Tasikoki Coastal Protection

A researched based advice into the mitigation of shoreline recession of the beach of the Tasikoki Wildlife Rescue and Education Centre

By

MDP Group 282

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April 2019

Course:
Multidisciplinary project – CIE4061-09

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Preface

This report is the result of a three-month Multi-Disciplinary Project conducted in the northern region of Sulawesi, Indonesia. As part of our Master program Hydraulic Engineering, Construction Management and Engineering and Offshore and Dredging Engineering at the Delft University of Technology. We were given the opportunity to investigate the mitigation of shoreline recession at the Tasikoki Wildlife Rescue and Education Centre, searching for a solution within the Building with Nature philosophy.

The aim of this report is to advice Tasikoki Wildlife Rescue and Education Centre on how to effectively protect their hinterland from flooding as a result of severe shoreline recession. The importance of protecting this hinterland has been made clear to us by our client Dr. Willie Smits, founder of Masarang Foundation. Another important aspect is minimalizing the impact of human activities on surrounding ecosystems. It is for these reasons that we have sought a solution that mitigates the problem without creating new ones. We hope this report can contribute to a greater cause than just the shoreline recession at the Tasikoki coast and lead as an example for future projects in Indonesia and the rest of the world.

We would like to thank the Masarang Foundation and the Tasikoki Wildlife Rescue and Education Centre for facilitating our needs during the course of our research. We have learned a great deal about wildlife and other ecological projects during various field trips to a variety of projects. Besides, it was pleasant working and living with the staff members. Also, we would like to thank our supervisors, Marian Bosch-Rekveldt, Jeroen Hoving and Jan van Overeem for guidance and steering of our project. Special thanks to Hans de Vroeg and Prof. Dr. Ir. Z.B. Wang for making time available to give advice on complex matters regarding the Unibest-model and model parameters such as tidal inlets. We would also like to thank Argoss and Deltares for providing us with data and software necessary to complete our model. Gratitude to Institut Teknologi Minaesa (ITM), staff and students for helping out during measurements and providing the necessary measuring equipment. Last but not least we would like to thank Dr. Willie Smits, for initiating this project, taking the time to visit the team, opening up his home to the team and helping to get things started on the implementation phase of the project. But most of all of giving us the opportunity to challenge ourselves to solve such a complex problem whilst working at one of the most beautiful and idyllic places on earth.

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Kema - Indonesia, April 2019

Abstract

The beach adjacent to the Tasikoki Wildlife Rescue and Education Centre is one of the many beaches worldwide suffering from coastline recession. This loss of coast has a negative impact on the environment, local society and ecology. In general, shoreline retreat is caused by sea level rise (SLR) and erosion. The main objective of this research is to determine which factors are causing recession at Tasikoki beach and consequently which solution would be best in terms of mitigating coastline recession and protecting the hinterland from flooding. A Building with Nature (BwN) design philosophy has been considered to utilise natural processes instead of traditional ones, creating benefits for society and nature. Additionally, a model will be created in Unibest to substantiate and test the final solution.

The research first aimed to describe the coastal characteristics, ecosystem and societal system of the Tasikoki coast. This mainly consisted of a desk-study which was based on literature, but also of examining the surroundings and talking to locals. This study revealed amongst others the significant contribution of climate change on the shoreline retreat at Tasikoki beach. The local SLR has been significant (0.7 cm/yr) over the last years, causing direct changes in shoreline retreat due to the mild slope of the beach at Tasikoki. Moreover, the societal impact is difficult to quantify. The industrial development of the surroundings will most likely have a negative impact on the ecosystem, especially because of a variety of pollutions. Among the stakeholders, a major blocking power is absent. Nevertheless, an engagement plan is written to explain the local fishermen how they will benefit from the potential solution in order to prevent resistance.

After gathering this general information to form a first impression, more location specific data was required to draw conclusions and setup the Unibest model. Every part of the required data has their own measurement method or source. Below these methods and sources are briefly elaborated:

- The bathymetry of the shallow part of the beach is measured with hand-made measuring equipment.
- More offshore bathymetry data is measured by attaching a sonar GPS measuring tool to a fishing boat.
- The sediment characteristics are determined by taking samples at several locations along the coast and subsequently sieving these samples.
- Wind and wave data are based on wind and wave models provided by Argoss.

After a thorough analysis on the wave and wind climate and the surroundings of the Tasikoki coast, it could be concluded that the dominant wave direction is coming from a direction of 164˚ north. This determines the dominant sediment direction, which is thus propagating northward along the shore. Next, the direct coastal retreat due to SLR was calculated by using the Bruun-rule. This resulted in the insight that SLR contributes for approximately 20% to the coastline retreat. The other 80% is caused by erosion due to longshore and cross shore sediment transport (LST and CST). Based on calculations and aerial image analyses, it was concluded that the two tidal inlets present at the Tasikoki coast play an important role in the erosion pattern. The larger tidal inlet updrift of the Tasikoki coast is demanding more sediment than available in the system, to restore the morphological equilibrium that is disturbed due to SLR. As the dominant LST direction is propagating northward along the shore, the downdrift coast is receiving less sediment and is therefore eroding. On the contrary, the sediment demand of the smaller tidal inlet is less than the available supply of sediment. This results in a growing ebb tidal delta, providing sediment for the adjacent downdrift coast and decreasing the erosion effects downdrift of the inlet. The four main nearshore (CST) processes impacting the Tasikoki coast are wave impact, long waves, turbulence and avalanching/sliding.

During the research, multiple possible solutions have been investigated which could mitigate the coastline recession. Based on a multi-criteria analysis, it was decided that a Biorock-based solution would suit the Tasikoki case best. This is a permeable submerged breakwater with a low current running through a steel frame to dampen waves and enhance nature at the same time. The design and configuration of the Biorock-based solution was revised; optimizing it for Tasikoki beach. This new design is called the TCP-cross. A submerged breakwater was modelled in Unibest at Tasikoki beach. The result was positive. The structure traps sediment and causes more accretion along the coast than the length of the structure itself; functioning like a 'sand engine'. Therefore, it was decided to construct the TCP-cross updrift of the Tasikoki beach. If the structure functions as planned and more budget becomes available in the future, it is advised to implement a second 100 m TCP-cross structure more downdrift. According to the model this should lead to accretion along the entire length of the coast. It should be mentioned though that this second structure should not be placed too close to the first one, as this could lead to undesired effects. A detailed implementation plan was written for the construction of the 100 m pilot at Tasikoki beach. Moreover, a monitoring plan is provided and multiple scenarios are considered to make the solution more future-proof.

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1. Introduction

More than 70% of sandy beaches worldwide suffer from coastal erosion (Bird, 1985). Argued is that sea level rise (SLR) is the most plausible cause for the omnipresent shoreline retreat (Zhang, Douglas, & Leatherman, 2004). The beach adjacent to the Tasikoki Wildlife Rescue and Education Centre (TWREC) is one of the many beaches worldwide suffering from coastal recession. Besides SLR as a big driver for coastal recession, there might be other factors contributing to this recession. These contributors should be investigated thoroughly to find out the core of the recession problem. This report mainly focuses on the protection of the Tasikoki coast. A thorough analysis, additional measurements and a model on effects of possible solutions for erosion will be the basis of finding the most optimal solution to mitigate coastline recession on the Tasikoki beach in order to protect the hinterland.

1.1. Location

The Tasikoki beach is adjacent to the Tasikoki Wildlife Rescue and Education Centre, located in North Sulawesi, Indonesia (Figure 1). Sulawesi is the largest island in Wallacea, which consists of many Indonesian islands that are separated by deep-water straits, stretching from the Asian to the Australian continental shelve. Wallacea is rich in biodiversity and unique wildlife. However, wildlife is not always conserved properly. Due to the strategic trade position of North Sulawesi to international markets a lot of illegal wildlife is traded through this region. Therefore, the TWREC has been developed to care for confiscated wildlife that has been illegally traded and kept (Tasikoki, 2019).

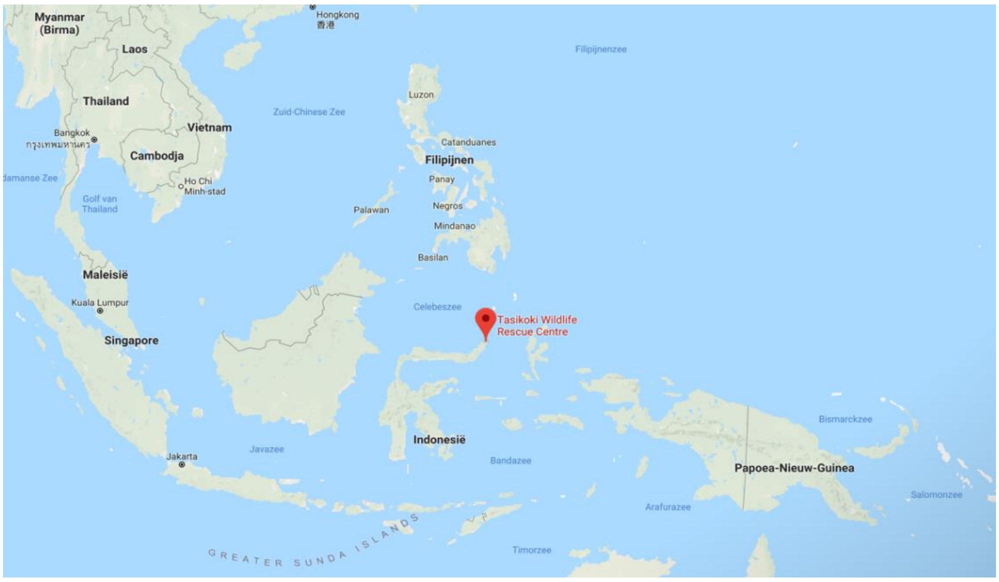


Figure 1 Location of Tasikoki beach (Google)

1.2. Masarang Foundation

The TWREC is part of the Masarang Foundation, the client of this project. The foundation is founded in 2001 by Dr. Eng. Willie Smits. The mission of the Masarang Foundation is 'to conserve nature through collaboration with and development of the local population'. The most urgent global problems are tackled by the foundation such as deforestation, biodiversity loss, climate change, poverty and underdevelopment (Masarang, 2019). Coastline recession and coastal erosion are among those urgent global problems. The question from the client is to come up with a solution that follows a Building with Nature (BwN) design concept to mitigate coastline recession to protect the hinterland of the Tasikoki coast. Making use of the BwN design concept hopefully allows additional benefits to occur such as an increase in biodiversity.

1.3. Problem description

Over the past 20 years the coastal area directly in front of the TWREC has lost approximately 18 meters of beach according to staff of the centre. As a rule of thumb for approximating shoreline retreat caused by SLR, often use is made of the Bruun rule. This rule states that the ratio between shoreline recession and the SLR is in the order of 50 to 100 dependent on the slope of the coast. This means that for every centimetre SLR the coast retreats with a half to one metre (Bruun, 1962). However, there is some discussion about the Bruun rule. Zhang, Douglas and Leatherman (2004) have found that a coast will retreat two orders of magnitude stronger than the SLR rate, which results in at least one metre shoreline retreat each centimetre of SLR. Nowadays, the average SLR rate is about 3 mm/year on a global scale and will further increase due to the melting ice caps (Dieng, Cazenave, Meyssignac, & Ablain, 2017). Stive (2004) argues that the Bruun rule and the additional findings of Zhang et al. (2004) are theoretically sound, but appends that the rule can be sub-ordinate to other effects. Therefore, other possible causes for coastline recession and coastal erosion need to be examined.

There are two foremost reasons for tackling the shoreline retreat. Apart from the fact that the beach is an important chain in the North Sulawesian ecosystem, it safeguards the hinterland from flooding. Any loss of coast can have devastating consequences on the environment, local society and ecology. Besides, the Masarang Foundation preserves two other coastal nature reserves nearby Tasikoki, namely Tulap and Temboan. These beaches are the sea turtle nesting locations of five endangered species (Tasikoki, Masarang Sea Turtle Project, 2019). The turtles make use of the beach by laying their eggs here. Once the implemented solution(s) at Tasikoki show a positive impact on stopping the recession, the solution(s) may also be utilised at Tulap and Temboan beach.

1.4. Research question

The aim is to stop the coastline recession of the Tasikoki beach and protect the hinterland from flooding. In order to conduct a successful project a research question has been drawn up, together with sub-questions and the scope.

1.4.1. Research question

What are viable BwN solutions to mitigate recession of the coastline of Tasikoki to protect the hinterland from flooding and how can the most optimal solution be implemented?

1.4.2. Sub-questions

- *Which factors cause the shoreline retreat and coastal erosion?*
- *How can a UNIBEST model be used to simulate the coastal dynamics of the Tasikoki beach in order to predict the effects of possible solutions?*
- *What are viable BwN solutions for coastal protection?*
- *What is an effective way to implement the solution at Tasikoki beach?*

1.4.3. Scope

The scope of the project is set to perform research on a viable solution for Tasikoki beach. To find the most optimal solution (or combination of solutions), a variety of different types of BwN solutions are considered, after which these solutions will be assessed on to be determined criteria. The most important criteria will be the effectiveness of coastline recession mitigation. However, other factors like costs, environmental and societal impact will weigh in on the decision. Multiple scenarios are assessed to create an anticipative tendency for the client.

Shoreline retreat is a problem that affects the whole of Indonesia, but almost every coastline has its own unique characteristics. As explained before, the focus of this project lies with the protection of the valuable hinterland of Tasikoki beach. However, the Masarang Foundation has several other beaches that require protection. The outcome of the research for Tasikoki beach could set the basis for two other locations, Tulap beach and Temboan Beach, but these beaches have different characteristics. A critical view on the criteria assessment is therefore required before implementing the same solution as is advised for Tasikoki beach.

2. Tasikoki coast

The system of the Tasikoki Beach can be described by three main factors, namely: coastal conditions, the societal system and the ecosystem. The major disrupter of these factors is climate change. All these factors influence each other and can also stimulate climate change, which consequently make them interdependent. The impact on the Tasikoki coast can thus be seen as a combination of these factors with climate change as its main disrupter. Knowledge about the system might clarify the essence of the coastline recession problem and provides insight in areas where further research is required. Given the fact that all factors involved in the Tasikoki case are interdependent, the report makes use of a framework which is shown in Figure 2. It can clearly be seen that any changes in climate affects the three general themes. This results in coastline recession and eventually leads to a higher probability of flooding of the hinterland.

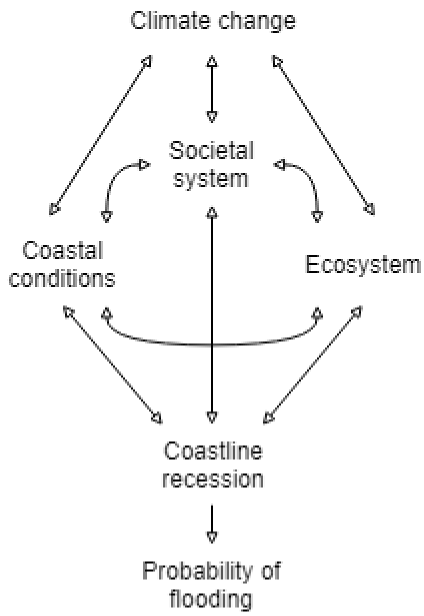


Figure 2 Framework of the Tasikoki coast

As mentioned before, climate change is the main disrupter of all three factors leading to coastal recession, namely the coastal conditions, the ecosystem and the societal system. These effects should be discussed in further detail per factor in this chapter.

2.1. Coastline recession

Before addressing the factors and drivers of the Tasikoki system, the basic principles of cross-shore transport (CST) and longshore sediment transport (LST), recession and retreat, erosion/accretion and regression/transgression of a coast will be explained. This information is provided to give the reader the required basic knowledge of the processes that lead to the advancing or retreating of coast and the terminology that will be used in the report.

2.1.1. Cross-shore and longshore sediment transport

Inside the surf zone (region of breaking waves) most of the sediment is transported along the coast, the so-called longshore transport. Waves are responsible for continuously stirring up the sediment from the bed. The sediment can subsequently be transported in longshore direction by wave-generated and tidal currents. These currents are generated by oblique incident waves that break in the surf zone. Sediment transport dynamics caused by cross-shore transport is considered a highly complex research field. The process contains “(…) a mix of bed and suspended load transport due to undertow, bound and free long waves, short wave skewness in combination with breaking-induced turbulence” (Bosboom & Stive, 2015, p.

331). Nevertheless, cross-shore sediment transport can have devastating effects on coastal regimes, changing the morphology of the beach drastically in relative short time frames. Moreover, LST and CST are interrelated as CST effects can lead to increasing and decreasing LST and vice versa. Furthermore, coastal changes occur in the case of gradients in sediment transport. A positive gradient in the transport direction will cause erosion. Accordingly, sediment transport is increasing along the shore, and hence more sediment is leaving than entering a considered section. A negative gradient results in accretion and if the gradient equals zero there will be no changes in morphology.

2.1.2. Transgression/regression

A storm or season may change the wave climate temporarily and therefore the position of the coastline, but in principle the mean position of the coastline does not change. This will only change when there is a structural loss or gain of sediment. Structural erosion may occur when sand disappears in cross-shore or alongshore direction. Moreover, the gradual relative sea-level changes determine in combination with the gradients in sediment transport and the coastal regime, whether a coast advances or retreats during a certain time period. The horizontal shift of the waterline is described by transgression and regression. Hence, regression of the sea leads to advance of the coast. Similarly, transgression implies retreat of the coast. Besides, transgression can also be described as coastline recession or coastline retreat. For many beaches, this phenomenon is currently occurring due to sea level rise. Even though no sediment is lost, the shoreline retreats due to this effect.

2.2. Coastal conditions

In this subchapter the coastal conditions of the Tasikoki coast will be elaborated. Once these coastal conditions are understood, the problem of the coastal retreat will become clearer. Data will be provided in chapter 4. Data in order to confirm the stated hypotheses of this chapter.

2.2.1. Climate

The climate in North Sulawesi is characterized as a tropical rainforest climate. The warm waters of Indonesia make sure that the temperature on land remains constant year-round. In January and December, the most precipitation is experienced while from June to September the driest months occur (Klimaatinfo, 2019).

2.2.2. Geographical location

The Tasikoki beach is located on the Sunda plate, or so-called Sundaland, marked with the red star in Figure 3. According to Kroker (2012), the Sundaland area is tectonically complex and seismically active. The Sunda plate moves eastward, causing a converging edge of the plate east of Tasikoki (Simons, et al., 2007). This leading-edge coast is characterised with a short, steep coast and straight rivers (Bosboom & Stive, 2015, p. 38). Because of the converging plates, there is a high density of volcanos near the TWREC, resulting in a volcanic sandy beach.

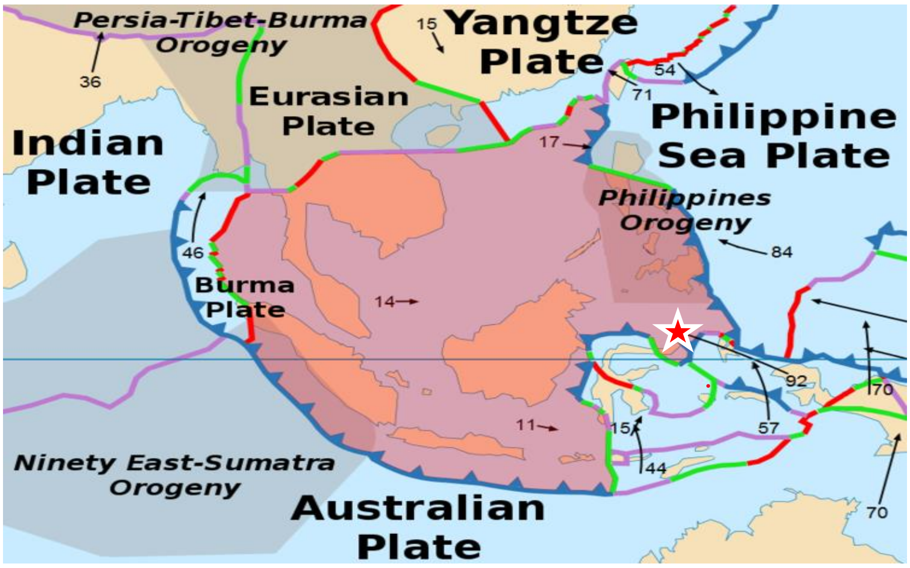


Figure 3 Sunda plate (Alatarisation, 2015)

2.2.3. Wind climate

The south-east Asian area is influenced by the monsoon wind system. This system is seasonally reversing. From October until March the wind has a south-western direction (i.e., wind that is blowing from the north-east) north of the equator (Figure 4). From April until September the system has a north-western wind direction (Figure 5) (ICCSR, 2010).

