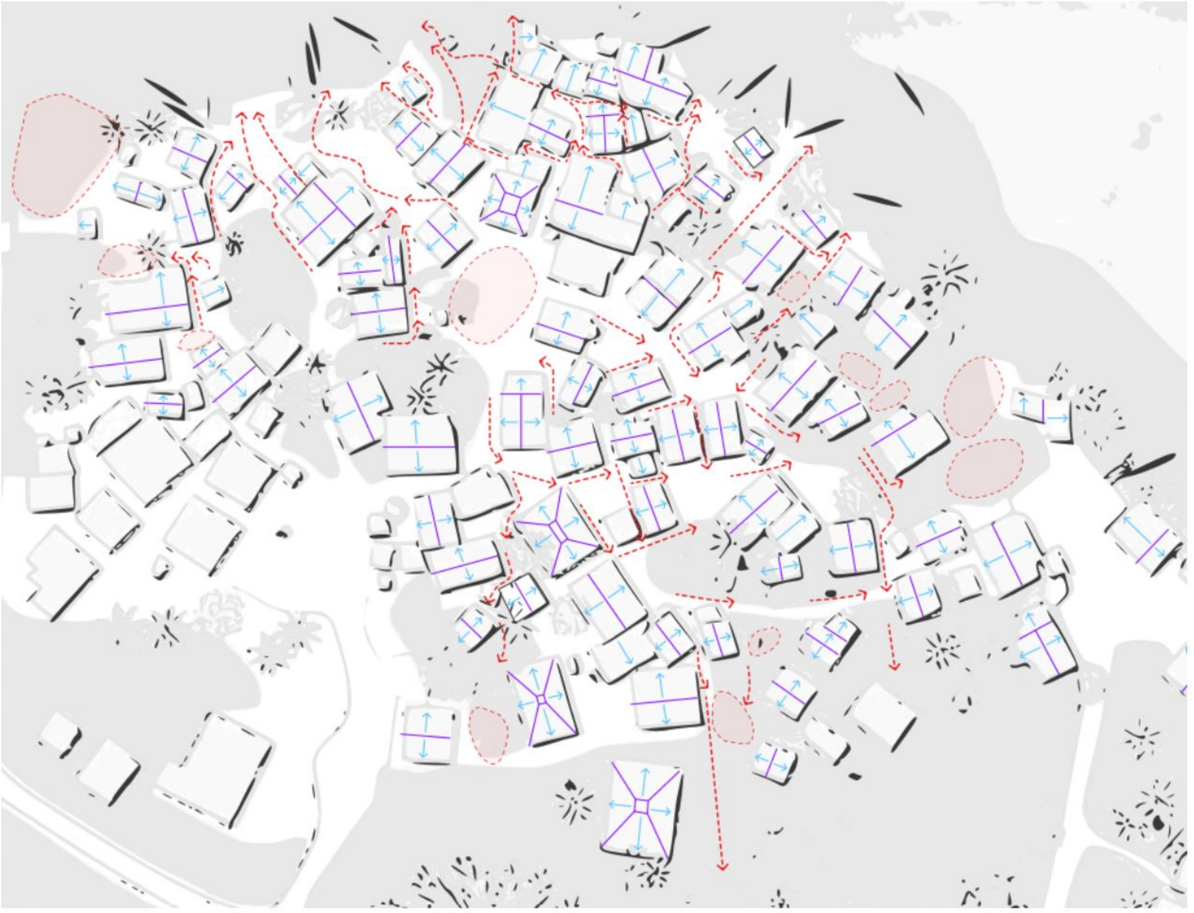
Further research if it's possible to include:
- Household drainage
- Sewage
- Septic tanks
- Survey grade height map

Usually, the first few steps for conduction of the map and recording the problem would be made with help of the local authorities. As Tucci & Maksimovic (2001) describe: '*One would start with a technical meeting with the municipal administration in order to prepare a diagnostic report on urban erosion in a municipality. For this they would need to obtain the following main information: detailed maps of the urban area; description of erosion occurrences (location, access, importance to the municipality, history of occurrence, control measures taken, drainage network in the catchment, possible projects carried out, hydrologic data, etc.)*"

For Ricanau Mofo, the research had to be conducted completely differently as knowledge concerning these topics in the village is not yet in existence and there are no previous reports about either erosion or measures taken. Therefore, much of the information had to be derived from locals and previous reports.

Information on hydrologic and urban characteristics is required to estimate model parameters and reduce the planning and project uncertainties (Tucci & Maksimovic, 2001).

In figure X the waterways and flow directions are depicted together with the shapes of the roofs. With the waterways and flow directions the waterways can be schematised.



When the areas of the houses are known, and it is known which parts of the houses lead the rainwater to which waterways, a rainfall event of 50 mm/hour can be modelled with python by the code below and the water intensities through each waterway can be modelled and figure X can be created.