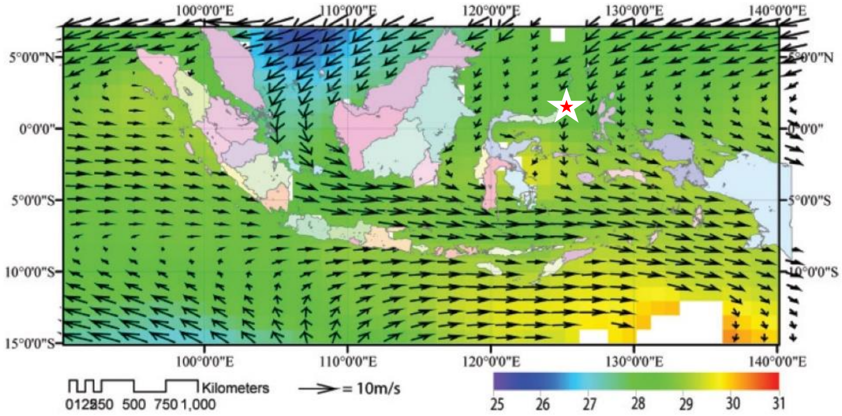


Figure 4 Indonesian wind patterns in January (ICCSR, 2010)

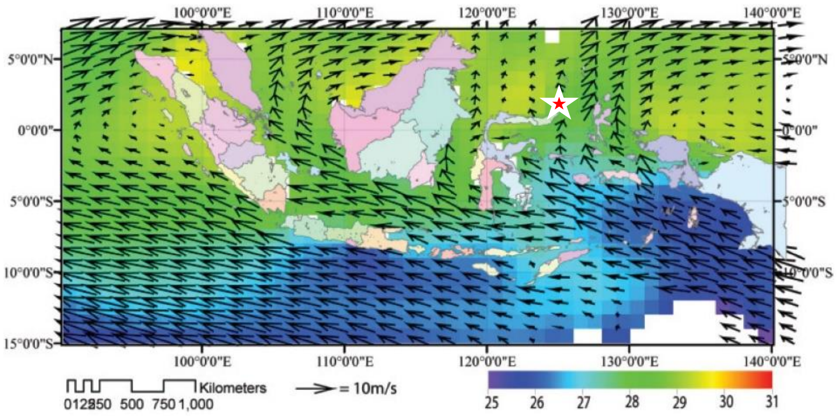


Figure 5 Indonesian wind patterns in August (ICCSR, 2010)

The reason for this seasonal difference is the impact of atmospheric circulations on the wind climate (Figure 6). These circulations are caused by continental warming during summer at the northern hemisphere, which leads to a high-pressure area above the Russian continent. During winter, the Russian continent cools down, creating a low-pressure area. This results in a south-western wind direction on the Tasikoki beach (Bosboom & Stive, 2015, p. 143). It is difficult to determine if the year-round dominant wind direction is south-western or north-western. Additional measurements are required to conclude the dominant wind direction year-round, which will be done in paragraph 4.1. Wind climate.

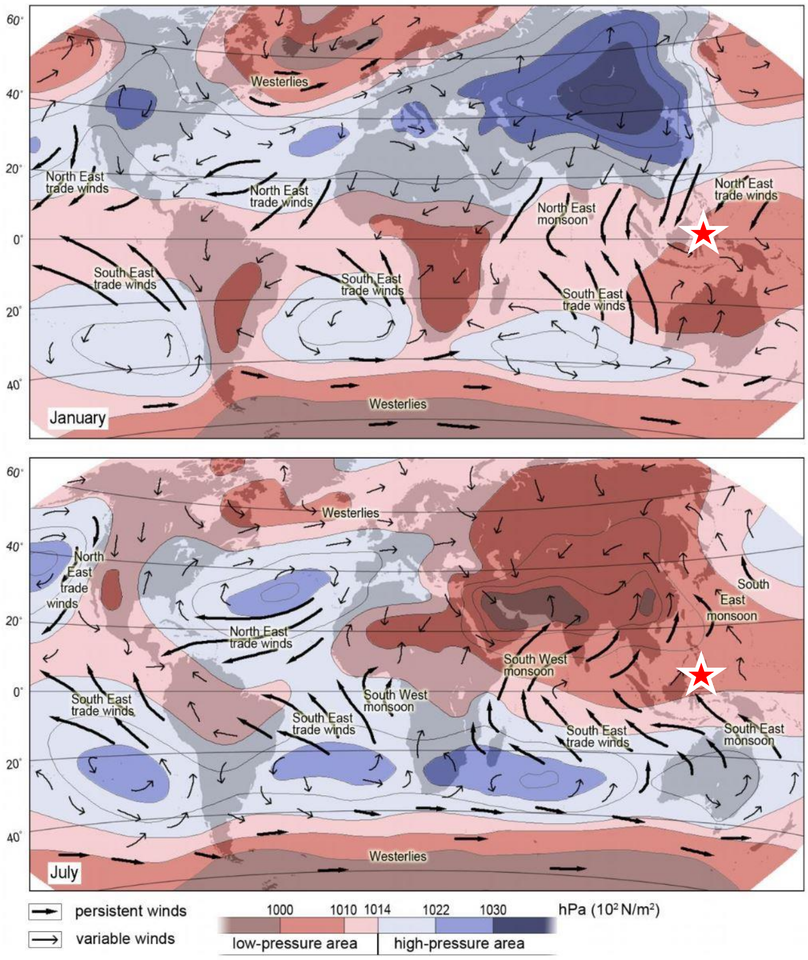


Figure 6 Global wind patterns indicating the main wind systems (Bosboom & Stive, 2015, p. 144)

2.2.4. Wave climate

The North Sulawesian wave climate is driven by three major influencers, namely atmospheric circulations, the Indonesian wave environment and oceanic circulations. The first driver, atmospheric circulations, is yet described in 2.2.3. Wind climate. The second driver, the wave environment of Indonesia, is described as a protected sea environment, which means the coasts are protected from fierce wave impact (Figure 7). However, the eastern coast of North Sulawesi is prone to incoming north-eastern waves, as the north-eastern area offshore of the coast is unprotected.

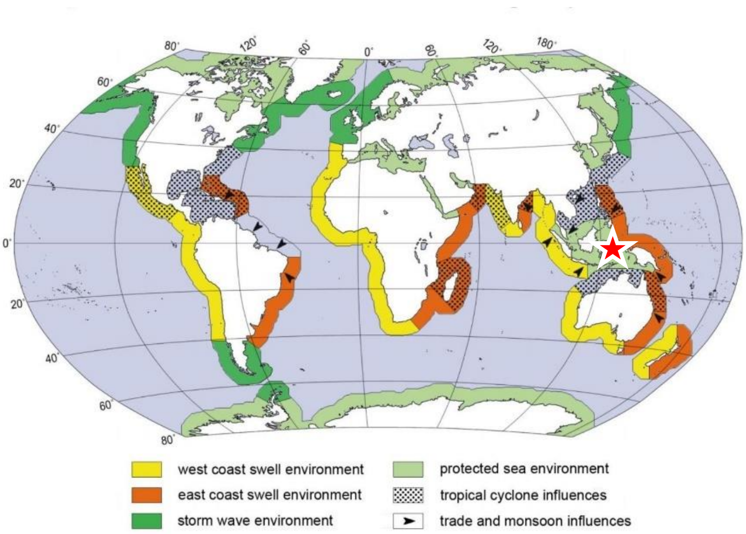


Figure 7 Global wave environment distribution (Bosboom & Stive, 2015, p. 148)

The last major influencer of the dominant wave direction is oceanic circulation, which is also called the great conveyor belt. The great conveyor belt transports a warm surface flow towards the North Sulawesian coast. This wind-driven surface current runs from the northeast to the southwest through Indonesia (Figure 8).

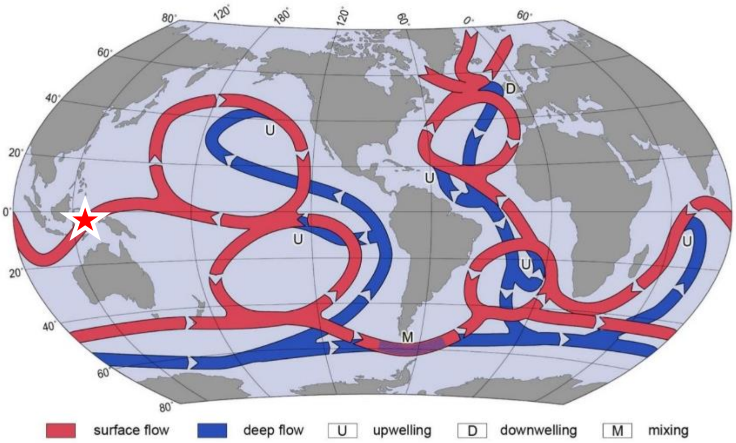


Figure 8 The great conveyor belt (Bosboom & Stive, 2015, p. 145)

Consequently, these main drivers of the wave climate indicate a dominant wave direction from the north-east. However, other influences like the location of Lembeh Island in front of the Tasikoki coast may cause a different dominant wave direction. Additional data is necessary to confirm the exact dominant wave direction. This will be discussed in paragraph 4.2. Wave climate.

2.2.5. Mixed tide and wave dominated

The Tasikoki coast is partly wave dominated. This can clearly be seen as the coast contains a relatively short steep beach which is fed by a lot of small rivers along the coast. These rivers transport volcanic sediment and do not evolve into giant deltas. The tidal amplitude is significant compared to the water depth, which develops elongated bars at the inlet mouths. It is therefore assumed that the Tasikoki beach is not purely a wave dominated coast. Also, through the present current, the incoming waves and the influence of the tide, spits are formed at the inlet mouths. These spits indicate the coast to be partly wave dominated. The Tasikoki beach is thus considered a mixed tide and wave dominated coast. Besides, scarps are observed along the coast. Scarps are a typical characteristic of coastal erosion due to increased wave impact induced by SLR (Orviku, Tõnisson, Kont, Suuroja, & Anderson, 2013).

2.2.6. Tidal regime

The tidal regime of the coastal area of Tasikoki is mixed mainly semi-diurnal which means that the semi-diurnal tide M2 is predominant with a significant inequality caused by the diurnal K1 tide (Ray, Egbert, & Erofeeva, 2005). During spring tide, it shows more semi-diurnal characteristics and during neap tide it shows solely diurnal characteristics (Figure 9). The largest tidal range at the Tasikoki beach is 1.59 m (Tide-Forecast, 2019). The monthly mean of the highest tidal range around Tasikoki beach is around 1.2 m to 1.4 m (ICCSR, 2010), which indicates a micro-tidal regime (Bosboom & Stive, 2015, p. 165). This type of tidal regime often occurs at open coasts like the Tasikoki beach. Besides, the rising period is shorter than the falling period. This means the flood duration is shorter than the ebb duration. This indicates higher flow velocities during rising periods, which is called flood dominant. Flood dominant tides are found at beaches with a large ratio for tidal amplitude over water depth (a/h) (Bosboom & Stive, 2015, p. 258). As the Tasikoki beach is very mildly steep and the tidal range is quite significant, the effect of the tide can clearly be seen. At high tide there is little beach left, while at low tide there is a noteworthy area of land visible.

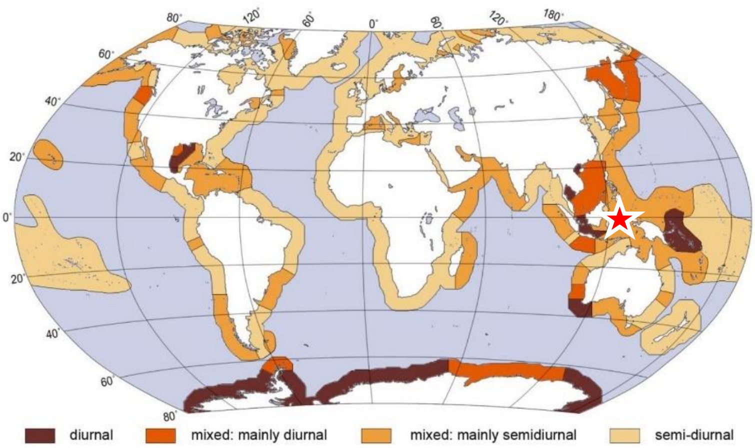


Figure 9 Global tidal environments (Bosboom & Stive, 2015, p. 153)

2.2.7. Mean sea level

The pace of SLR is different per location. Moreover, there are multiple models created and researches done to forecast SLR in the future. Thus, when considering the long-term impact of SLR, different scenarios must be considered. For the Tasikoki coast, making use of altimeter data, SLR is 0.7 cm/yr. Projected is a rise of 37.5 ± 2.5 cm in 2050 and 80.0 ± 5.0 cm in 2100. The ICCSR article also mentions a more extreme scenario where several models, such as that of the Intergovernmental Panel on Climate Change (IPCC), are combined with the dynamics of the ice mass melting in Greenland and Antarctica. Approximation of this scenario is a SLR rate of 1.76 cm/yr for the Tasikoki coast which means a SLR of 87.5 cm in 2050 and 175 cm in 2100 (ICCSR, 2010). The most extreme scenario of SLR globally is a rise of 70 cm in 2050 and 180 cm in 2100 which takes into account all individual high end estimates for each sea level component considered by IPCC and assumes a perfect correlation between these sea level contributors (Jevrejeva, Grinsted, & Moore, 2014). The forecasted rate of SLR of the extreme scenario is 2.2 cm/yr.

The impact of SLR on the Tasikoki beach can be calculated by making use of the Bruun rule, as also mentioned in the introduction. The rule states that for every cm of SLR the coast retreats 50 to 100 cm dependent on the slope of the coast (Bruun, 1962). The Bruun rule is formulated in Equation 1 and describes the horizontal displacement of the coastal zone due to the change in mean sea level (MSL) (Stive & Ranasinghe, 2009).

Equation 1 The Bruun rule (Bruun, 1962)

$$R = \frac{L * S}{B * h} = \frac{S}{\tan(\beta)}$$

Where,

$$h = maximum\ depth\ (beyond\ this\ point\ no\ exchange\ of\ sediment\ between\ near\ and\ offshore)$$
$$L = horizontal\ distance\ from\ coastline\ to\ maximum\ depth$$
$$S = sea\ level\ rise$$
$$B = dune\ crest\ height$$
$$R = coastal\ recession$$
$$\beta = average\ slope\ of\ the\ active\ profile$$

To see what the general impact is on the shoreline retreat of this phenomenon, a thorough analysis is required. Additional data on beach topography is collected in 4.5. Bathymetry. In order to make realistic assumptions on the results, the average slope of the active profile will be calculated for every cross-shore profile that has been measured. Use is then made of the different scenarios of SLR mentioned above to calculate the actual impact. This will be discussed in paragraph 4.4. Coastal recession through SLR. Only the first two scenarios are used to assess the impact of SLR because they are location specific while the third scenario of 2.2 cm/yr SLR is not and therefore only used for future anticipation.

2.2.8. Coastal storm regimes

Coastal regimes can change in relative short time frames due to severe weather events. Due to climate change the probability of occurrence for these severe weather events and thus storm regimes is rising. This can have devastating causes for the hinterland as these coastal regimes can also lead to a higher probability of flooding. The factors that influence the impact of the storm on the coastal regimes can basically be subdivided into two categories according to (Sallenger, 2000), namely hydrodynamic boundary conditions and geomorphological properties.

Extreme climate events

Predicted is that the frequency of extreme climate events (e.g. El Niño and La Niña) will increase. This intensification of extreme events is caused by the increasing intensity of global warming. Occurrence of El Niño and La Niña will increase from once every three to seven years to once every two years. El Niño is an extreme climate event that causes a decrease in sea surface temperature (SST) and a shift of the warm-pool winds. Consequence of this event in Indonesia is a rainfall decrease. Sea levels then can fall up to 20 cm, which stimulates coral bleaching (Ampou, et al., 2017). By contrast, El Niña causes heavy rainfall due to an increase in SST and a temporary rise of the sea level around 10 cm to 20 cm (Trenberth, 1997). Along with the increased abrasion, the probability of flooding increases significantly. Additionally, these extreme climate events contribute to tropical storms and tidal waves, resulting in increased erosion independently of the shoreline retreat caused by SLR (ICCSR, 2010).

Hydrodynamic boundary conditions and geomorphological properties

The hydrodynamic boundary conditions consist of storm surge properties (surge height, duration and spatial gradients) and properties of wave forcing (wave height, wave period and spectral shape). The second item, geomorphological properties, covers mainly the coastal morphology and the resistance against severe weather events. Firstly, the geometry is an important aspect as the crest height of the dunes determines whether or not overtopping and overflow of water is likely to occur. Secondly, the resistance against storm erosion should be considered by analysing the grainsize and the compaction of sediment as they strongly determine the angle of repose of the beach slope. Besides, the presence of any kind of vegetation in the coastal zone will increase the resistance against erosion. Lastly, the presence of structures and/or buildings can have a significant influence on storm erosion, as they tend to stimulate local erosion. According to (Sallenger, 2000) there are four main storm regimes that can be distinguished. The storm regimes can be divided into the swash regime, the collision regime, the overwash regime and the inundation regime.

Swash regime

The swash regime is basically the first stage during a storm where the coast is still experiencing normal weather conditions. This means the maximum wave runup, also known as R_{high}, is still lower than the elevation of the dune toe, also known as D_{low}. Visualizations of the four different regimes are retrieved from the lecture notes of Coastal Dynamics II and the visualization of the swash regime can be seen in Figure 10. Hence, that only the beach is affected by the hydrodynamics and not the dunes. This can cause accretion of the beach.

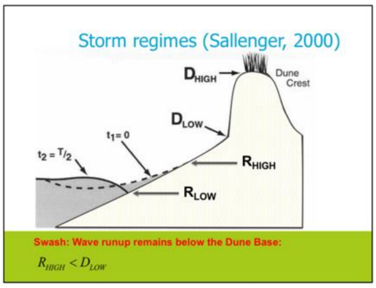


Figure 10 Swash regime (Coastal Dynamics II)

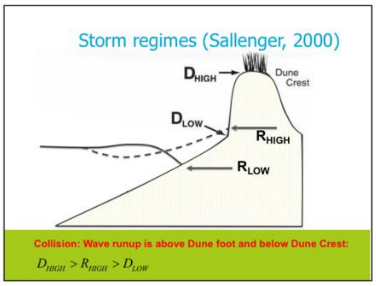


Figure 11 Collison regime (Coastal Dynamics II)

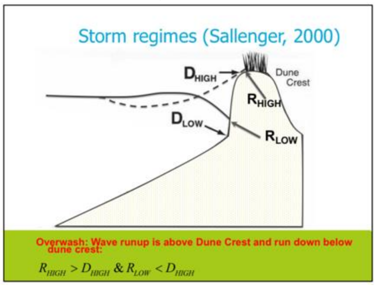


Figure 12 Overwash regime (Coastal Dynamics II)

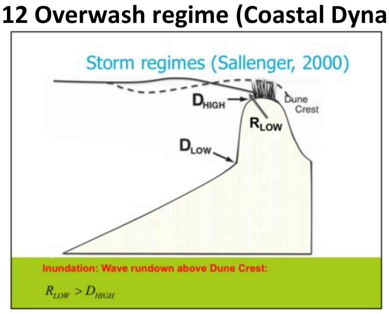


Figure 13 Inundation regime (Coastal Dynamics II)

Collision regime

The collision regime starts occurring when the storm increases in intensity, causing higher waves and a higher sea level. The waves are now able to reach the dunes before they have lost their energy as they tend to feel the bottom resistance less. This means the R_{high} is lower than the elevation of the dune crest, also known as

D_{high}, but bigger than the D_{low}. Hence, a part of the dune face starts eroding and the extracted sediment is distributed over the cross-shore profile of the coastal zone. (Figure 14) Therefore the beach slope becomes milder and more in tune with the storm conditions. In many cases the eroded sediment can be found back on the beach itself. This only holds if there are no sinks or sources in the beach profile, like a strong alongshore sediment transport. A visualization of the collision regime can be seen in Figure 11.

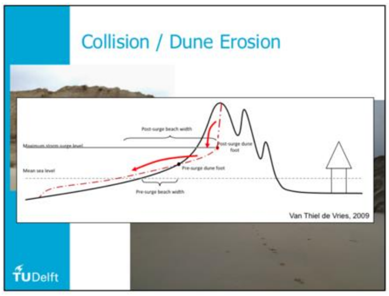


Figure 14 Collision/dune erosion (Coastal Dynamics II)

Overwash regime

The overwash regime occurs when the sea level and the wave height further increase. The R_{high} in this case is bigger than the D_{high} but the R_{low} is still lower than the D_{high}. This means water is occasionally overtopping the dune crest, but the MSL is still lower than the dune crest. The overflowing water can take substantial sediment to the back of the dune. This can have dramatic effects on the coastal morphology, because the sediment cannot return to the seaward side of the dune over time. Hence, there is a loss of sediment of the coastal cell, with a structural altered dune profile as result. A schematization of the overwash regime can be found in Figure 12.

Inundation regime

The last regime described by (Sallenger, 2000) is the inundation regime. In this case the R_{low} is higher than the D_{high}, which means there is a permanent overflow of water over the dune crest. This causes fierce erosion as a lot of sediment is transported to the back side of the dunes. High flow velocities, especially during the peak of the storm, are capable of moving sediment a long way behind the dune crest. Furthermore, the overflow of water can cause serious flooding of the hinterland when the dune row has only one line of defence. A schematization of the regime is illustrated in Figure 13. If the inundation continues long enough the elevation of the dune crest can become lower than the MSL. If this happens breaching of the dunes start to occur, with even more dramatic flooding as result.

Regime of Tasikoki

In the Tasikoki case the effects of the collision regime are clearly visible in Figure 15. Nevertheless, the beach is mostly experiencing a swash regime in which only the beach is affected by hydrodynamics. No evidence has been found on the Tasikoki beach of any overwash or inundation regimes in the past.

Figure 15 Beach scarps on Tasikoki beach

Nearshore processes during storms

According to (Van Rijn, 2009) there are four major nearshore processes that have impact on coastal erosion: wave impact, long waves, turbulence and sliding/avalanching of the dune face. The water level is not included in this list, as it is not a nearshore process on itself. Though, it has significant influence on the four major nearshore processes that have effect on coastal erosion.

Wave impact

The first nearshore process that affects coastal erosion is the wave impact on the dune face. The process can be described by Equation 2 and a schematization can be seen in Figure 16.

Equation 2 Dune erosion volume (Coastal Dynamics II)

$$dune\ erosion\ volume = f(force\ in\ the\ wave\ uprush).$$

It basically says that the bigger the wave force is on the dune face, the bigger the dune erosion volume would be. For steeper beach slopes the wave impact is higher, thus resulting in higher erosion rates. Note that the beach slope becomes milder and more in tune with storm conditions during a storm, thus decreasing the impact of this process.

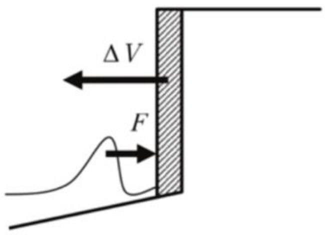


Figure 16 Wave impact (Coastal Dynamics II)

Long waves

The second nearshore process is the impact of long waves on coastal erosion. Short waves tend to break earlier in coastal zones than long waves. Short waves therefore have a significant lower impact on dune erosion than long waves. Whereas short waves reduce in amplitude, long waves grow in amplitude when they come closer to the shore. This consequently leads to a higher wave runup and thus more erosion.

Turbulence

During severe weather events waves increase in intensity. This consequently leads to an increased sediment stir up, also known as turbulence. Close to the shore the turbulence is highest due to breaking waves, wave reflection and rollers. Moreover, increased turbulence combined with undertow and/or alongshore sediment gradients can lead to fierce erosion.

Sliding/avalanching

The last important process is sliding or avalanching. This process is largely influenced by the water level, as a higher water level increases the saturation level of the dune face. If the dune face contains more water, the dune face becomes heavier. Moreover, the saturation level of the dune face determines the angle of repose of sand. A higher saturation level indicates thus a smaller angle of repose, which means the dune face becomes more vulnerable for sliding or avalanching. The presence of vegetation can prevent the dune face from sliding or avalanching as it enhances the stability of the dune.

2.2.9. Tidal inlets and deltas

The Tasikoki beach contains two tidal inlets. The inlets consist both of an ebb tidal delta, a tidal channel and tidal flats. An overview of the beach can be seen in Figure 17, the tidal inlets are highlighted. The larger inlet is deep enough to let small boats pass during low tide, but even bigger boats during high tide. This makes the inlet perfect for the deployment of a small fishing harbour. Historical images in Google Earth show that the fishing harbour has expanded in the past 18 years. However, human interventions have so far been negligibly small. Historical images (Figure 18) also show no big changes in the ebb tidal delta for the large tidal inlet. The smaller tidal inlet shows however a significant increase of the ebb tidal delta. According to Bosboom and Stive (2015, p. 438) tidal basins are disrupted by SLR due to climate change. There are two plausible scenarios. The first scenario describes the hypothesis of a growing tidal prism and the second of a tidal prism that stays the same.

Unchanged tidal prism

The first hypothesis is the scenario in which SLR causes no change in the tidal prism. This is due to the intertidal flats that grow in the same pace as SLR. In this way the amount of water flowing in and out of the tidal basin in one tidal cycle, also known as the tidal prism, remains unchanged. However, due to the SLR the volume of the channels will increase. The volume of the channels thus become to large, which leads to a demand of sediment for the channels. This demand of sediment has to come from a sediment source outside of the tidal basin, thus the adjacent coast or ebb tidal delta. Therefore, the adjacent coast and ebb tidal delta will get prone to coastal erosion. The tidal basins will in this case act like a sink of sediment.

Growing tidal prism

The second hypothesis states that due to SLR the tidal prism increases. This is caused by the fact that the tidal flats will not adapt to SLR. The tidal prism will therefore stay the same, forcing the channel to transport more water. The channel should therefore adapt to the new conditions, leading to an outflow of sediment to the ebb tidal delta and adjacent coast. The tidal basins will in this case act like a source. Paragraph 4.7. Tidal basins affected by SLR, provides detailed data regarding the tidal basins, whether or not they act like a source or a sink.

Figure 17 Tidal basins with channels, delta's and coral area's

Figure 18 Difference in size of ebb tidal deltas between 2002 and 2018

2.2.10. Bathymetry

The North Sulawesian coast is characterised by its protective wave climate due to the coral reefs that function as a barrier between the open ocean and the shore (Figure 17). The slope of the beach is therefore very mild until it reaches the coral reef. Beyond the reef the sea bottom drops down steeply. By using sonar equipment, a detailed bathymetry map can be created. The methodology and results of these measurements will be elaborated in paragraphs 3.3. Bathymetry, 3.4. Beach topography and 4.5. Bathymetry.

2.2.11. Current

The dominant current of Tasikoki beach is dependent on two important processes. Firstly, the wave and wind affect the current and secondly the current is influenced by the tidal constituents.

Wave and wind affected current

The current which is present at the Tasikoki beach is dependent on wind climate, wave climate and tidal currents. As is already laid out in 2.2.3. Wind climate and 2.2.4. Wave climate, the dominant wave and wind direction is seasonally reversing. Around January the current has thus a southward direction and around July the current has a northward direction. Further research on this topic should clarify what the dominant current direction would be, this will be discussed in sub-paragraph 4.2.2. Dominant wave direction and current. Observations, however, provide an educated guess on the dominant current direction. North of the Tasikoki beach, a small harbour was built in 2007 (Figure 21). Historical images show the difference between 2009 and 2018. Over the years sand has accreted at the south side of the harbour, and consequently eroded at the north side. The coastline differences are indicated with lines (Figure 19 and Figure 20). To conclude, this indicates a current direction from south to north.

Tidal current

The semi-diurnal tide M2 is dominant for the Tasikoki beach with a diurnal inequality due to the K1 tide, as mentioned in 2.2.6. Tidal regime. These different tides cause tidal currents in different directions, where M2 has a higher mean barotropic energy flux (Ray, Egbert, & Erofeeva, 2005). M2 and K1 are both barotropic tides, which means that they are 'basically a large-scale wave with a wavelength of about 6000 km that sloshes around the ocean basins, while being forced by the gravitational forces of the moon and sun' (Hawaii Ocean-Mixing Experiment, 2019). So, the energy of the M2 tidal wave is higher at the location of Tasikoki than the energy of the K1 wave. M2 has a current direction from south to north. By contrast, the current direction of K1 is from north to south (Appendix A). Consequently, when both M2 and K1 are in the same phase, their flows counteract each other. The maximum tidal flow velocity at Tasikoki is thus the same as the maximum flow velocity of the M2 tide, which is around 0.1 m/s to 0.2 m/s and has a current direction northward (Appendix B).

Figure 21 Tasikoki beach with location of the harbour north

Figure 19 Harbour in 2009

Figure 20 Harbour in 2018

2.2.12. Sediment

The sediment composition of Tasikoki beach is highly diverse. The beach has multiple sources of sediment of which the sediment input of the nearby located volcanoes has the largest influence. As can be seen in Figure 22, the beach has a dark looking colour, which indicates volcanic sand. Besides, the coral reefs play a large role as well in the sediment input of the beach. Dead coral degrades into smaller carbonate-like particles which eventually become sand (Chave, Smith, & Roy, 1971). Furthermore, the coral reefs house a variety of sand producing species. To find out more about these species, research outside of the scope of this project should be done. The beach is also the natural border of the biodiverse hinterland which produces a lot of silt and clay. It is therefore expected that the river mouths contain more muddy sediment than offshore-lying locations. Muddy sediment like clay and silt with a higher order of cohesiveness are better resistant against coastal erosion, if the sediment has sufficiently been consolidated (Houwing, 1999). Measurements on grainsize distribution of the sediment should clarify this assumption on cohesiveness of sediment per location.


Figure 22 Tasikoki beach at low tide

2.2.13. Jetty

At first it was expected that the jetty (Figure 22) would affect the sediment transport. After further research on historical aerial images of the beach it was concluded that the jetty is so permeable that it does not influence the coast.

2.3. Societal system

The societal system is elaborated in this paragraph. A stakeholder analysis and the impact of the societal system are discussed.

2.3.1. Stakeholders

Next to the hydrodynamical and geomorphological aspects around Tasikoki Beach, the interests of the involved stakeholders are considered as an important aspect given their daily interaction on and around the area. Since the aim is to implement a possible solution that has minimal negative effects on the (local) environment, it is assumed that every actor has a positive direction of interest towards this project. However, it is imaginable that for instance fishermen and local villagers that this attitude changes when the implemented solution has impact on their way of living. For example, if the solution consists of a structure that blocks the common routes for the fisherman. Therefore, a broad investigation of the stakeholders needs, goals and interests are elaborated in this paragraph. A stakeholder overview is presented in Table 1.

Masarang Foundation

For the Masarang Foundation, coastal protection is of high importance. The beach at Tasikoki is adjacent to the wildlife rescue and education centre. As mentioned before, the beach belongs to the natural environment and safeguards the hinterland from flooding. Thereby, this coastal protection project may be a benchmark for other beaches of the foundation, such as Tulap and Temboan beach (both located on the east coast of North-Sulawesi), which are the natural habitat of endangered sea turtles. The turtles make use of the beach by laying their eggs there. If the Tasikoki project shows positive results, the solution may also be used at the beaches of Tulap and Temboan. Thus, the Masarang Foundation will potentially benefit on a larger scale from a successful case-project. This gives the project an additional incentive.

The foundation operates multiple wildlife rescue and education centres, reforestation projects and has a large local network in and around Indonesia and especially North-Sulawesi and Kalimantan. As the initiator of the project, they will provide the funding for the implementation of the solution. However, seen that it is a foundation, funding will not be unlimited and a tight financial plan might be necessary. The foundation does not depend on any other actor and there is no knowledge of any permit that should be required to implement a solution. The aim is to take the interest of locals into account also. Though, if this cannot be achieved fully, the foundation has the power to decide 'for the greater good' and to search for a proper compensation. All in all, the Masarang Foundation is a critical actor to achieve a successful project result.

Residents and fishermen

Whether the fishermen and local villagers benefit from the protection of the Tasikoki coast, depends on the solution. A solution with for instance the growth of coral may stimulate the ecosystem, which attracts more fish and other underwater species. The direction of interest towards a solution like this, is likely to be positive from the fishermen’s perspective. However, if the solution blocks the daily fishermen’s routes, there might be resistance towards the project. Even though the fishermen do not have a lot of resources, they are the direct neighbour of the wildlife and rescue centre. This means a negative direction of interest is unwanted. For the decision of the optimal solution, this must be considered. A topic for negotiation might be the replaceability of the fishermen’s working space. Due to the large sea, it is doubtable and discussable if an implementation is a barrier for their work as there are plenty of fishing spots left. Moreover, the final solution could also attract fish, corals and vegetation, providing a new source of income for the local community. The fishermen will not be a thread for the project if the project’s aim is clearly discussed and if their interests are kept in mind.

Local villagers have the same problem as the TWREC, namely the possibility of flooding. However, it is not likely that these villages can provide the funds to implement sort-like projects as this project. This makes them dependent on (local) authorities for the initialization of similar projects. Another effect that must be considered while deciding the optimal solution is its impact on adjacent beaches. The coastal system is larger than Tasikoki beach only. Solutions such as breakwaters might work for the Tasikoki beach, but often the previous problems are shifted towards neighbouring coasts. It is not likely that the local villagers will be resistant, because the shifted negative effects are only visible in multiple years. Though, this is not an excuse to only protect the Tasikoki beach and stop caring for other coastlines. Therefore, side effects of possible solutions are considered in the MCA.

Recreationists

The recreationists are not a very important actor in this project. Main interest of this group is related to a good-looking beach, which is not the goal of this project. As the coastline around the Tasikoki area is characterized by long stretched sandy beaches with similar accessibility options, other alternatives could easily replace the recreational purpose currently exploited at Tasikoki Beach. Resistance from locals when the attractiveness of the beach decreases, will likely not form a thread for the project. Thereby, it will cause no problems to ignore them in the project because they do not have a lot of resources and power.

Local authorities

There are some other projects in North Sulawesi focusing on coastal protection. The role local authorities play in these projects is relatively limited, as the works will be carried out on private property. Interviewing local people and visiting reference projects (Appendix C, Appendix D) clarified that there is no necessity to involve local authorities for the implementation of the project, for it is private property. The local authorities are a powerful actor and if they decide to intervene, they can act as a blocking power. However, the client has mentioned that this will most likely not happen. The Tasikoki project could be interesting for the local authorities if a feasible and successful solution is implemented. As mentioned before, the plan might be used in other coastal protection projects if the results are successful.

ITM Tomohon

To acquire the necessary data efficiently, a collaboration between the project team and ITM Tomohon is started. They are in possession of historical data about wave height and currents, which are needed for modelling effects of possible solutions. The project is in their interest because they acquire the study to coastal protection in an area close to their university, what could be input for further research. Thereby, some students of ITM will join the measurements and learn how to collaborate in an international, multidisciplinary team. ITM Tomohon thus is a partner of the coastal protection project and has resources to support the project. On the other hand, their role is strictly advisory as they have no direct interest and influence on the project outcome.

Table 1 Stakeholder overview

Stakeholder	*Resources*	*Replaceability*	*Dependency*	*Critical actor*	*Direction of interest*
Masarang Foundation	High	Low	Low	High	Positive
Fisherman	Low	Medium	High	Medium	Positive
Local villagers	Low	Low	High	Medium	Positive
Recreationists	Low	High	High	Low	Positive
Local authorities	High	Low	Low	High	Positive
ITM Tomohon	Medium	Medium	Medium	High	Positive

2.3.2. Local industry

Tasikoki is located south of the industrial city of Bitung (Figure 23). In the past years the city experienced a steady real GDP growth of more than 6% per year (Knoema, 2017). Given its strategic location near Indonesian Archipelagic Sea Lanes, depth of the sea port and richness in natural resources, the Indonesian Government declared Bitung as a Special Economic Zone (SEZ) in 2014 to encourage the development of the area (Indonesia Investment Coordinating Board (BKPM), 2018). From then on, the development of the area skyrocketed. Multi trillion IDR investments have been made to build a Manado – Bitung toll road, expand the Bitung Harbour and build the International Hub Port Bitung Designation. While these regional infrastructures are expected to open in 2019, the effects of these investments on the surroundings (which include the Tasikoki Beach) are unknown. Given the investment incentives which are provided by the conditions of the SEZ, it is expected that the development of Bitung and its surroundings will keep growing in the coming years.

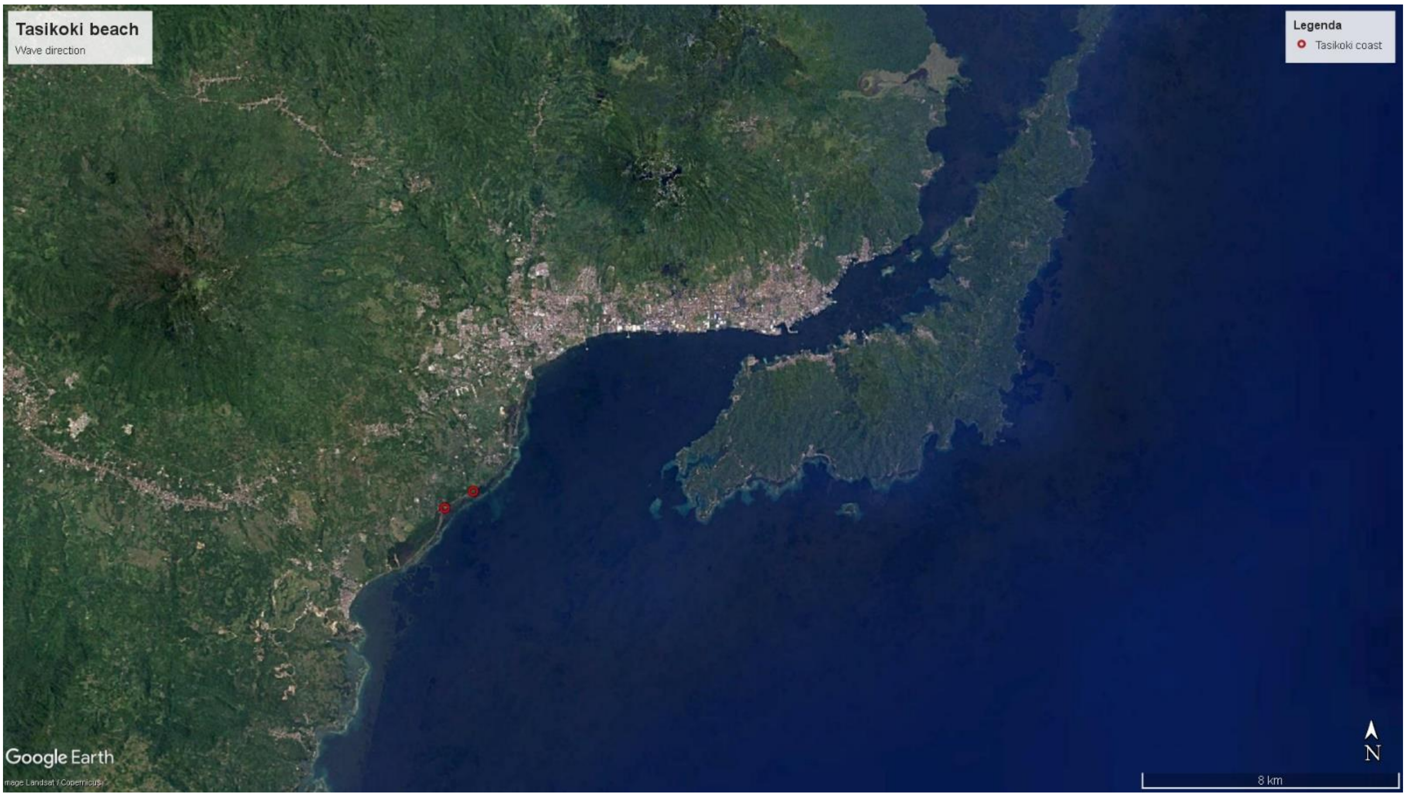


Figure 23 Tasikoki and its surroundings

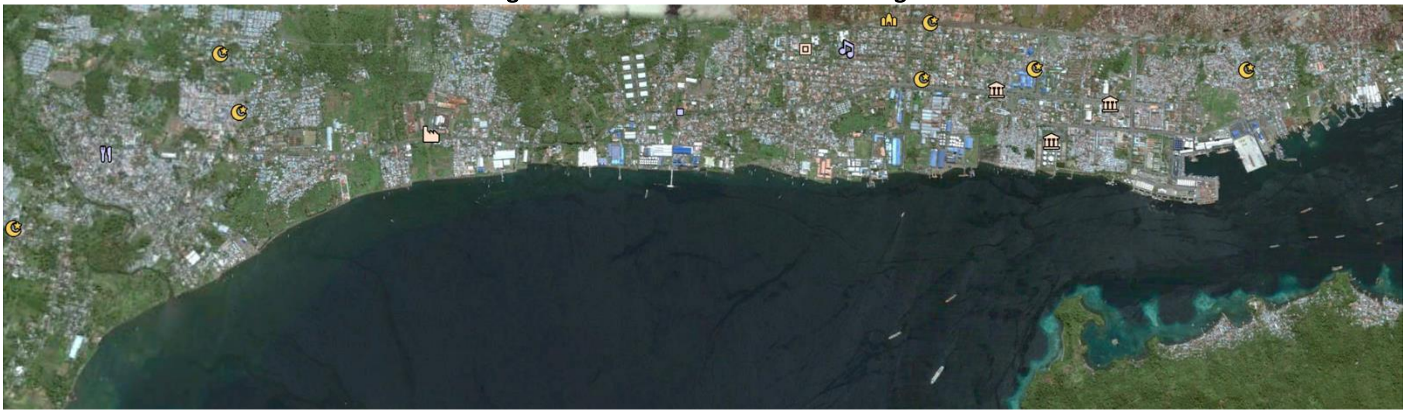


Figure 24 Bitung harbour area in 2004

Figure 25 Bitung harbour area in 2018

In Figure 24 and Figure 25, the coastline of Bitung in respectively 2004 and 2018 can be seen. The Bitung Harbour expansion, located on the south-east of Bitung, is clearly visible on the pictures. Thereby, the amount of business located along the coastline around Bitung shows a continuous development. Rapid economic growth also has several downsides as it does not only bring advantages for the area. Local pollution, depletion of natural resources and uncontrolled spatial development are common nowadays problems in the Bitung region. Oil and gas terminals, fresh fish processing companies and vegetable and palm oil factories popped out of the ground along the Bitung shoreline, causing often dense high and waterways. Additionally, further development of the coastline consists of hard structures like quay walls and jetties. Consequences of the construction of these hydraulic structures may influence the sediment transport in and around Bitung.

2.3.3. Fishery

Once Bitung was one of the biggest fishery hotspots in Indonesia, processing hundred thousand tonnes of fish a year covering 54% of the total fisheries products landed in Indonesia in 2011 (The Oceans and Fisheries Partnership, 2012). Large vessels unloaded their daily catch consisting mainly (81%) tuna species like the skipjack, yellowfin and bigeye. Other species like: scad, squid and marlin are also brought to the North Sulawesian shore for either domestic consumption and export to other ASEAN countries, Europe and the United States (Brugess-Herbert & Silvestre, 2016).