Limitations

- Rain is assumed to fall straight down. Therefore roofs will receive the amount of rain per *horizontal* area, not their roof area. Due to the limited time scope it is not possible to add reliable data on the angle rain lands on the surface.
- Only the rainfall falling on the roof area is taken into consideration.

Further usage

The map would be useful for various stakeholders, including STEORR, *het ministerie van openbare werken (OW)*, subsequent project groups and villagers of Ricanau Mofo. Having reliable information and oversight of the situation will reduce costs and time for implementing improvements to the water drainage system, as well as highlight priority areas.

Appendix B.2 Python code

File too large, please request code to the authors

Appendix B.3 MCA

Intervention	Effect on erosion	Controlled water runoff	Maintenance	Life expectancy	(negative) Impact on community	Sustainability of materials
Roof gutters	2; Reduces splash erosion completely	2; For the part of the system where gutters are placed, they control the water completely	1; Roof gutters require regular maintenance	2; If placed correctly they should be able to last a long time	2; The community is already farmiliar with roof gutters	0; Plastic roof gutters (the ones available in Moengo) are not sustainable materials
Ground gutter	1; Reduces most splash erosion, but some erosion will take place next to the ground gutters	1; Ground gutters can be placed in such a way that they partially control the water runoff	1;Ground gutters require regular maintenance	2; If placed correctly they should be able to last a long time	1; Small amount of houses already have a similar system + little effect on daily life	1; Ground gutters can be made with sustainable materials like wood or stone
Cocos sheets	1; Cocos sheets combat erosion, but will not fully prevent it	0; Cocos sheets do not control water runoff	2; If placed correctly, requires little to no regular maintenance	2; If placed correctly they should be able to last a long time	1; cocos sheets might be placed in public spaces, however they should not interfere much with daily life	2; Cocos sheets are a sustainable solution
Hardened channels	2; hardened channels will completely reduce erosion	2; Channels control the water runoff	1; Requires regular maintenance in the form of keeping the channels clean	1; concrete structures in these densely populated areas wont last longer than 15 years	0; hardened channels will be placed on places where people walk, making them dangerous	0; Concrete is not a sustainable material

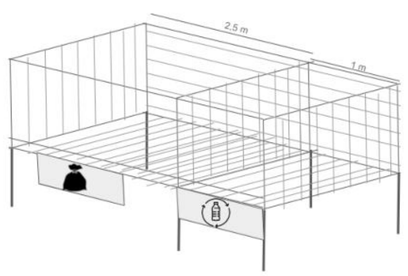
					for children to walk	
Vegetated channels	1; vegetated channels will reduce erosion, but allow some erosion to take place	2; Channels control the water runoff	1; Requires regular maintenance in the form of keeping the channels clean	2; Vegetation should be able to last a long time	1; vegetated channels will be placed on places where people walk, however when dry, people can still walk here	2; Vegetation is sustainable
Vegetation	1; vegetation will reduce erosion, but allow some erosion to take place	0; Does not control water runoff	2; If placed correctly, requires little to no regular maintenance	2; Vegetation should be able to last a long time	2; Vegetation does not need to interfere with daily life in Ricanau Mofo	2; Vegetation is sustainable
Eyebrow terraces	0; Eyebrow terraces have not been proven to reduce erosion for the case of Ricanau Mofo	0; Does not control water runoff	2; Eyebrow terraces are self maintaining after placement	2; If placed correctly, it should be able to last a long time	1; terraces are quite large and might interfere with daily life in Ricanau Mofo	2; No materials are used for this solution
Wooden plank terraces	1; Wooden plank terraces trap sediment and therefor partially reduce erosion	1; Partially controls water runoff by slowing down the water at some specific points	1; Requires maintenance if the wooden planks are broken, otherwise they loose their full functionality	1; During heavy weather conditions, the terraces may fail	2; People are already familiar with the concept and terraces are already present in Ricanau Mofo	2; Only a wooden plank is required for this solution
Gabion Wall	1; Gabion walls trap sediment and therefor partially reduce erosion	0; Does not control water runoff	1; If placed correctly, requires little to no regular maintenance	2; Should be able to last more than 15 years	0; People are not familiar + it will be quite a big structure in the public space	1; gabion walls are made out of metal and stone, which are partly sustainable
Geo Grid	1; Geo grid trap sediment and therefor partially reduce erosion	0; Does not control water runoff	2; after placement, requires little to no maintenance	1; after placement geogrid should last for more than 15 years	1; geo grids might be placed in public spaces, however they should not interfere much with daily life	1; Geogrid is basically plastic in the ground, which is not sustainable, however it is used to trap the natural sediment

Appendix C.1: Comparison of the different waste collectors

1. Steel rack on posts

Durable option, with the advantage that steel can be easily cleaned. The rectangle shape is chosen as the container needs to be able to hold 50 bags, but all bags need to be within arms reach of the garbagemen. Apart from that, it is easier and cheaper to fabricate the straight beams and flat meshed surfaces than any other shape would be. A basic design was made, where a few options had been considered:

- Addition of a roof. This brings more costs, but adds extra protection against the sun and rain.
- Separate recyclables compartment. It could make the container more useful for future sustainable usage. However, as there is currently no separated collection we and local stakeholders were afraid that it could lead to misuse and confusion.
- Wooden sheet decoration: these sheets could be decorated by the children of the school, creating more ownership and giving the container a more friendly look. It has not been possible to organise this with the kids within the time we had in Ricanau Mofo so we've decided not to add the sheeting.