Rich fish populations swimming in the Celebes and Molucca Sea attracted not only the attention of local fishermen. Large (inter)national operating fishing vessels operated in the seas, leading to a huge illegal, unreported and unregulated (IUU) fishing business. Consequences of these activities led to an estimated yearly loss of 4 billion USD for Indonesia related to illegal fishing. In order to protect its waters to such incriminating activities, the Indonesian Government intervened with the so-called anti-IUU fishing policy in 2014. From then on, international operating and produced vessels were labelled as illegal and seized and even destroyed when caught. This intervention was catching international attention, as the enforcement led to a 90% decline of international fishing activities in Indonesian waters (Gokkon, 2018).

The governmental intervention was not only palpable for internationally operating fishing companies. In Bitung, several fish operating companies had to shut down their factories as the fish supply decreased drastically within a short timeframe. Local fishermen, who could hardly reach their daily quotas, benefited generously from the absence of large vessels nearby Bitung (Soeriaatmadja, 2016). On the other side, thousands of workers in the fish processing industry lost their job. Such governmental interventions with an initiated goal to protect the domestic fishing industry has therefore far reaching consequences. Also, the increase in small fishing boats increased the number of anchors near shore. Anchor damage of coral reefs is expected to have risen because large vessels would dock at a harbour instead of near shore.

2.3.4. Tourism

Unlike Bali, Java and Sumatra, North Sulawesi is relatively unknown to tourists visiting Indonesia. To provide an idea: Bali welcomes around 450.000 foreign tourists a month, where North-Sulawesi was visited by only 5.000 tourists in May 2017 (Trading Economics, 2019) (The Jakarta Post, 2017). Most tourists visiting North Sulawesi go to Bunaken National Park, famous for its enormous and living coral reefs surrounded by steep cliffs. On the other side of the island, a close by island called Lembeh provides excellent underwater views. Besides diving and snorkelling, tourists visit the lakes and volcanoes in the area.

A vast majority of tourists visiting North-Sulawesi are coming from China, followed by Singapore and Germany. Given the limited number of visitors, tourist facilities are minimal on the mainland of North Sulawesi. Some resorts are located around the shoreline and the capital Manado has a few large hotels. A future increase of tourist influx is however expected, as the Sam Ratulangi Airport of Manado is operating more frequent flights to Denpasar (Bali) and Singapore, initiating more options for international tourists to visit North Sulawesi. Negative impact of the few tourists on the local environment is negligible, compared to the industrial development the area is currently experiencing. The effect of tourism on Tasikoki coast is therefore minimal.

2.3.5. Pollutants

North Sulawesi is famous for its rich natural marine and coastal resources. High levels of marine biodiversity, large mangrove forests and sea grass areas are all part of the biosphere along the 1837 km coastline around North-Sulawesi (WCS Indonesia, 2018). Impairment of the local biosphere around Tasikoki beach could be affected by a broad set of pollutants, described from a local perspective.

Air pollution

Most developing countries lack sufficient waste processing facilities, leaving the people and companies on their own in finding ways to get rid of it. The common method used in North-Sulawesi is simply the burning of all different types of waste, leading to significant local air pollution. Smoke releases SO_2 into the air, making it toxic. Next to the contribution to global warming, it may cause acid rain on a local scale which pollutes the water and soil in the future, which in high concentrations, can have far-reaching negative impact on the local environment. Next to the burning of waste, is the daily use of motorbikes, old trucks and cars contributing significantly to the local air pollution. Thick plumes of dark smoke are clearly visible while driving the roads of North-Sulawesi, contributing to an increase of PM, NO_x and CO_2 levels in the air. Altogether, with all other sources contributing to local air pollution, Bitung scores an 8 on the Air Quality Index ranking, which is actually a good score. The score is based on initiating $PM_{2,5}$ and PM_{10} levels over 24 hours from midnight to midnight on 21/03/2019 (AirVisual, 2019). Data initiating the CO_2, SO_2, NO_x, NH_3, VOC, CO and CH_4 levels are currently lacking, so a full overview of the development of the local air quality is unfortunately not possible. Given the rapid industrial development of Bitung, the local air quality will most probably deteriorate further and its impact will increase.

Water pollution

Both licensed and unlicensed mining is taking place across the North-Sulawesi province. Given its rich soil containing minerals and metals like gold and iron ore. The mining process often covers the use of acid materials consisting (among others) mercury, which is being dumped into nearby rivers (Palapa & Maramis, 2015). Given the absence of connections to a fresh water system, rural areas use such rivers for their daily needs. Contamination of these rivers can therefore cause significant risk to the public health and contaminate the soil dramatically. As the water flows from the river into the sea, the contaminated water can result in severe damages to the local hydrosphere.

Land-based pollution like rain water run-off brings industrial pollutants as well as sedimentation to the ocean which affect the ecosystem, especially the coral (Edinger, Jompa, Limmon, Widjatmoko, & Risk, 1998). Sedimentation is a consequence of deforestation, something that is a problem in the whole of Indonesia as well as at Tasikoki's surroundings.

Besides industry, contaminated soil and the use of toxic materials in the mining, a lot of trash is dumped into the rivers by both companies and residents. All these plastic, tires, sanitary materials and other objects will finally flow into the sea which is known for its pristine water and rich marine life. Presence of such non-natural products in areas with a high level of marine biodiversity can cause serious harm as investigated by Taylor, Gwinnett, Robinson, & Woodall (2016). Sea turtles and other larger animals can get stuck in larger pieces of plastic and other types of waste, causing serious injuries and even death. Thereby, of all materials dumped into the waters of North-Sulawesi, micro-plastics seriously harm mostly filter feeding underwater species causing illness and death. Research of Romeo et al. (2015) concludes that consumption of plastics containing fish could have effects on human health.

Noise, light, radioactive and thermal pollution are less relevant for the Tasikoki beach, given the absence of nearby sources causing these kinds of pollution.

2.4. Ecosystem

The ecosystem present at Tasikoki Beach and its surroundings play a very important role in this project. The Tasikoki area consists of a large and diverse ecosystem that has a direct influence on the coastal erosion of this area. The most important components of this ecosystem will be discussed in this paragraph. The goal of this project is to find a solution for the coastline recession problem at hand. It is therefore likely that the ecosystem will be affected by the implementation of the solution, either positive or negative. As part of the research is to investigate the BwN concept, components of the ecosystem could be part of the solution.

2.4.1. Coral

As will be discussed in sub-paragraph Impact on coral reefs, the coral reefs present near Tasikoki beach protect the beach from wave energy. Furthermore, coral reefs are largely responsible for the production of sediment and therefore the nourishment of beaches (Chave, Smith, & Roy, 1971). The provided natural protection is an important resource that should be considered when deciding on which solution to implement. Moreover, possible solutions should not disturb this phenomenon. Another characteristic of coral reefs is that they contain a large biodiversity, creating fishing grounds for local fisherman, which is an important economic driver in North Sulawesi.

Impact on coral reefs

As mentioned in sub-paragraph Extreme climate events, the fall of sea levels during El Niño is a major cause of coral bleaching, especially for shallow coral reefs (Ampou, et al., 2017). The depth of the Tasikoki coral reef can indicate if the reef is prone to coral bleaching caused by sea level fall. Additionally, more frequent occurrence of El Niño and La Niña cause more abrupt SST changes, which also stresses coral. Namely, coral reefs are highly affected by sudden temperature changes. Additionally, SST rise forms a thread for the coral reefs on the long term, as the water temperature is gradually rising. SST rise at Tasikoki beach is projected at 0.019 ℃/yr. This calculation forecasts an SST increase of 1.10 ℃/yr in 2050, and 2.15 ℃/yr in 2100. High rates of SST rise have negative effects on fishing grounds and coral reefs. Fishing grounds will probably shift to cooler oceans. The damage to coral reefs may be avoided when the rates stay between the reef's adaptive capacity. However, the ideal water temperature for a coral reef is about 26 ℃ to 30 ℃ (ICCSR, 2010). With an average water temperature around 28.5 ℃ (Temperature, 2019), the coral reefs in front of the Tasikoki coast are likely to be subject to coral bleaching due to the temperature changes and SST rise.

Land-based pollution such as sedimentation and industrial pollution reduced biodiversity in a 3 m deep reef (similar to Tasikoki) with 30-50%. Other damages like anchor damages in shallow water reefs decrease approximately 50% in biodiversity (Edinger, Jompa, Limmon, Widjatmoko, & Risk, 1998). Thereby, the sea level is rising at such a high rate that coral reefs, the natural protection of the beach, cannot grow in the same pace. This increases the impact of waves hitting the shore, leading to fierce erosion.

2.4.2. Seagrass

Seagrass is one of the most underestimated ecosystems out there, providing for a large diversity of sea life (Reynolds P. L., 2018). Indonesia is located in the most diverse seagrass populated area of the world (Short, 2011). Surveys of the area show that Tasikoki beach has large seagrass beds. Therefore, it is important to mention the ecological value of seagrass.

Seagrass can produce up to 10 L of oxygen via photosynthesis per square meter per day and act as perfect shelter for small invertebrates and different sizes of fish. 40.000 Fish and up to 50 million invertebrates can be found in one acre of seagrass. Moreover, the plant-like structure of seagrass affects the surroundings in different ways. The leaf-like part, visible underwater, catch nutrients, sediment particles and slow down water flows. The roots keep these particles and nutrients on the seafloor, stabilizing it. This process results in higher quality of water and buffer coastlines against storms, leading to less erosion of surrounding coastlines (McLachlan & Brown, 2006). In addition, seagrass meadows could provide (part of the) protection of the coral reef due to the utilisation of inorganic carbon. In other words, seagrass enhances the resilience against negative impact of ocean acidification on coral (Unsworth, Collier, Henderson, & McKenzie, 2012).

2.4.3. Mangroves

For most parts, the hinterland as well as the tidal basins adjacent to the Tasikoki beach are covered in a mangrove forest. Mangroves are found in tropical and subtropical tidal areas, specifically intertidal. The harsh conditions to which these species are adapted to, prevent the vast majority of other species from thriving here. Although mangroves are not necessarily a sign of high biodiversity, the root systems do provide a unique ecosystem. Algae, barnacles and oysters are commonly found within the root system. Furthermore, the roots protect coastal areas from erosion (Thampanyaa, Vermaat, Sinsakulc, & Panapitukkul, 2006). The complex root systems are very effective in dissipating wave energy. However, mangroves are typically found in areas with low wave energy. They are most effective during storm surges and tsunamis, protecting hinterlands from losing large pieces of land (Danielsen, et al., 2005). Protecting the mangrove forests behind the Tasikoki beach is therefore a crucial step in protecting the hinterland at the TWREC.

2.5. Conclusion

As explained in the introduction, climate change is the main disrupter of the systems that influences coastal retreat. These systems are respectively the coastal conditions, the societal impact and the ecosystem. Regarding hydrodynamics there are three holistic causes for shoreline recession, respectively SLR, CST-processes and LST-processes. The Tasikoki beach is to some extent affected by these causes. The first cause of shoreline recession, SLR, causes direct shoreline retreat, explained by the Bruun rule. An approximation of its actual impact will be calculated in paragraph 4.4. Coastal recession through SLR, together with its estimated contribution to the total coastline recession. The two scenarios of SLR (0.7 cm/yr and 1.76 cm/yr) applied for these estimations should create an anticipative tendency for the project. Besides, SLR affects CST and LST-processes.

The wave and wind climate are important factors in determining the dominant longshore current and thus the direction of the LST. Due to climate change and human interference the LST can get disrupted, potentially causing erosion of sediment. Further research should clarify whether the disruptors have an actual effect on the LST. Special attention should be given to the effect of the imbalance of tidal basins present at the Tasikoki beach. It can to a large extent clarify why certain parts along the beach have been retreated more than other parts. Also, the coral reefs should be investigated further as they function as a protective barrier between the sea and the shore. Especially absence of protective coral reefs can indicate a larger erosive tendency at some parts of the beach.

CST-processes like respectively wave impact, long waves, turbulence and avalanching/sliding are prone to climate change and human interference. Besides, they are the four major nearshore processes that have the largest impact on coastal erosion. In order to find a suitable solution to mitigate the shoreline recession of the Tasikoki beach these four nearshore processes should be considered. Chapter 4. Data provides comprehensive data regarding coastal conditions. This will give a better understanding of the effects of various processes on shoreline recession.

Societal impact on the Tasikoki coast by the stakeholders is considered low. There is an absence of a major blocking power. The implementation does not include complex stakeholder engagements. However, an engagement plan might still be necessary. This might be helpful for instance, when there is a blockade for the local fishermen. This has to be considered while advising on the implementation.

The industrial development of Tasikoki's surroundings has grown the past years and will only increase in the future. It can be said that the external societal impact on the coast is likely to increase, even though the large-scale fishery has been forbidden. Direct effects can be caused by the increase of structures at the shoreline and offshore. This might affect the LST. However, it is assumed that this will not have a large impact on the Tasikoki beach as the expected dominant current is going northward. Sub-paragraph 4.2.2. Dominant wave direction and current should confirm this expectation.

Pollution will rise with the increased industry. Pollution of air, soil and water negatively effects the ecosystem. Especially coral is sensitive to pollution which eventually results in dead coral. Absence of coral reefs decreases its wave dissipating capacity which will lead to an increase of erosion.

For a BwN solution, there are three potential elements present in the ecosystem, namely coral, seagrass and mangroves. Further research should be done regarding theq possibility of utilizing these elements whilst providing a solution against coastline recession. The impact of the developing industry has to be considered when a solution containing one of these elements will be implemented.

3. Data collection

This chapter describes the methods used for the measurements of the Tasikoki beach and surroundings. Data is collected for wind and wave climate, bathymetry and beach topography, sediment characteristics and the existing jetty dimensions Also, the collection of a general overview of the vegetation in the surroundings of Tasikoki Beach will be discussed.

3.1. Data and sources

An overview of required data and their possible sources is presented in Table 2.

Table 2: Data overview and sources

Data	*Variables*	*Units*	*Data kind*	*Possible source*	*Source*
Wave	Height Period Direction	m s degrees	Quantitative	Measurements and observations Forecast wave and wind models Literature	AGROSS Coastal Dynamics I
Wind	Velocity Direction Duration	m/s degrees h	Quantitative	Observations Forecast wind models Literature	ARGOSS Coastal Dynamics I
Sediment characteristics	Granulometry Composition	mm %	Quantitative and qualitative	Measurements and observations Literature	Tubular samples Sand sieves
Water levels	Tide SLR Storm surge	m mm/yr m	Quantitative	Measurements Forecast tide	Tide chart
Bathymetry	Depth	m	Quantitative	Measurements Nautical charts	Garmin Sonar Navionics
Beach topography	Waterline position Profiles	- -	Quantitative	Measurements	-
Jetty	Element type Element dimensions Material density Element quality Structure profile	- m kg/m^3 - -	Quantitative and qualitative	Measurements and observations	-
Ecology	Seabed type Shoreline vegetation	- -	Quantitative and qualitative	Observations	-

Reference point

In order to convert measurements to one clear data set, a reference point is necessary. The bathymetry measurements are performed during a period of days. This means the water level changes due to tides. In order to have a clear data set for the bathymetry of the coast, all measured elevations need to be translated with respect to the reference point. The Mean Lower Low Water of the city of Bitung will be the reference point. In local tide charts this level will be indicated by 0.0 m water level.

3.2. Wave climate

Normally waves are measured with wave measuring equipment like Wavedroids. Unfortunately, the accessibility to this advanced equipment is limited in North Sulawesi. An alternative to these measurements is to use wave models provided by Argoss.

3.2.1. Argoss wave data

Argoss has provided the Tasikoki Coastal Protection team with excess to their wind and wave climate model. This can be excessed through waveclimate.com. The closest data point to the Tasikoki beach is located south of the beach. This point is representative because of the distance to the shore. However, some modifications to the data set have to be made. As the Tasikoki beach is protected by land in the 0°-90° region, it is unlikely that waves will be generated from this direction. The location with respect to the Tasikoki beach is highlighted with a white mark in Figure 26, the Tasikoki beach boundaries are illustrated as red circles. The following data will be needed for the Unibest-model:

- Significant wave height (H_{m0} [m])
- Peak wave period (T_p [s])
- Wave direction (Dir [°N])

Figure 26 Data point of wave model (1˚N;125˚E) (ARGOSS, 2019)

3.3. Bathymetry

As a part of the data collection to model the coastal dynamics around Tasikoki Beach, the bottom depth of the area is measured. Within the selected grid, installed sonar equipment is used to conduct a bathymetry survey. The following equipment is used to compose the bathymetry map:

- **GARMIN GPSMAP 585**
  This sonar tool, equipped with a GPS tracker, will constantly measure the water depth while sailing a certain track. The GARMIN GPSMAP consists of a 5-inch display which shows what is measured by the GARMIN Sonar Transducer. Originally, the sonar transducer is used as a fish finder, but it also measures water depth. The sonar waves are sent to the bottom of the seabed where they reflect and are thus sent back to the transducer. The information derived from this echo consists of the water depth at certain coordinates, combined with a value of the hardness of the soil. Altogether, this forms a bathymetric nearshore map of the Tasikoki Beach.
- **Boat**
  A local fishing boat from a security guard at TWREC will be used to conduct the survey. These boats are very suitable for this task, as they are able to reach the very shallow parts of the Tasikoki coast. Furthermore, the transducer can be easily mounted on one of the side beams. (Figure 27)

Figure 27 Traditional fishing boat used for bathymetry measurements

As the Tasikoki Beach is 1000 m wide, a northern and southern border have been indicated by two big bamboo markers, so the team on the boat knows the exact area they have to map. To get a detailed map of the coastal area in front of the Tasikoki Beach, the boat will consecutively sail in the longitudinal direction from the northern border to the southern border and back in the transverse direction. As the fish finder combines the GPS data with the water depth at that location, the data for the bathymetry will simply be collected by sailing. To create a detailed map of the bathymetry it is needed to sail in several patterns within the borders of the set grid.

Since the area is relatively big, it will take multiple hours to sail the total area. A result of this is that tidal effects will influence the water depth throughout the day. To compensate for this effect the tide difference from the reference point will be documented every 10-15 minutes. Later on, the data can be modified so the tidal effects do not affect the output.

3.4. Beach topography

Unfortunately, the beach bathymetry cannot be measured with the use of sonar equipment as mentioned above, as sonar uses water to propagate. Besides, precision measuring tools are often not available in remote areas as this. Furthermore, they are expensive and need certain expertise. However, this data is necessary to create a correct model of the situation. The use of a more basic method has thus to be used to profile the beach. The method is described in the scientific paper 'A Simple Method of Measuring Beach Profiles' by F. Andrade (2006). He himself has based his method on an earlier method created by K.O. Emery in 1961. The method is based on the principle that bodies of fluid in communicating vessels form a surface that is in hydrostatic equilibrium. Two poles marked off with a scale in centimetres (can be any unit) are connected by a transparent tube filled with water (communicating vessel). When they are placed vertically on a slope with a certain distance in between the poles, they will have different readings on the markings. This difference will then correspond with the difference in elevation (Andrade & Ferreira, 2006)(Figure 28, Figure 29).

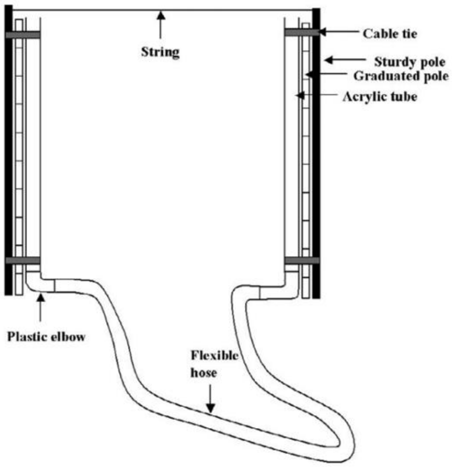


Figure 28 Beach topography tool (Andrade & Ferreira, 2006)

Figure 29 Beach topography tool by TCP

The Tasikoki beach is approximately between 10 m and 20 m wide (depending on the tide). It has therefore been determined to place the poles 5 m from each other, giving 3 to 5 readings over the width of the beach. Placing the poles closer together will result in significant more readings for the whole beach. Placing them further apart will not give an accurate profile of the beach. The Tasikoki beach is approximately 1000 m long, requiring a large amount of measurements to create a complete beach profile. The measurements will be made with a spacing of 50 meters at predetermined locations as depicted in the three figures below. The beach has been split up into three segments, namely A, B and C (Figure 30, Figure 31, Figure 32). Each sector containing different starting points. At each starting point the beach profile will be measured in a straight line towards the shoreline. Measurements will continue for another 20 m to 50 m in the water, as the boat with sonar will probably not be able to reach these areas. At each measuring point the elevation difference will be noted together with the GPS location, using the ViewRanger application on a mobile phone. The data will be collected in a pre-made form.

Figure 30 Base-line A, south segment of beach

Figure 31 Base-line B, mid segment of beach

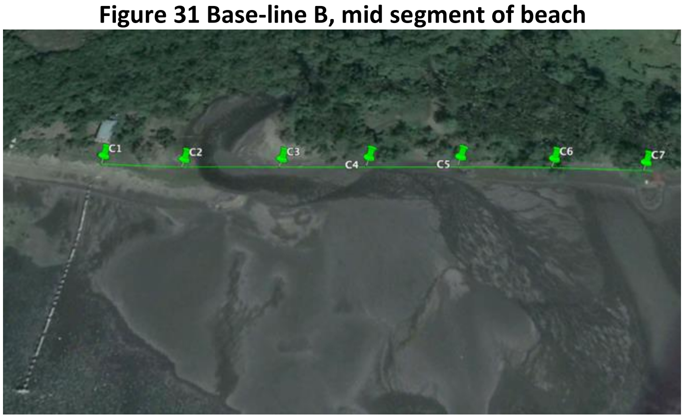


Figure 32 Base-line C, north segment of beach

3.5. Sediment characteristics

The soil type of the Tasikoki beach is determined to ensure realistic outcomes of the model. This is done by conducting a soil sample analysis. The first samples are taken from different locations on and off the beach. After which sieving will take place which gives the grain distribution.

3.5.1. Location of samples

The samples are taken from different locations at the Tasikoki beach. One of the soil samples is taken at the shoreline in the middle of Tasikoki beach. Two samples are taken inside the tidal inlets. The other three samples are extracted from offshore locations. As the surface could be contaminated with all kinds of organics and waste. The sample are therefore taken below the sea bed to reduce the chance of contaminated soil. The locations are tracked by the GPS-application ViewRanger. Figure 33 contains the locations with reference to the beach, Table 3 contains exact coordinate locations.

Figure 33 Soil sample locations

Table 3 Soil sample coordinates

Soil sample	*Latitude*	*longitude*
Shore sample 1	1°23'33.33"N	125° 6'23.56"O
River sample 1	1°23'22.17"N	125° 6'6.45"O
River sample	1°23'37.55"N	125° 6'30.84"O
Offshore sample 1	1°23'19.63"N	125° 6'13.15"O
Offshore sample 2	1°23'26.93"N	125° 6'22.79"O
Offshore sample 3	1°23'33.54"N	125° 6'34.17"O

3.5.2. Sample extraction

The samples taken at the shoreline are extracted by using a tubular sample. The offshore samples are extracted by hand, because of a limited range of useful equipment. This is possible due to the shallow shoreline of Tasikoki beach. The samples can directly be deposited in boxes of similar sizes.

3.5.4. Drying of samples

The samples are placed in aluminium trays for the drying process. As no oven is available, another method needs to be used. Drying the samples in the sun for a period of two days ensure the samples to be water free (Figure 34).

Figure 34 Samples in trays and sieve tower

Figure 35 Sieve tower with 9 different mesh sizes

3.5.5. Sieving

Sieving of each sample will be done with the use of a sieving tower (Figure 35). This tower contains 10 different layers, each layer with a different mesh size and a collection tray on the bottom. The sample is placed in the top tray with the biggest mesh size, and then manually shaken for a couple of minutes. The sand passes through each layer and stops at the representing mesh size. With this information the grain size distribution D50 and D90 can be calculated, both input parameters for the UNIBEST model. Table 4 provides an overview of the different mesh sizes.

Table 4 Sieves and respective mesh size

Sieve number	*Diameter (mm)*
1	2.0
2	1.5
3	0.8
4	0.5
5	0.315
6	0.2
7	0.165
8	0.08
9	0.05
10	0.01

4. Data

In this chapter the results of the measurements and the gathered data regarding coastal conditions are presented. These results and data, in combination with the information represented in chapter 2. Tasikoki coast, will serve as input for the model and will give better insights in the problem that is causing erosion. Besides, the coral reef will be investigated in further detail, to see what the dissipating effect is of the reef.

4.1. Wind climate

At Tasikoki beach the year-round dominant wind direction is from the south-east (Figure 36). During the months April until September the wind direction is from the south-east as well (Figure 37). This confirms the assumption made in sub-paragraph 2.2.3. Wind climate that during these months the system has a north-western wind direction. In the months October until March, the wind direction is more south/south-east (Figure 38). This differs from the assumption made in sub-paragraph 2.2.3. Wind climate where it is argued that the dominant wind direction during these months is south-west. The most probable reason for this is the location of Tasikoki, which is very close to the equator. As explained earlier in sub-paragraph 2.2.3. Wind climate, the wind rotates from a south-west direction to a south-east direction when it passes the equator. So, it is assumed that Tasikoki is located on the transition of these rotating winds. The mean yearly wind speed is 4.3 m/s (Figure 39) and reaches the highest speeds in the summer months when the wind is from the south/southwest (Figure 36, Figure 40).

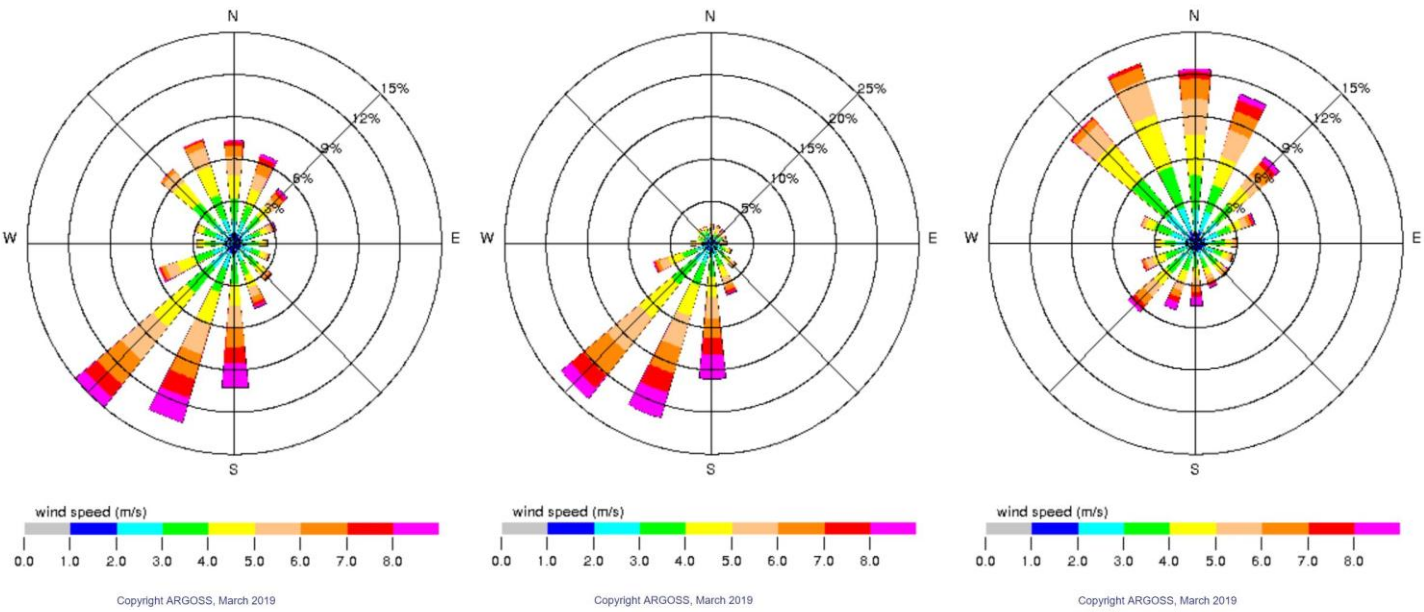
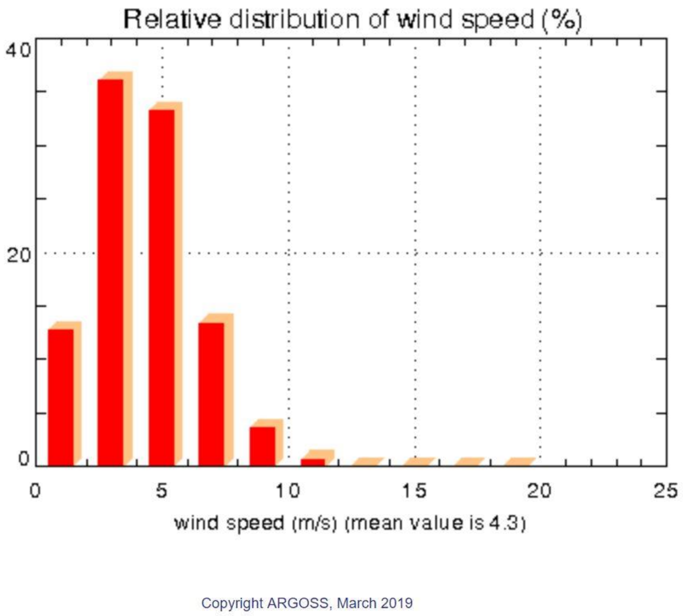


Figure 36 Wind direction and speed year-round (left) (ARGOSS, 2019)

Figure 37 Wind direction and speed April until September (centre) (ARGOSS, 2019)

Figure 38 Wind direction and speed October until March (right) (ARGOSS, 2019)



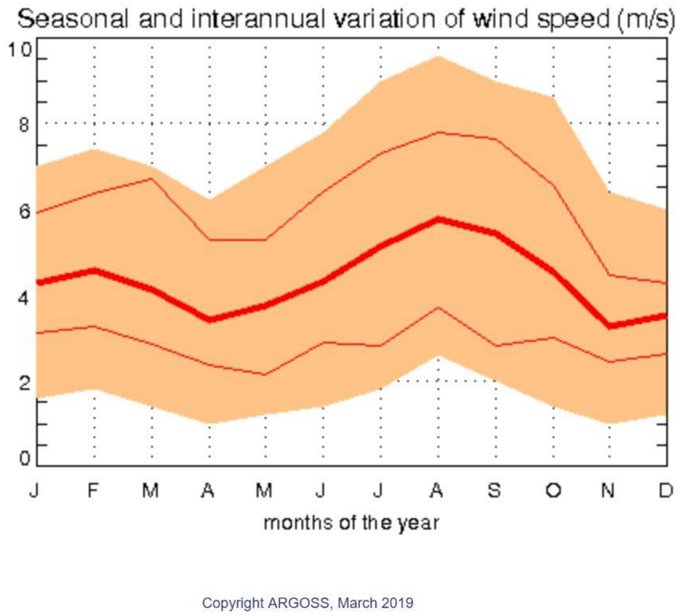


Figure 39 Relative distribution of wind speed (left) (ARGOSS, 2019)

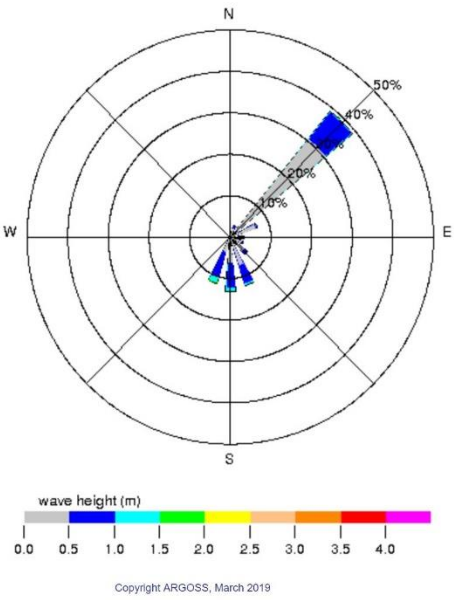
Figure 40 Seasonal and interannual variation of wind speed (right) (ARGOSS, 2019)

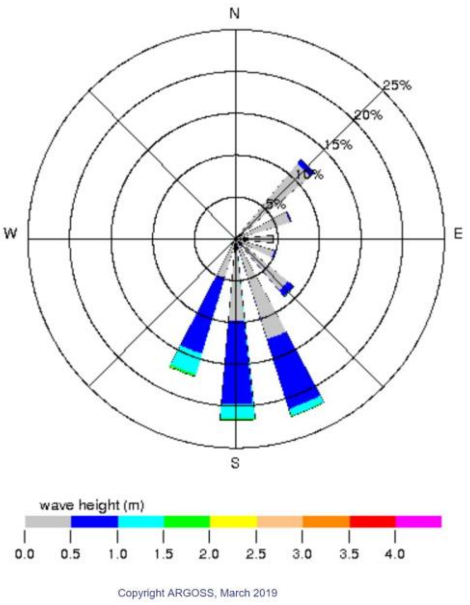
4.2. Wave climate

The wave climate data exists of three main themes, namely wave characteristics, dominant wave direction and current and the wave period data.

4.2.1. Wave characteristics

The most frequent year-round wave direction is from the north-east (Figure 41), which confirms the assumption that waves are coming from the unprotected offshore area north-east of Tasikoki. Also, this is the direction of the flow of the great conveyor belt as described in sub-paragraph 2.2.4. Wave climate. Besides, the seasonal difference in wave direction confirms the assumption that the waves are driven by atmospheric circulations, i.e. seasonally rotating winds. During the months April until September, the dominant wave direction is from the south (Figure 42). During October until March, the dominant wave direction is north-east (Figure 43). What is notable is that the wave heights during April to September are higher than during October to March (Figure 45). Mean year-round wave height is 0.4 m (Figure 44). Another important aspect depicted from Figure 45 is the maximum offshore wave height of 2.5 m. In the design phase this maximum wave height should be considered in order to protect the beach from erosion during these storm events.





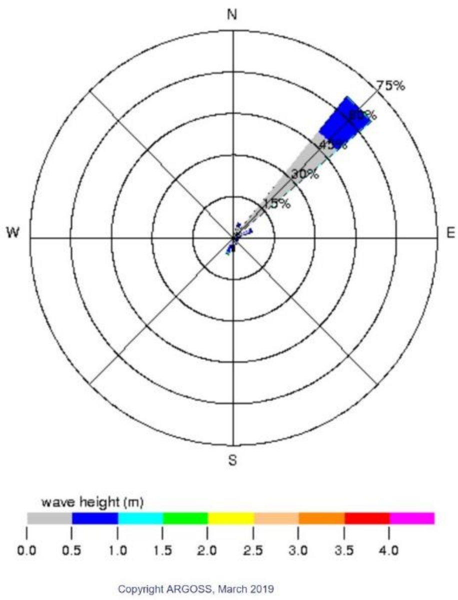
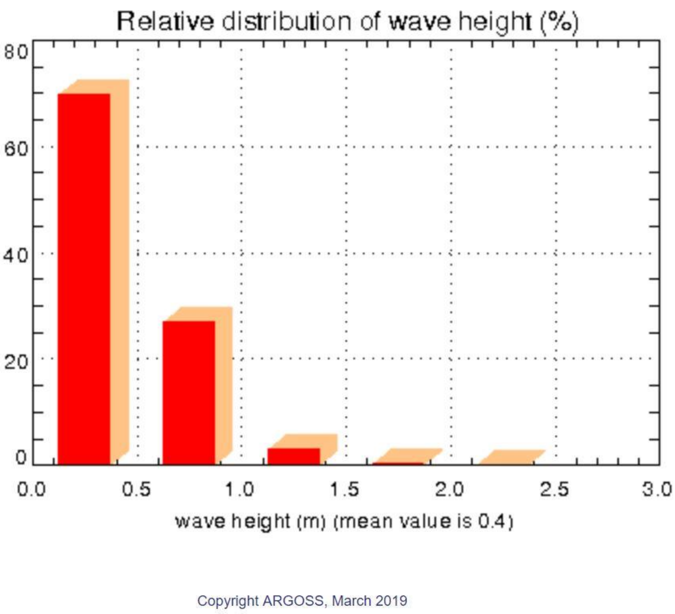


Figure 41 Wave height and direction year-round (left) (ARGOSS, 2019)

Figure 42 Wave height and direction April until September (centre) (ARGOSS, 2019)

Figure 43 Wave height and direction October until March (right) (ARGOSS, 2019)



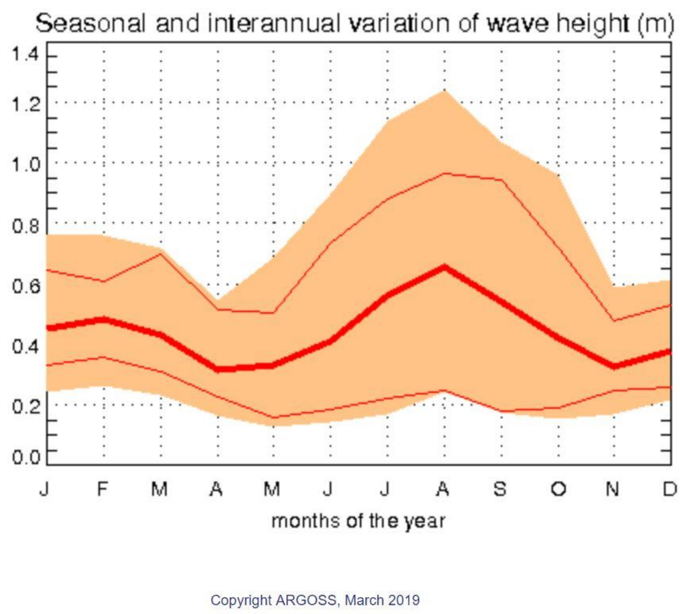


Figure 44 Relative distribution of wave height (left) (ARGOSS, 2019)

Figure 45 Seasonal and interannual variation of wave height (right) (ARGOSS, 2019)

4.2.2. Dominant wave direction and current

The dominant wave direction, however, differs from the most frequent year-round wave direction from the north-east. The dominant wave direction is determined by the direction of the most energetic waves. LST, without further description, is often meant to be the total or bulk transport in the alongshore direction (Bosboom & Stive, 2015, p. 344). Advanced LST formulations (like Bijker's) calculate the distribution of the sediment over the surf zone. Bulk LST formulations only calculate the total transport over the entire width of a considered section. Considering the large uncertainties in transport computations (Bosboom & Stive, 2015, p. 348), more advanced formulations are not necessarily better in predicting the transport computations compared to bulk LST formulations.

The CERC formula is one of the oldest bulk LST formulations and is still widely used (Bosboom & Stive, 2015, p. 349). Only the effects of wave-generated longshore currents are included, tidal currents are not considered. Since Tasikoki beach is mixed tide and wave-dominated with a wave-dominated tendency (2.2.5. Mixed tide and wave dominated), this is not a problem. In the CERC formulation, the volume of transported sediment (S) is related to the wave height at breaking (H_b) to the power 2.5 (Equation 3)

Equation 3 CERC formulation

$$S =: H_b^{2.5}$$

Where,

$$S = Volume\ of\ transported\ sediment$$
$$H_b = Wave\ height\ at\ breaking$$

As a simplification, to determine the dominant wave direction (in terms of sediment transport), the CERC formulation has been used. The offshore wave data provided by Argoss had first to be translated to nearshore wave data. From examining the surroundings, it is concluded that offshore waves coming from 0˚ to 90˚ and 180˚ to 225˚ north can only reach Tasikoki beach when they diffract. Hence, waves lose wave energy and wave height by a factor 2 when they arrive at the shore (Bosboom & Stive, 2015, p. 166). Offshore waves from other directions were not adjusted to translate them to nearshore waves. Next, all wave heights in the nearshore wave climate (Figure 41, Figure 42, Figure 43) were subjected to the power 2.5 and had to be multiplied, per wave direction, with their percentage of occurrence of the total wave spectrum. A weighted average was calculated. This resulted in a dominant wave direction of 164˚ north. In Appendix E this same result is found in the Unibest model. Overall can be concluded that, on a weighted average, the waves coming from 164˚ north are dominating the coastal evolution at Tasikoki beach. It can therefore be concluded that the dominant LST is going in a northward direction along the shore.

4.2.3. Wave periods

Besides the dominant wave direction and the corresponding dominant current, the wave periods of the waves entering the Tasikoki beach are of great importance. The spectrum of wave periods determines to what extent a potential solution will dissipate waves. They are thus determining the mitigating effect per solution. The total wave spectrum can be depicted in Figure 46. The wave periods range from 1.0 s to 20.0 s, with a mean value of 7.0 s.

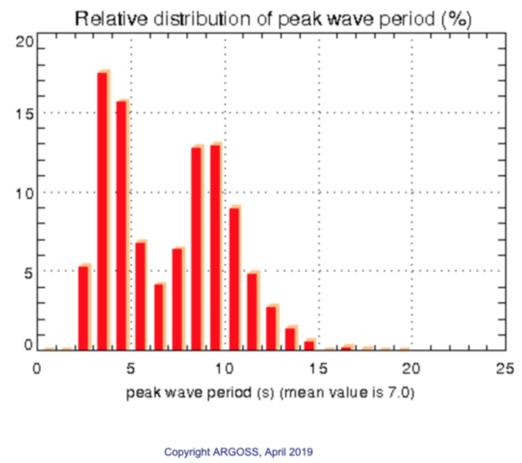


Figure 46 Relative distribution of peak wave period (ARGOSS, 2019)

4.3. Mixed tide and wave dominated

To confirm the hypothesis of sub-paragraph 2.2.5. Mixed tide and wave dominated, use can be made of Figure 47. As depicted from Figure 47 the mean wave height is 0.4 m, which has already explained in 4.2.1. Wave characteristics. Furthermore, the mean tidal range is approximately 0.87 m (Tide-Forecast, 2019). The Tasikoki coast is thus mainly wave dominated with a strong influence of the tide.