2. Reuse a rack that is currently in Moengo.

We found a 3x0,7x0.7 steel cage in a backyard in Moengo. This could be used for free, saving a lot of costs and materials and improving the circularity of the rack. However, on closer inspection the material turned out to be somewhat degraded and rusting, which compromises the strength and durability of the container. If the budget had been smaller this would have been an option to consider.

3. Wooden bin on posts

Wood is cheaper and more readily available from the DC. The DC indicated a willingness to provide an update when more funds are available. The advantage of wood is that it can be painted by children/villagers, fostering ownership. If sourced sustainably, wood can actually be a carbon negative building material. On the downside, it is more difficult to sanitise the wood, and damages to the lacquer can result in slow degradation of the wood.

4. Prefab container

In Paramaribo many of these containers are used, combining waste from dead-end streets. A downside is that waste collecting services don't have garbage trucks with lifting mechanisms, which means bags have to be picked up out of the container manually. Also, this container requires more maintenance as liquids and loose trash will remain at the bottom, resulting in rotting and smells.

5. Stone walled pit

Instead of building a whole container, another option would be to allocate a certain location to be the waste collection point, and build a small wall and a roof around it. It would be a relatively cheap option, making use of locally available materials. The downside from this design is that trash is stored at ground level, making it more vulnerable for pests and water.

6. Separate compost bin

Separating organic waste prevents it from rotting in the general waste, which would produce methane, a strong greenhouse gas. Additionally, organic waste can be put to good use. However, there is a question of how residents will separate this waste and whether the project will become too large. Better handling of organic waste in Suriname would be a good follow-up project

Appendix C.2: Letter to the DC

Studenten TU Delft in samenwerking met Stichting STEORR
Sumatrastraat, Moengo
DC Dominie
Commissariaat District Marowijne
Moengo, 20 maart 2024
Betreft: Afvalophaalplaats Ricanau Mofo

Geachte Districtscommissaris Mevr. Dominie,

Door middel van deze brief zouden we u graag het ontwerp voor de afval-ophaalplaats delen, en u en het commissariaat updaten over het project omtrent afval in Ricanau Mofo.

Zoals besproken tijdens onze laatste afspraak hebben wij het ontwerp van de afval ophaalplaats verder uitgewerkt. Dit ontwerp is in de bijlage bijgevoegd. Zoals ook tijdens ons gesprek is besproken, zien we tijdens onze stageperiode wekelijks de uitdagingen waar het dorp, met name in het oude centrum, mee wordt geconfronteerd. Een afval ophaalplaats zou een goede stap zijn om het afvalprobleem in het dorpscentrum en de dorpen stroomafwaarts te verminderen, door te zorgen dat het afval door de verantwoordelijke instanties kan worden opgehaald waarna het kan worden verwerkt in Moengo.

Bij het ontwerp van de ophaalplaats hebben wij rekening gehouden met de lokale factoren, waaronder de wateroverlast, dieren, en uiteraard het beperkte budget wat voor deze oplossing beschikbaar is. Momenteel hebben wij contact met een lasser die een schatting gaat maken van de kosten van het ontwerp als dit uit staal vervaardigd is. Als het van hout gemaakt zou worden is de schatting dat er ongeveer 25 meter aan houten balken, en 5 m2 aan planken nodig is.

Ook zijn wij in gesprek met de kapitein en inwoners van Ricanau Mofo waarmee wij gezamenlijk de gunstigste locatie voor de ophaalplaats zullen bepalen. Wij zouden hier ook graag de afvalophaaldienst in meenemen aangezien zij deze plaats iedere week zouden moeten bezoeken om het afval op te halen.
Aangezien Ricanau Mofo te klein is voor eigen afvalverwerking is een afval ophaalplaats de enige stap voorwaarts om dit probleem op te lossen. Mocht deze afvalplaats echter niet wekelijks geleegd worden ontstaat het risico dat de afvalplaats door de dorpsbewoners niet meer gebruikt kan worden omdat deze vol is, of dat deze door het afval wat er langdurig ligt gaat stinken en/of ongedierte aantrekt. Daarom is het van belang dat Ricanau Mofo wekelijks door de afvaldienst wordt meegenomen in de ophaalronde.

Wij zouden graag in contact komen met de afvalophaaldienst om het bovenstaande te bespreken. Daarnaast horen wij graag wat de mogelijkheden van het commissariaat zijn om bij te dragen aan het realiseren van de ophaalplaats.

Met vriendelijke groet,

Christiaan van der Feltz, Tijn Schell en David Spaargaren