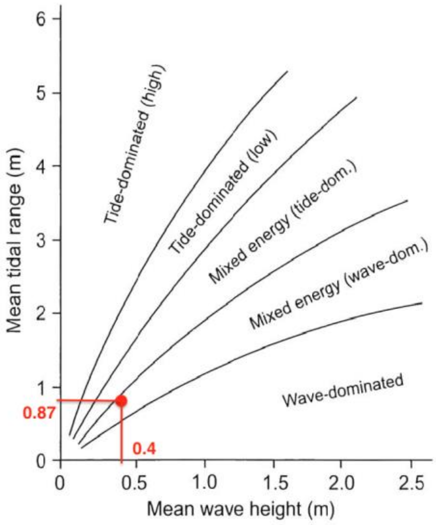


Figure 47 Tidal range and wave energy classification of the Tasikoki coast (Bosboom & Stive, 2015, p. 154)

4.4. Coastal recession through SLR

Mentioned in sub-paragraph 2.2.7. Mean sea level, impact of SLR on the coastline recession can be calculated with the Bruun-rule. Beach topography data is extracted from the data collection in paragraph 3.4. Beach topography. In order to make realistic assumptions on the results, the average slope of the active profile has been calculated for every cross-shore profile that has been measured (Appendix F). To simplify the whole situation, it has been assumed that the slope of the beach has not changed over the past years. This has mainly been determined after interviewing Hans de Vroeg of Deltares, to verify whether this simplification was legitimate. According to ICCSR (2010) the sea level of the Tasikoki region is increasing with 0.7 cm/yr. To estimate the approximate shoreline recession caused purely by the increased MSL, use is made of Equation 1 The Bruun rule . The yearly shoreline recession and the recession from 2002 until 2018 are listed in Appendix F per cross-shore profile. As can be seen, the shoreline is divided into three main sectors A, B and C, which are subsequently divided into multiple cross-shore profiles (Figure 49).

Table 5: Impact of SLR on the coastline recession

Coastal retreat due to SLR 2002 - 2018

Median A	1.57 m
Median B	2.14 m
Median C	2.27 m
Median overall	2.14 m

Google earth coastline retreat 2002 - 2018

Erosion A	7 m
Erosion B high	18 m
Erosion B low	12 m
Erosion C	8 m
Average impact	11.25 m

SLR impact on coastline retreat 2002 - 2018

Impact A	22%
Impact B high	12%
Impact B low	18%
Impact C	28%
Average impact	20%

The shoreline recession per cross-shore profile listed in Appendix F shows some outliers. These outliers can be caused by measurement errors or are the cross-shore profiles of coastal spits. However, when you extract the outliers from the data using the median function in excel, the median shoreline recession per sector is more or less equal except for sector A (Table 5). To estimate the impact of the horizontal displacement due to SLR on the total shoreline recession, first the total shoreline recession should be determined. The total shoreline retreat is determined by analysing historical images from (Google Earth). The numbers, which are listed in Table 5 *Google earth coastline retreat*, however are still rough estimations and should be considered with reservations (Figure 48). Sector B has significant higher recession numbers. It implies that for sector B other processes causing coastal retreat also play a role. In Figure 17 it can clearly be seen that in front of the large tidal inlet of the Tasikoki coast there is no coral reef present. This gap in between the coral reefs, offers no protection against incoming waves. This might thus be a clear cause of the higher erosion at sector B as the dominant wave direction is coming from 164˚. On average the share of coastal retreat caused by SLR is approximately 20% (Table 5 *SLR impact on coastline* retreat). This means the other processes causing recession, namely longshore sediment transport and cross-shore sediment transport, have a combined impact of 80%.

Figure 48 Shoreline development 2002-2018 (Google)

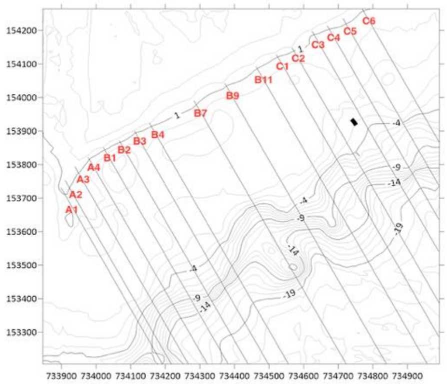


Figure 49 Overview of Tasikoki beach divided in sectors

For the future impact, two other scenarios are drawn up. The first assumes that sea level is rising at the same rate as the past 16 years of 0.7 cm/yr, as mentioned in sub-paragraph 2.2.7. Mean sea level (ICCSR, 2010). The second scenario uses a SLR of 1.76 cm/yr based on the extreme hybrid scenario based on models and melting ice caps, also mentioned in sub-paragraph 2.2.7. Mean sea level (ICCSR, 2010). Making use of these scenarios, a forecast of shoreline retreat due to SLR is calculated (Table 6). As mentioned before, the shoreline retreat due to SLR is only part of the total recession.

Table 6: Scenarios of shoreline retreat due to SLR

Senario	Period	SLR	Median retreat per year	Median retreat
Actual SLR	2002-2018	0.0070 m/year	0.13 m	2.12 m
Moderate SLR	2018-2050	0.0070 m/year	0.13 m	4.24 m
Extreme SLR	2018-2050	0.0176 m/year	0.34 m	10.65 m

4.5. Bathymetry

The results of the manual and sonar measurements of the bathymetry as explained in paragraphs 3.3. Bathymetry and 3.4. Beach topography show a short part of mildly steep beach with a long shallow stretch until it reaches the coral reef. After the coral reef the depth increases significantly (Figure 50, Figure 51,

Figure 52). A full overview of the bathymetry contour with multiple sections and the location of the datapoints are provided in Appendix G. This data functions as important input for the model. Subsequently, it confirms the indication of the location of the coral reefs making use of the bathymetry contour overlay on satellite images (Figure 51).

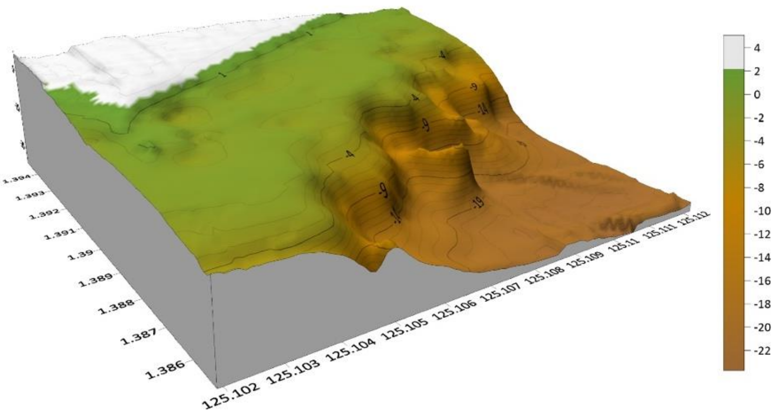


Figure 50 3D visualisation of the Tasikoki bathymetry

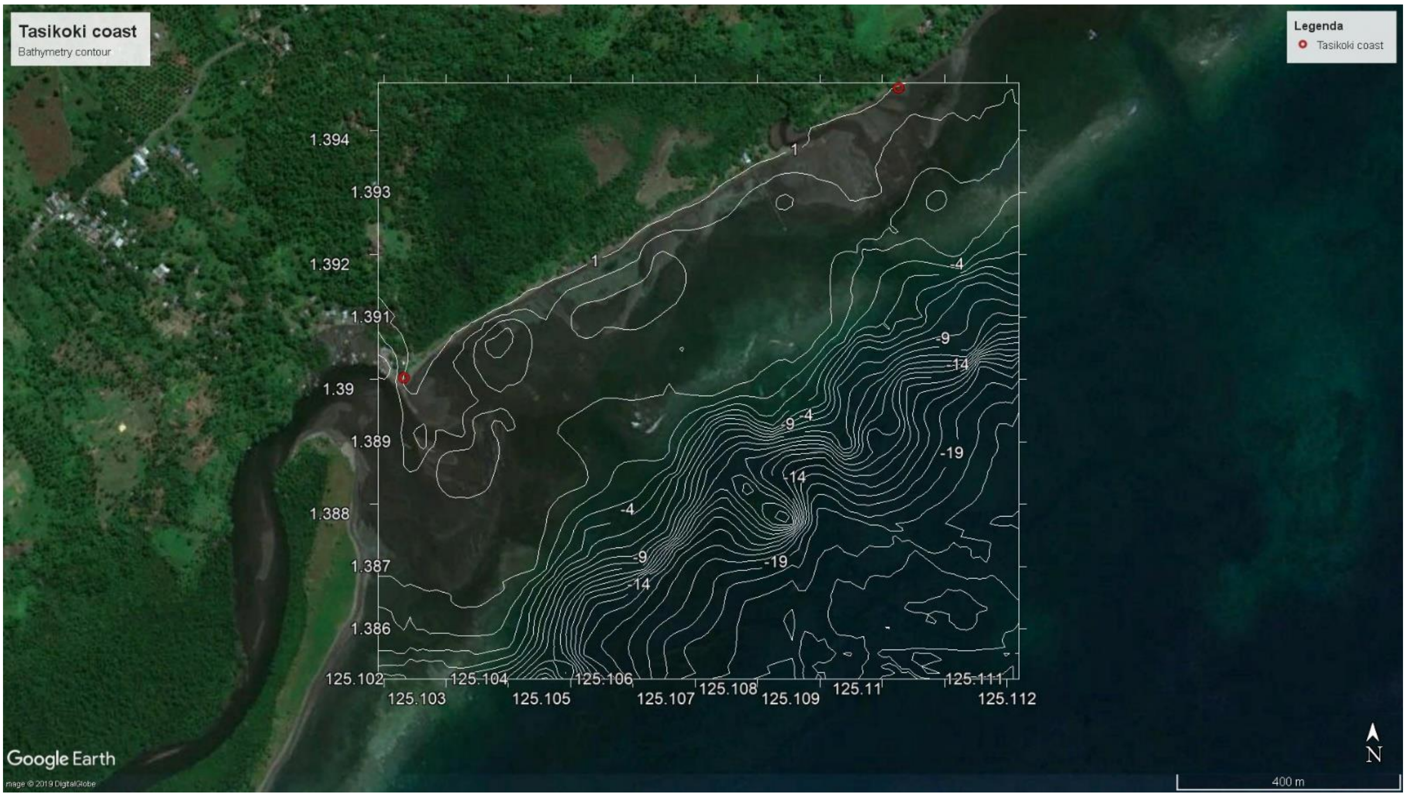


Figure 51 Bathymetry contour lay-over for Tasikoki beach

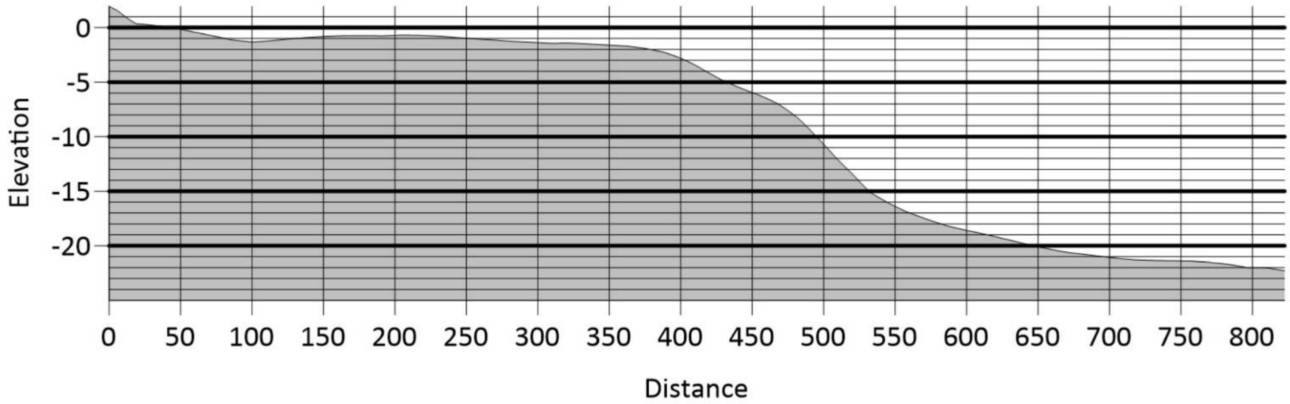


Figure 52 Representative section of Tasikoki bathymetry

4.6. Sediment

As mentioned in 3.5.1. Location of samples, there are six different locations where sediment samples were taken (Figure 33). The grainsize distribution of all six samples is presented in Figure 53 and Appendix H. The channel samples and the shore sample are similar. Offshore sample 2 and 3 are also similar. What is odd is that offshore sample 1 is not similar to the other offshore samples, rather to the channel samples and the shore sample. This can be explained by looking at the location of the sample. Offshore sample 1 is taken at the end of the channel of the tidal inlet. This confirms why its grainsize distribution is more similar to the other channel samples.

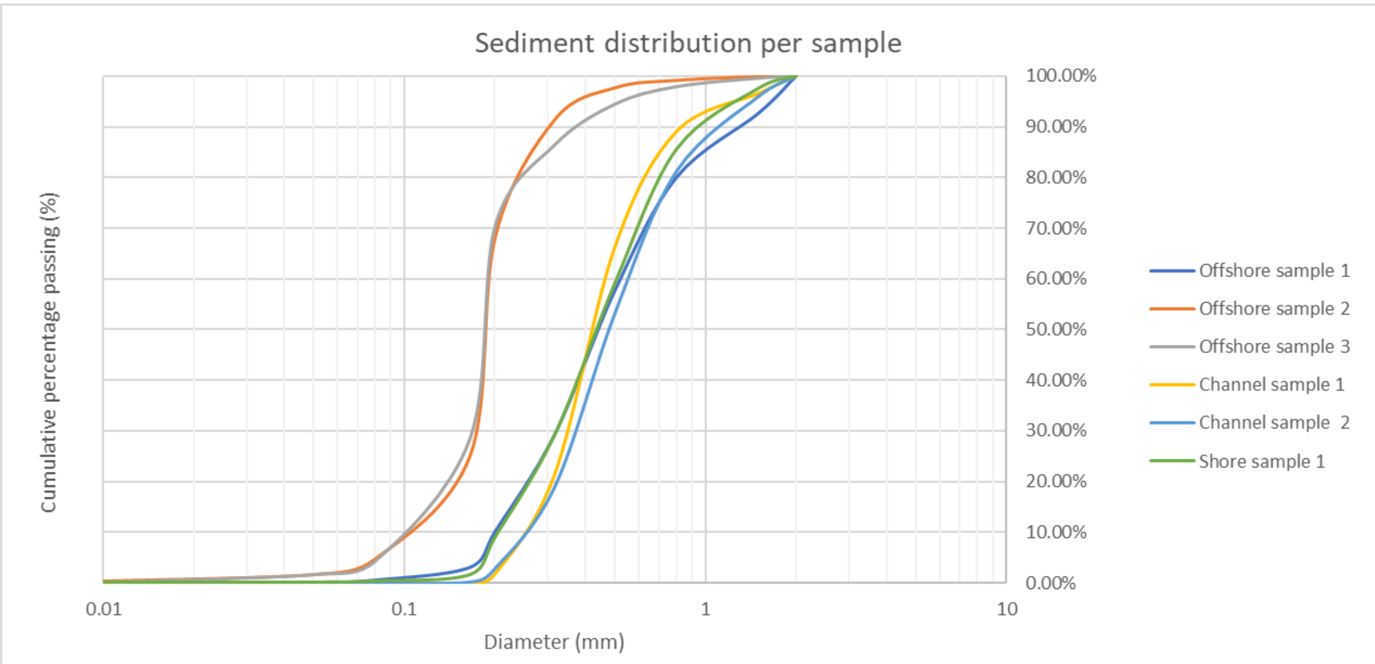


Figure 53 Sediment distribution per sample

The sediment does not consist of significant cohesive sediment. Muddy sediment consists of clay and silt, which have a grainsize smaller than 0.0625 mm (Wentworth, 1922). Cohesive sediment contains more than 20% mud by weight (Houwing, 1999). Given the sample data in Appendix H, this is not the case for the sediment of the Tasikoki coast. Thus, the assumptions made in sub-paragraph 2.2.12. Sediment about higher concentration of muddy sediment in the channel mouths is false.

4.7. Tidal basins affected by SLR

To verify the hypotheses of sub-paragraph 2.2.9. Tidal inlets and deltas use have been made of Google Earth Pro, Excel and the empirical relationships for the tidal channel and the ebb tidal delta of Bosboom and Stive (2015, pp. 410-436). A list of the specific areas, such as tidal flats, tidal channel and ebb tidal delta can be retrieved from Appendix I. In the following sub-paragraphs, the two hypotheses will be verified.

4.7.1. Unchanged tidal prism

In the case of an unchanging tidal prism, the channel volume increases, causing a sediment demand for the channel. To calculate this demand the total channel area has been multiplied by the SLR for both the big basin as the little basin. The demanded sediment will in the first place be extracted from the ebb tidal delta and secondly from the adjacent coast. If the total sediment volume of the ebb tidal delta of the big basin grows with the SLR, this will still not be enough to compensate the demand (Table 7). In this case the sediment is thus extracted from adjacent coasts. Hence, that the dominant current is going northward along the shore. Thus, the beach updrift is eroding and the LST is disrupted. This leads to an eroding Tasikoki beach. For the little basin the increase of sediment volume of the ebb tidal delta is more than enough to compensate the demand of sediment of the channel of the little basin (Table 8). The ebb tidal delta thus increases and the downdrift beach erodes less (both phenomena are clearly visible on the aerial images in Figure 17 and Figure 18).

Table 7 Sediment demand big basin in case of unchanged tidal prism

Category	Year	Input	Unit	Number
Big basin	2018	Sediment demand channel	m3	31.590
Big basin	2018	Sediment output ebb tidal delta	m3	19.226
Big basin	2018	Shortage	m3	12.364

Table 8 Sediment demand little basin in case of unchanged tidal prism

Category	Year	Input	Unit	Number
Little basin	2018	Sediment demand channel	m3	605
Little basin	2018	Sediment output ebb tidal delta	m3	4.708
Little basin	2018	Abundance	m3	(4.103)

4.7.2. Growing tidal prism

In case of a growing tidal prism, the tidal flats are not able to keep up with SLR. The channels thus have to process more water in a tidal cycle. This leads to erosion of the channel and thus sediment supply for the ebb tidal delta and the adjacent coast. Calculations were made, using the empirical relationship formulae of Bosboom and Stive (2015, pp. 410-436) for the big and small tidal basin. This resulted in very unrealistic numbers (in the order of millions m^3). As no such sediment supply is visible on aerial images, this hypothesis can be disproved. The previous hypothesis (described in 4.7.1. Unchanged tidal prism) has way more realistic outcomes. However, the exact numbers should be taken with reservations as the case is drastically simplified.

4.8. Conclusion

This chapter mainly has the function to verify hypotheses stated in chapter 2. Tasikoki coast and to provide the required data input for the Unibest-model.

The dominant wave direction is coming from 164˚ north. This is mainly due to the higher wave energy of waves coming from the south. Besides, waves coming from a direction of 90˚ north or less are diffracted by Lembeh Island. This decreases the wave height of these waves and thus also decreases the wave energy. The same principle is valid for waves coming from 180˚ or higher. It is assumed that these waves lose half of their wave height when they diffract. The dominant LST direction is mainly determined by the wave energy and the tidal current. However, as the coast is classified as a mixed energy coast with a slight tendency to be wave dominated, the dominant LST direction is mainly determined by the wave energy. The dominant LST direction is therefore going northward along the shore.

The Tasikoki coast has retreated significantly over the past years. One of the main causes of the recession is SLR. At some parts of the coast, sector B, the coast has even retreated with 18 m. This can be explained by the fact that there is no coral reef present in front of the large tidal inlet. If considering a dominant wave direction of 164˚ this is logical. Waves are not dissipated by this gap in the coral reef, causing higher erosion rates at sector B. After having calculated the coastal retreat, by using the Bruun-rule, the impact of an increased MSL could be derived. This impact is approximated on 20%. The other 80% of the coastal retreat can therefore be caused by CST-processes and LST. Limited data have been gathered regarding CST-processes (except for wave impact) like turbulence, avalanching/sliding and long waves, as this could not be realised in the relative short period of our project. Moreover, the required measurement tools were not available. Common sense and knowledge regarding these processes should be used in order to realise a solution that impacts all these processes.

SLR also has a major influence on tidal basins. For the Tasikoki case the hypothesis that tidal basins will serve as a sink of sediment is confirmed. The large tidal basin demands sediment from the ebb tidal delta. However, the maximum increase of sediment of the ebb tidal delta is less than the maximum increase in sediment demand of the channel. This means the ebb tidal delta shrinks and the adjacent coast erodes. As, the dominant LST direction is going northward along the shore, the updrift coast will be prone to erosion. This disrupts the LST along the shore, which also causes less sediment to reach the Tasikoki coast. The sediment capacity however is still the same, causing major erosion on the Tasikoki coast. At the same time can the little basin demand be compensated by the increase of sediment of the ebb tidal delta of the little basin. This way, the ebb tidal delta of the little basin increases and sediment becomes available for the downdrift coast. These phenomena area confirmed by analysing aerial pictures of Google Earth Pro.

The sediment present at the Tasikoki coast is less muddy than expected. The influence of volcanic rock is thus considered to be higher. A coast consisting of more cohesive material is better in mitigating erosion. It is therefore advised to look further into solutions that enhances the cohesiveness of the coast.

5. Modelling

To simulate the complexity of the hydrodynamics present at the Tasikoki coast, a model in Unibest is created. In this chapter, output of the Unibest model will be presented and discussed. Firstly, there will be elaborated on the validation of the model. Next, two common structures are modelled to observe their effects. At last, the applications and limitations regarding the model will be discussed. Furthermore, the model will be used in 7. Design and implementation to substantiate the final solution and the implementation plan. In Appendix E the Unibest software package is introduced and detailed information about the input parameters is presented.

5.1. Validation model

To validate the model, the coastline changes over the years are compared with aerial images obtained from Google Earth. The vegetation border in 2018 is presented with a green line and the vegetation border in 2002 is presented with a white line in Figure 54. The modelled red line corresponds with the waterline in 2002. The model is considered valid when the red line moves land inwards and approximately matches the actual 2018 water line (like in the figure). This shoreline recession should however be taken with reservations as no information is provided about the tidal conditions at the specific moments the 2002 and 2018 pictures were taken. Moreover, the situation has drastically been simplified in Unibest.

Figure 54 Unibest model Tasikoki beach

After setting up the model, a basic situation without implemented solutions was run for a simulation time of 16 years to validate the model. The result is presented in Figure 55. An erosion rate graph is presented offshore to indicate the amount of erosion at several locations. The erosion along the coast as simulated by the model is similar to the actual erosion. Hence, more erosion in the middle of the coast and less at the boundaries. The red line corresponds with the waterline in the picture. Therefore, the model is considered valid.

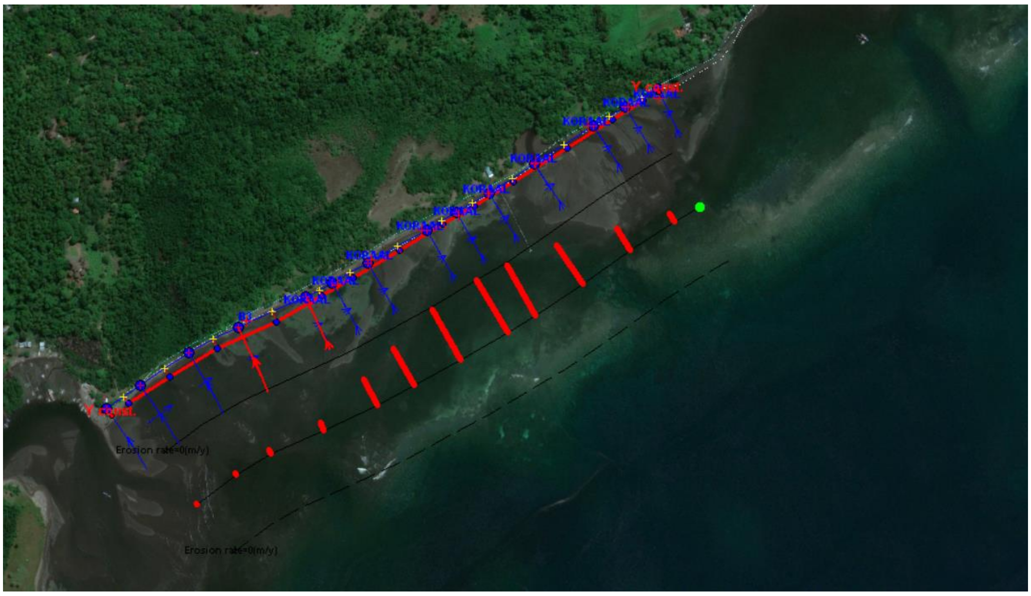


Figure 55 Result of running the model for 16 years to validate it

5.2. Modelling solutions

A groyne and breakwater are modelled to gain insight in their effects on the Tasikoki coastline. A simulation with a groyne is presented in Figure 56. As expected, a groyne would lead to sedimentation on the updrift side and erosion on the downdrift side. This would not be a viable solution for Tasikoki beach.

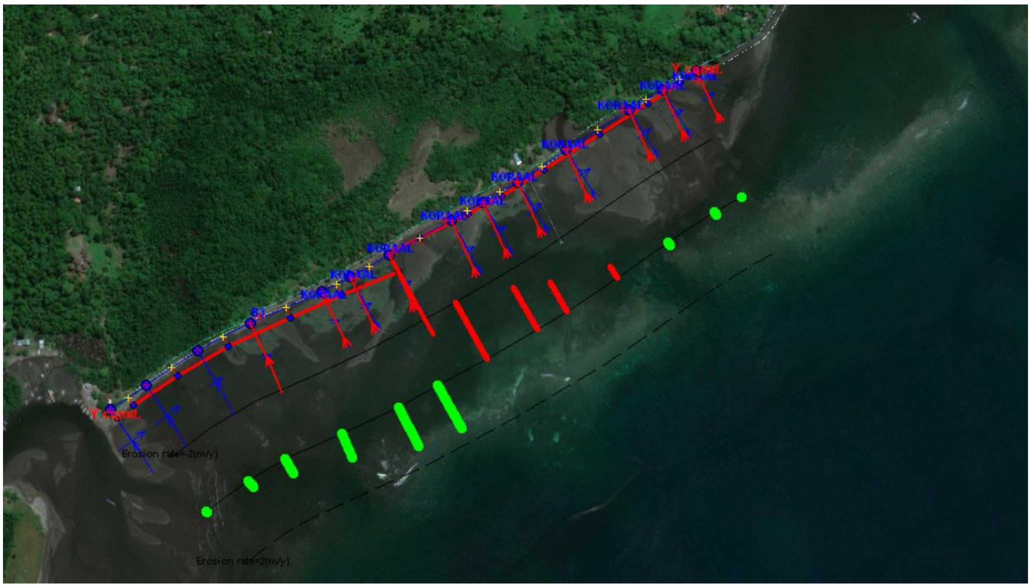


Figure 56 Result of modeling a groyne at Tasikoki beach

According to the model, a breakwater along the entire coast would lead to a positive result. Hence, sedimentation along the entire coast and restoration of Tasikoki beach. This result is presented in Figure 57.

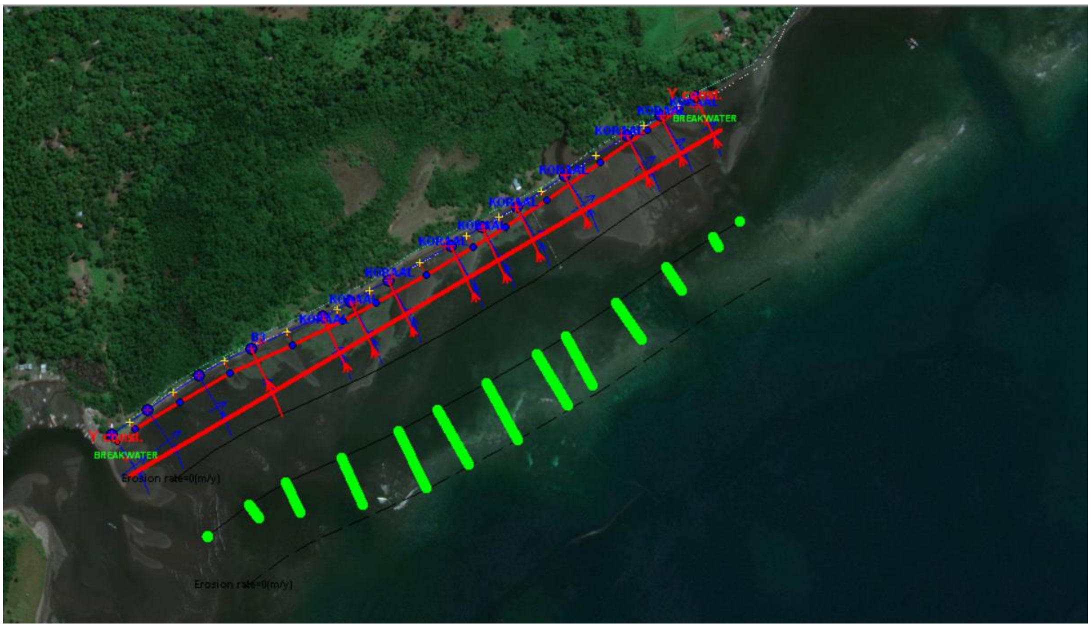


Figure 57 Result of modeling a breakwater along the entire coast at Tasikoki beach

5.3. Conclusion and discussion

The model can be used to gain insight in the coastline development under varying circumstances by implementing various structures. There has been decided to not present yearly sedimentation rates, since this model should be used as a visual indication. In Appendix E the amount of required data (input) is presented to give the reader more insight on how to model a coast. Gathering of data was done as comprehensive as possible, but unfortunately not all required data was available. Therefore, simplifcations had to be made to overcome this problem. The simplifications are explained in this paragraph. The results of the model should thus be taken with reservations.

The wave climate input for the model is based on an offshore wave climate prediction model provided by Argoss. The offshore model point used for this data did not consider the diffractive effect of Lembeh island and the southward located coasts on the waves approaching the Tasikoki beach. This offshore data had thus to be translated to onshore data. Therefore, the wave height of the waves coming from 0˚ - 90˚ (Lembeh Island) and the waves coming from 180˚-225˚ (southward located coast) were reduced by 50%. It can be discussed whether this is the right approach to translate offshore wave data to onshore wave data. Nevertheless, due to a limited amount of time and limited resources, this seemed to give viable data for the model.

Assumptions had to be done regarding the tidal inlets. After interviewing Hans de Vroeg from Deltares, it became clear that the implementation of tidal inlets in Unibest is almost impossible due to its complex processes. It was therefore decided to omit the tidal inlets from the model. Though, tidal inlets actually have influence on the coastal dynamics and thus on coastal erosion. More information on the most plausible hypothesis for the tidal inlets can be found in sub-paragraph 2.2.9. Tidal inlets and deltas.

The boundaries of the Tasikoki beach in the model are considered to be fixed. This means they cannot change in position over time. After having analysed the beach by doing research on aerial images provided by Google Earth Pro, the boundaries more or less did not seem to change over time. This proved our hypothesis. However, it is not realistic to think these boundaries will never change position.

The tidal current of the Tasikoki coast is quite significant according to section Tidal current of sub-paragraph 2.2.11. Current. However, as the tide is mixed semi-diurnal, it is complicated to implement this in the model.

It would rather give unrealistic outcomes than that it will enhance realistic results. Therefore, the tidal current is left out of the model.

The observed spit growth is not similar to the outcome of the model. The spit is located at the lower boundary of the model. After consulting Deltares, it was concluded that it is almost impossible to model the spit evolution. This is due to the complexity of the tidal inlet evolution and the corresponding dynamics.

It is not possible to take sea level rise into account in Unibest. So, to determine the netto coastline change, an estimation of the SLR has to be considered. This is performed with the Bruun's rule in 4.4. Coastal recession through SLR.

Altogether, a lot of effects which influence the coastal dynamics are left out of the model. This is done for the aforementioned reasons. As a consequence of these simplifications of the model, the conclusions based on the model are limited due to these assumptions and dynamics left out.

6. Possible solutions

After acquiring clear insight on the problem of shoreline retreat at Tasikoki beach, this chapter examines multiple possible solutions that prevent the hinterland from flooding. Although protection of the hinterland is the main goal, the other factors in the framework are also necessary to include (Figure 2). In other words, the most optimal solution significantly mitigates coastline recession while keeping in mind its impact on the coastal conditions and the societal and ecological systems. Mitigating the coastline recession will abate the probability of flooding and thereby increases the protection of the hinterland.

In order to make a thought-out decision on the most optimal solution, a multi-criteria analysis (MCA) will be performed. The weight of a criterion determines its importance. All criteria are based on the factors in the system, namely coastline recession and coastal conditions, societal system and ecosystem. The criteria are comprised of the following:

- Protection of hinterland
- Cost
- BwN
- Ecological
- Societal
- Operational

The order of appearance is the same as the order of importance. Individual weight per criterion is shown in Table 9. The protection of hinterland is based on the positive change of coastal conditions. This results in the mitigation of coastline recession and thereby lowering the probability of flooding of the hinterland. Cost is a constraint due to finite financial abilities of the client and therefore an important criterion for the solutions feasibility. Building with Nature addresses the constructability of the solution in terms of making use of and contributing to nature and natural processes. The impact on the natural habitats, biodiversity and environmental quality is assessed in the ecological criterion. Both BwN and ecological criteria take the ecosystem into account. Next, the societal criterion keeps in mind the impact on the local economy and stakeholders. The last criterion assesses the operationality of the solution, considering for instance maintainability and energy-use. Similar to the cost criterion, operationality is a feasibility criterion for the client.

In the rest of this chapter, the possible solutions will be assessed based and the stated criteria. At the end, a full MCA is performed. The explained solutions consist of Biorock, mangrove, seagrass, oyster reefs and hard structures.

6.1. Biorock

Biorock is a concept where permeable steal structures, in any form imaginable, are placed on the seabed to become an artificial reef. The steel frame (cathode) is subjected to a low current and placed next to an anode (preferably titanium mesh), in order to create electrolysis (Figure 58). The electrolysis in seawater has two effects. The first is that the steal cathode is protected against corrosive seawater, due to the electrical charge. Steal structures in seawater are normally very vulnerable to corrosion. The second effect is the stimulation by the current on the growth of calcium carbonate on the steel frame. Decomposed limestone minerals react with the anode and form a sort of hard coral. These coral-like structures act the same as coral and therefore provide a perfect habitat for softer coral, sponges and other marine life. Essentially creating an artificially grown reef. The limestone rock can grow up to 2 cm/yr, under the right conditions. Faster growing rates are possible with a higher electrical current. However, the material then becomes less strong (Goreau & Trench, 2013).

Another important effect is the wave dissipating characteristic of Biorock. Natural coral reefs are able to reduce 97% of the wave energy (Ferrario F. , et al., 2014). Artificial reefs should have a similar effect on dissipating wave energy. If designed correctly and placed strategically, Biorock can have great impact on the prevention of coastal erosion. Furthermore, the ecosystem created around these Biorocks contribute to the sediment input of the area. As observed in previous projects, calcareous algae settle near Biorocks and produce sediment (Goreau & Prong, 2017).

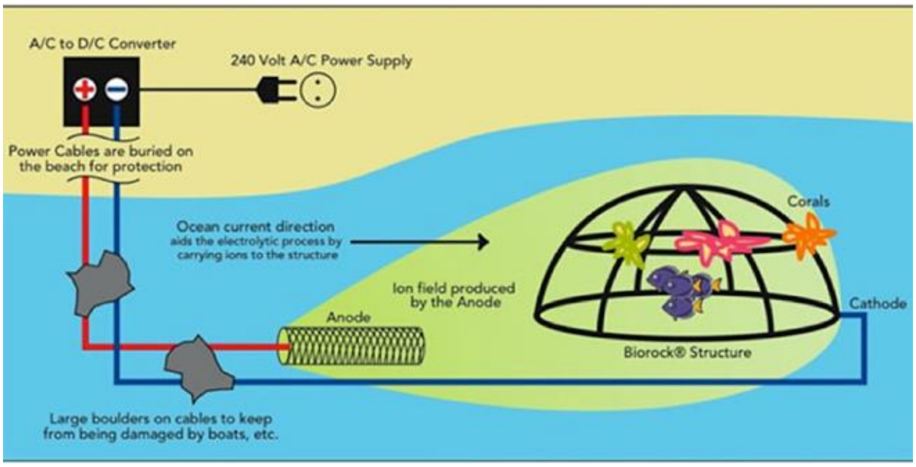


Figure 58 Basic Biorock principle

6.1.1. Protection of hinterland

Initially Biorock was not created for coastal protection, but for coral restoration. Scientific data discussing the effects of Biorock on coastal erosion remains minimal. Only several articles are available, solely written by the creator of Biorock. However, a similar project on Gangga island, a small island north of Tasikoki beach, has had staggering results. Not only did the Biorock system stop the beach from further erosion, it also rapidly grew back the beach. Over the course of several months the beach grew back about 15 meters, over a stretch of 200 meters (Goreau & Prong, 2017). The project on Gangga island added a gabion filled with rocks to the steel structure which acts as a permeable submerged breakwater as additional mitigation of erosion. Adding to this, the function of natural coral reefs on coastal erosion is known. It can be discussed that simulating coral reefs should have a similar effect on the coast. The arc shape of the steel structure is chosen to dissipate wave energy as much as possible. With a correct placement and design the Biorock may be a very effective way of protecting the hinterland. On top of protection the hinterland, it might even cause the beach to grow back.

6.1.2. Costs

The Gangga island project costs have been estimated on 250 million IDR (about 17,500 USD) for 100 meters of coastline according to Paulus Prong. On that 100 meters 40 Biorocks were placed, each Biorock costing 375 EUR. Gangga Island is a remote location that can only be reached by boat, so a significant part of the costs was made on transportation of materials. Therefore, it is plausible that costs could be less for implementation at Tasikoki beach.

6.1.3. Building with nature

Biorock uses simple manmade technology to create a favourable environment for coral and ecosystems. Biorock also creates a natural way to protect the shore and the growth of corals can even lead to beach nourishment on the long-term. Disadvantageous is that the ecosystem will not survive without human interference. As soon as the power is turned off the favourable conditions disappear, which leads to the oxidization of the steel construction. Marine life will move to other locations and eventually the construction will collapse (Goreau & Prong, 2017). It might be possible that after decades of growing limestone the ecosystem is strong enough to become self-sufficient, although no scientific data supports this theory yet.

6.1.4. Ecological

As the original idea of Biorock was to enhance ecosystems, the alternative where its structure works as a submerged breakwater will probably only have positive effects on the ecology. On local scale, the system will create a biodiversity hub. On larger scale, the stimulated corals will spread their seeds in the area with the possible effect of creating new coral patches in surrounding areas. Smaller organisms of marine life growing on the Biorock will naturally attract bigger marine life, such as fish, sea turtles and other marine vertebrae.

6.1.5. Societal

The enhanced biodiversity in the area will improve the fishing grounds for the local fishing community. It will, however, not be possible to fish in close proximity to the Biorock with nets, as they will most likely get entangled with the structures. Due to its optimal effect, the location of the Biorocks probably will be close to shore. Most of the fishing happens at sea, but there are periods during low tide that the local fishers will hunt at the coral reefs for marine life like squid. The area covered with Biorock structures thus might become a new fishing hotspot for the local fishermen.

6.1.6. Operational

The system is low in maintenance and low in operational costs. The 40 Biorock systems on Gangga island uses the equivalent of one air-conditioning unit for the whole system (Goreau & Prong, 2017). The only downside is that it can never be turned off for extended periods. Maintenance of the system will include weekly check-ups of the Biorock modules, including removal of non-organic waste from the frame and checking each wire connection. After storm surges the placement of the Biorocks must be checked relatively to each other and the beach. As the weight over time will increase, the likelihood of shifting Biorocks will decrease over time.

6.2. Mangrove breakwaters

A mangrove is a small tree that grows in coastal salty or brackish water in tropical or subtropical climates (Ecoshape Building with Nature Guidelines, sd). A mangrove-based barrier can be constructed offshore to dampen waves and enhance nature at the same time; a mangrove breakwater. The mangroves should be installed in permeable dams to increase their survival rate, especially during juvenility, storms, high water and earthquakes. A picture of a permeable dam is presented in Figure 59. The construction of mangrove breakwaters is still in its infancy, so a first-order feasibility study was performed to check how realistic a mangrove breakwater would be at Tasikoki beach. The conditions were divided in four topics, namely soil, atmospheric, biotic and water-related conditions. The result is presented in

Appendix J. From this study was concluded that, even though mangroves grow onshore, there is not enough fresh water supply (from an outflowing river for example) for the mangroves to grow offshore at Tasikoki beach.

Figure 59 Construction of a permeable dam

6.2.1. Protection of hinterland

Since a mangrove breakwater is permeable, it will not fully dampen or reflect waves like hard breakwaters would. But because it is emerged, it will reduce the wave energy more significantly compared to other BwN-based submerged breakwaters. Furthermore, mangroves are able to efficiently trap sediment, this will help to restore the beach faster to its morphological equilibrium after a storm event. So besides protecting the hinterland, mangroves contribute to trapping sediment to control coastal erosion. Additionally, mangroves are capable of growing and accruing sediment with the same pace as the sea level rises, given that there is sufficient sediment available (Lovelock, et al., 2015).

6.2.2. Costs

No information about the costs of previous mangrove breakwater projects were found. A mangrove restoration project (so not constructing a new mangrove breakwater) costed, based on 109 projects, 62,689 USD per hectare on average (Elisa Bayraktarov, 2016). A width of approximately three to five meters over the total length of the Tasikoki Beach (1000 m) would lead to a total surface of 3,000 to 5,000 square meters, which equals 0.3 to 0.5 hectares. So, it would cost 18,807 USD for 0.3 hectare and 31,345 USD for an area covering 0.5 hectare. These costs only cover the restoration of mangroves. To grow new mangroves offshore, extra facilities like a breakwater and fresh water supply are required. Furthermore, since these kinds of projects are still in its infancy, budgetary setbacks have to be considered due to failures. Overall, these factors would significantly increase the costs. At last, high operational costs are expected. This will be elaborated in sub-paragraph 6.2.6. Operational.

6.2.3. Building with nature

A mangrove breakwater is an innovative BwN-solution. The mangrove-based barrier dampens waves and enhances nature. The natural process of growing a forest is used in order to achieve the goal of protecting the hinterland while creating a new ecosystem. This will be further explained in the next sub-paragraphs.

6.2.4. Ecological

Like coral reefs, mangroves create their own ecosystem and provide a habitat for numerous species (Marine life, science and ecosystem - mangrove forest, sd). Moreover, mangroves provide a nursery habitat for fishes until they mature (they will move to coral reefs and other ecosystems when they mature). This protects the species and provides the fishermen mature fish. Furthermore, the organisms that live there are important for the mangroves, because they impregnate the soil and support the flushing of salt (Ecoshape Building with

Nature Guidelines, sd). At last, the mangroves are sensitive to (oil) pollution due to clogging of the roots (Ecoshape Building with Nature Guidelines, sd). At present, there is no contamination observed, except for plastics.

6.2.5. Societal

Based on previous mangrove (restoration) projects, a lack of community involvement can lead to a failure of mangrove restoration efforts as people/local fishers may damage restoration sites (Elisa Bayraktarov, 2016). The acceptance of the community and fishermen is a risk that has to be mitigated with an engagement plan. On the long run, the enhanced biodiversity stimulates the local fishing economy. The fishermen will thus benefit, if the breakwater is not placed too much offshore in their fishing waters.

6.2.6. Operational

A mangrove breakwater will result in less reflection of waves compared to hard breakwaters. This is a pro, because reflection results in erosion in front of the structure and may hinder fishing boats. Another operational pro is the sustainability regarding climate change, as the mangroves tend to grow in the same pace as SLR. This increases the flexibility of the breakwater. An operational con would be the required time to grow a mangrove. It will take a long time before a mangrove breakwater is fully grown. Also, a 150 m width is required to grow a sustainable forest and to effectively dampen waves (Ecoshape Building with Nature Guidelines, sd). So, it is important to keep the breakwater intact at all time. When a mangrove dies, a mature mangrove has to be replanted. This increases the operational workload (and thus costs). Finally, as described in the introduction, the facilitation of fresh water supply would have to be engineered and maintained to grow mangroves offshore.

6.3. Seagrass

Seagrass is a sort of flowering plant, which has roots, leaves and rhizomes, commonly found in marine environments. Just like land-based flowering plants seagrass photosynthesizes and is therefore mostly found in shallow and sheltered waters where enough light is present. Seagrasses come in patches or meadows which can be single or mixed species. As discussed before in sub-paragraph 2.4.2. Seagrass, North Sulawesi is one of the most diverse regions of the world in terms of seagrass species, containing up to 15 different types (Reynolds P. L., 2019).

Seagrasses have the ability to dissipate wave energy from incoming waves by creating a rough seabed surface with their leaves. This slows down currents by which sediment flow is allowed to settle. The root systems trap this sediment, stabilizing the seabed (Christianen, et al., 2013).

For the Tasikoki beach, seagrass would be planted in vacant areas along the shoreline in between the coral reef and the shore. The depth of the present seagrass should be used as a benchmark for the depth of new seagrass because conditions at deeper locations are not favourable for seagrass growth. Estimated from satellite imagery is that 20% - 40% of the shallow parts in which seagrass can grow already contain meadows.

6.3.1. Protection of hinterland

Seagrass beds have the ability to stabilize the seabed in a region and prevent the soil from eroding fast during storm surges. Due to climate change an increase in frequency and intensity of storm surges is expected. It can therefore be assumed that the presence of seagrass meadows will become a more important factor in protecting the hinterland. SLR is another effect of climate change. However, seagrass hardly has an effect on SLR, as seagrass does not occur on the shore line and it will not lead to the entrapment of sediment. The mere presence of seagrass will thus not protect coastal areas from retreat. However, it can play an important role in combination with other solutions.

6.3.2. Costs

The costs of restoring 1 hectare of seagrass have been estimated around 100,000 USD. This has been done by averaging 64 restoration projects. However, when including operating expenses (only available for 22 projects), the costs run up to almost 400,000 USD per hectare. This is however a cost estimation based on projects done in developed areas such as USA, Europe and Australia. The same report covers coral reef and mangrove restoration projects with costs of respectively 11 and 226 times lower for projects in developing countries. It should also be mentioned that seagrass restoration projects have the smallest survival rate compared to coral reef and mangrove restoration projects, with only 38% of 141 projects surviving. Moreover, developing countries only have a survival rate of 11%. Overall it is very difficult to make an accurate estimation of the costs for the Tasikoki beach. Furthermore, it can be discussed that the chances of survival do not outweigh the anticipated high costs. (Bayraktarov, et al., 2016)

6.3.3. Building with nature

This solution is essentially 100% building with nature, as only new seagrass is added and no non-organic materials are used.

6.3.4. Ecological

As discussed in sub-paragraph 2.4.2. Seagrass, seagrass has a great ecological impact. Creating living environments for a wide variety of marine life. Therefore, restoring seagrass meadows at Tasikoki beach will have no negative effect on the ecology.

6.3.5. Societal

Similar to the Biorock solution the local fishing community will most likely benefit from the rise in marine life in the area. Fishing boats will also not be affected by the seagrass and are able to manoeuvre freely. Though, it should be mentioned that during the starting phase of the restoration the area cannot be accessed by humans. To achieve the highest rates of restoration the area must be protected in order to let the seagrass fully mature and settle.

6.3.6. Operational

Restoring of seagrass meadows is a highly intensive process which can typically be done in one or two ways. Adult plants can be taken from healthy meadows and planted in vacant areas or seeds can be taken from healthy meadows and planted in these areas. Both methods have the risk of harming the donor meadow. Instead, plants and seeds can be collected from the beach after a storm, meaning no harm will be done to the donor meadow. However, this complicates the process, as the project is dependent on storm surges (Oceana, 2010). It is advised for each method to bring in an expert team of biologists with practical experience in restoring seagrass meadows, in order to maximize the chances of survival.

6.4. Oyster reefs

Using a submerged breakwater made of naturally present species in front of the relatively shallow coastline could provide a promising solution for the Tasikoki Coast. Oysters are born as planktonic larvae which attach to oysters, shells or other hard objects. Reefs are created by oysters growing on each other which form a large three-dimensional reef. The shape of oyster reefs may differ per location as it is influenced by factors like sedimentation rates, direction and speed of currents, the soil conditions and the tidal conditions (zu Ermgassen, Greene, Hancock, & Douglas Spalding, 2016).

Oysters and oyster reefs are multi-functional as they filter pollutants in the water and provide food and shelter for fish, crabs and shrimps. As the incentives for the implementation may differ per project, artificial oyster reefs have provided multiple successful stories by increasing the local water quality, improving and maintaining the biodiversity and providing a barrier to prevent shoreline erosion (Moody & Miller-Way, 2017). Surveillance around the Tasikoki coastline have shown the presence of shellfish attached to the concrete jetty near the beach house, which indicates the possibility to create artificial reefs of hard-shelled species. However, surveys investigating the salinity levels, water quality and temperature, substrate conditions, prevalence of diseases, tidal range, oxygen concentration, algae concentration, prevalence of predators should be carried out by experts in order to confirm the possibility to successfully create oyster reefs (Byers, et al., 2015).

Installation of artificial oyster reefs is often carried out in areas which lost significant oyster capacity over the years. Aspects like overharvesting, diseases, dredging, pollution and sedimentation contributed to the declined oyster population (La Peyre, Sierra, Joyner, & Humphries, 2015). Investigation of the historical images and interviews with locals show that this is not the case at the Tasikoki coast. In order to make the use of artificial oyster reefs a success, the earlier mentioned survey needs to be carried out extensively. As the scope of this project does not cover all these aspects, it is recommended to hire a marine biologist in order to carry out the survey regarding the feasibility of oyster reef installation.

Construction of oyster reefs can be realized in numerous forms using different materials. Some popular concepts that have been installed over the previous years are (Moody & Miller-Way, 2017):

- REEFBLK (REEFBLOCK): Steel rebar cages with a zig-zag pattern filled up with oyster shell bags.
- Reef Ball: Concrete domes with a rocky surface and holes in it, to provide shelter for several species and a surface for the planktonic larvae to grow on.
- Bagged shells: Plastic mesh bags filled up with oyster shells.

Besides these three examples there are a lot of other possibilities to build oyster reefs in the shape of a submerged breakwater. Concrete objects can be poured in unlimited forms to create an oyster reef and the shape steel rebar structures can be formed in any desirable form. The examples provided are just an example to initiate the possible materials that can be used to create oyster reefs. They all have their different characteristics and related costs, durability, consequences for the environment etcetera.

6.4.1. Protection of hinterland

Building artificial oyster reefs should be done in such a way that they function as a submerged structure. Positioning of the submerged structure can be done in several ways, like a consecutive breakwater parallel to the coastline, multiple interrupted breakwaters parallel to the coastline or multiple groynes perpendicular on the coastline. Oyster reefs are characterized as semi-permeable structures, which will be located in intertidal areas and would therefore function as a (tidal dependent) submerged structure. These structures and their shape form three-dimensional reefs which reduce wave energy, modify water flow directions and trap and stabilize sediment (Walles, et al., 2015). Besides these continuously ongoing processes, oyster reefs are known to significantly reduce the impact of storm surges on the coastline given their high density and hardness (Matchar, 2018).

6.4.2 Costs

In line with the amount of alternative oyster reef construction methods, protection of the Tasikoki coast by installing oyster reefs could be carried out in numerous ways. As mentioned before, the distinction will be made between: REEFBLK, Reef balls and bagged shells which are respectively made out of rebar and plastic net, concrete and plastic nets or steel wire gabions. Most literature reviews investigating previously conducted artificial reefs mention themselves that the cost indications are extremely different per project, varying from 12,000 USD to over 1 M USD per hectare (La Peyre, Furlong, Brown, Piazza, & Brown, 2013). Another review of Bayraktarov, et al. (2016) comes up with a median of 66,821 USD and a mean of 386,783

USD per hectare out of 23 samples. Further explanation regarding the type or material used for the artificial reef lacks in both referene articles.

Independent of the type of submerged construction that could be installed, a width of three to five metres over the total length of the Tasikoki Beach (1000 m) would need a total surface of 3,000 to 5,000 square metres, which equals 0.3 to 0.5 hectare. The price range for the oyster reefs would be between 3,600 USD and 300,000 USD for 0.3 hectare and between 6,000 USD and 500,000 USD for an area covering 0.5 hectare. These costs are only for the installation of the oyster reefs. As the oyster reefs would need repeated surveying and measuruments regarding the development over the years, these proceedings will add up to the total costs.

6.4.3. Building with nature

Using the present natural conditions to come up with solutions which improve and enrich the quality of the area, is a part of the BwN-philosophy and is thereby in line with the idea of the creation of artificial oyster reefs. Working with, instead of against natural processes is one of the focal points when installing the oyster reefs. As the material surrounding the oyster reefs are not naturally present in the local ecosystem, it is necessary to become self-sufficient over time. Given the fact that the concrete will be covered, the steel frames will corrode and the plastic mesh will perish over time, the idea is that the grown oyster reefs won't need these support structures anymore and become autonomous coastal protection objects (de Vriend & van Koningsveld, 2012). By growth and expansion of the oyster reefs, the natural hydrosphere will be enriched, wave energy will be decreased and sediment will be trapped and settle which are all in line with the project goals regarding Tasikoki beach. However, high uncertainty regarding the natural situation will remain present. Dealing with both ecological and societal challenges therefore demands an approach keeping both in mind when implementing and operating the oyster reefs. Communication with locals, expert surveying and monitoring the evaluation of the reef and nearshore bathymetry will therefore be key for long term success of the project (van Slobbe, et al., 2013).

6.4.4. Ecological

In order to make the artificial reefs a flourishing area with a healthy growth rate of oysters and other shellfish, attraction of fish, crabs and birds looking for shelter and food, water filtration and shoreline stabilization, it has to adapt to the local hydrosphere (Beck, et al., 2011). Independent of the oyster reefs base material, the substrate needs to attract planktonic larvae in order to settle and grow the reef. Growth rates and health of the reefs can however be influenced by sedimentation, substrate limitations, degraded water quality, predation and diseases (Walles, et al., 2015). As mentioned before, the added value to the ecological system around the Tasikoki Coast by instalment of the oyster reefs can be colossal. However, success or failure of an artificial oyster reef can be caused by the smallest conceivable factors (La Peyre, Furlong, Brown, Piazza, & Brown, 2013).

6.4.5. Societal

Tasikoki beach is surrounded by local fishermen daily looking for species in shallow waters during low tide. Desirable consequence of the installation of oyster reefs would be the attraction of fish and shellfish species. Improvement of the biodiversity would therefore be a desirable side effect together with the main purpose of protecting the hinterland. The location of the artificial oyster reefs will be in relative proximity to the Tasikoki Coast, which probably will not interfere with the daily fishing routes. Altogether it is assumed that any problems regarding the installation of oyster reefs would not occur from the nearby residents and fishermen.

On the other side, the installation of oyster reefs may cause overharvesting. As the reefs will grow and more and more species will be attached to the reefs, it will gain attention from locals willing to harvest fresh oysters and other shellfish. While the main purpose focusses on protecting the hinterland, overharvesting could interfere with the initiated purpose as erosion is mitigated to a lesser extent when the growth of the reef is hampered (de Vriend & van Koningsveld, 2012).

6.4.6. Operational

Constructing these oyster reefs can be done by using hard substrates, where old oyster shells, rocks or crushed concrete are often the base packed together in either steel frames or plastic mesh bags (Matchar, 2018). As the oyster shells needs to be protected for washing away as a consequence of tide and storms, loose spreading of materials is undesirable and will not result in the initiated protection of the shoreline (de Vriend & van Koningsveld, 2012).

Failure of operating oyster reefs can be caused by numerous aspects, differing from bottom conditions to the presence of predators (zu Ermgassen, Greene, Hancock, & Douglas Spalding, 2016). Adequate site investigation must prevent failure based on all possible factors that could influence of larvae growth on the substrates (Bayraktarov, et al., 2016). The optimal location of the artificial reefs is difficult to determine, as the consideration has to be suitable for oyster reef development on side, one and in line with the hydrodynamical conditions on the other side. Sustainable reef development which would shift an artificial reef into an autonomous reef, tidal emersion, substrate conditions and sediment dynamics need to be investigated in order to design, construct, operate and maintain the reefs in a proper way (Walles, et al., 2015).

6.5. Hard structure solutions

This conservative approach to coastal protection includes structures made from stone, steel and concrete in different formations. Most common are groynes, (submerged-) breakwaters and revetments. Due to the wide use of these types of protection the effects are well known, and reference projects are easily found. ‘Soft’ solutions are considered to be more environmentally friendly. However, it is sometimes unavoidable to use hard elements to meet a certain level of protection.

6.5.1. Protection of hinterland

On the one hand, hard structure protection offers great protection of beach fronts (during strong storm surges), as rock, concrete and steel are not easily damaged or eroded. On the other hand, a hard structure can lead to an increase in local erosion rates. Solid structures can reflect waves (instead of dissipating them) and therefore cause higher erosive stresses in proximity of the structures. Meaning, depending on the type of hard measure, more erosion can occur in front, next or downdrift of the structure (Hoek, 2018). Moreover, currents may be intensified behind a groyne or breakwater which increases erosion. Also, a revetment can lower the beach due to its weight and may become unstable if erosion continues.

6.5.2. Costs

It requires expert knowledge to construct a hard structure (in sea). In developing countries with less expertise in this field of work, where design standards are lower and where high-quality or adequate-sized material is less available, it is difficult to construct a perfectly stabilized and durable hard structure. A low-cost structure, designed below standards, will demand intensive monitoring and maintenance levels. In combination with the high initial costs, it can be concluded that a hard structure solution will be very costly (over the years).

6.5.3. Building with nature

Although hard structures are completely man-made and tend not to comply to the BwN philosophy, they can actually add value to the local environment. This is explained in the sub-paragraph below.

6.5.4. Ecological

Hard structures can act as an artificial reef, also known as the artificial reef effect (Dannheim, et al., 2017), creating a new habitat for marine life. However, as a jetty and a coral reef are already present, it is unlikely that a hard structure will attract a significant amount of new species in this case. Though, there might be some increase in marine life and a shift in biodiversity. Hence, habitat is created and marine life may be attracted to these habitats.

6.5.5. Societal

The opportunity that may arise for the fishing community has been discussed for other potential solutions. Yet, a structure may hinder fishing boat and/or nets, especially if it is solid and not passable. Though, because of the large scale of these types of projects it can create opportunities for the area. A large workforce will be needed to construct the structure, after which large scale monitoring and maintenance will be required. This creates direct and indirect employment opportunities.

6.5.6. Operational

As described in 6.5.2. Costs, rock and concrete structures will need ongoing monitoring and maintenance to ensure they keep functioning properly. This is expected to be a significant amount of work.

6.6. Scoring solutions

After investigation of the possible solutions, the MCA is performed to make a thought-out decision on the most optimal one for Tasikoki coast. The complete MCA is shown in Table 9. The weight per criterion and its sub criteria is given. Scores are on a scale of one to five. One being very negative and five very positive. The weighted average of all scores is the total score. The solution with the highest total score is the most optimal. So, for the Tasikoki coast, the Biorock principle is the most optimal solution with a score of 4.08.

Table 9 Multi-criteria analysis

Critera	Weight	Sub criteria	Weight	Biorock	Mangroves	Seagrass	Oyster reefs	Hard structures
Protection of the hinterland	40%	CST mitigation	30%	5	3	3	5	5
		LST mitigation	30%	4	3	2	3	5
		Robustness against SLR	40%	4	5	2	4	4
			Subtotal	1.72	1.52	0.92	1.60	1.84
Costs	20%	CAPEX	60%	3	2	4	2	1
		OPEX	30%	4	2	1	4	4
		Required expertise	10%	3	2	2	4	1
			Subtotal	0.66	0.40	0.58	0.56	0.38
BwN	15%	Enhancement of natural processes	50%	5	4	4	4	1
		Making use of nature	50%	4	5	5	4	1
			Subtotal	0.68	0.68	0.68	0.60	0.15
Ecological impact	10%	Natural habitats	33%	5	4	5	5	1
		Biodiversity	33%	5	4	4	5	1
		Environmental quality	33%	4	4	4	4	1
			Subtotal	0.47	0.40	0.43	0.47	0.10
Societal impact	10%	Economy	50%	4	2	3	4	2
		Stakeholders	50%	4	3	3	2	2
			Subtotal	0.40	0.25	0.30	0.30	0.20
Operational	5%	Maintainability	40%	3	2	1	2	4
		Energy use	20%	2	5	5	5	5
		Circularity of materials	40%	4	3	3	5	2
			Subtotal	0.16	0.15	0.13	0.19	0.17
			Total	4.08	3.40	3.04	3.72	2.84

7. Design and implementation

The optimal solution for the mitigation of shoreline retreat at the Tasikoki beach considering its ecological and societal impact is Biorock, as elaborated in the previous chapter. Basic essence and capabilities of the solution are already laid out in chapter 6. Possible solutions. This chapter will comprehensively elaborate the design for Tasikoki beach. Specifics as position, size, orientation and shape will be clarified. After design explanation, the design decisions are expounded. All these design decisions are based on previously executed and explained analysis of the hydrodynamics, geomorphological characteristics, ecological and societal impact at Tasikoki coast.

7.1. Possible Designs and cluster configurations

In total three different designs have been made, in three different cluster configurations, all of which have been tested and analysed. Cost estimations have been made for each design and cluster configuration, with a total budget of 350,000,000 IDR leaving approximately 50,000,000 IDR for labour and transportations costs. In Appendix N an overview of material calculations for each structure, price calculations for each structure and the total projects costs will be presented. In Figure 60 shows the three different structure designs, in Figure 61, Figure 62 and Figure 63 the different cluster configurations are visible. The clusters in these figures are made with the TCP-Cross, however clusters can be made up of each design.

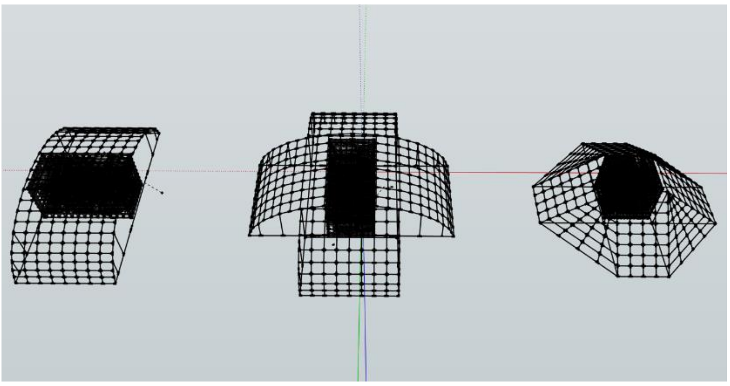


Figure 60 from left to right: TCP-Basic, TCP-Cross and TCP-Circle

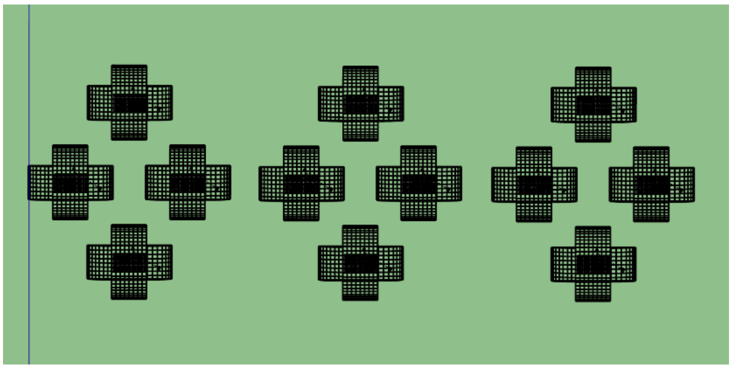


Figure 61 Cluster configuration 1

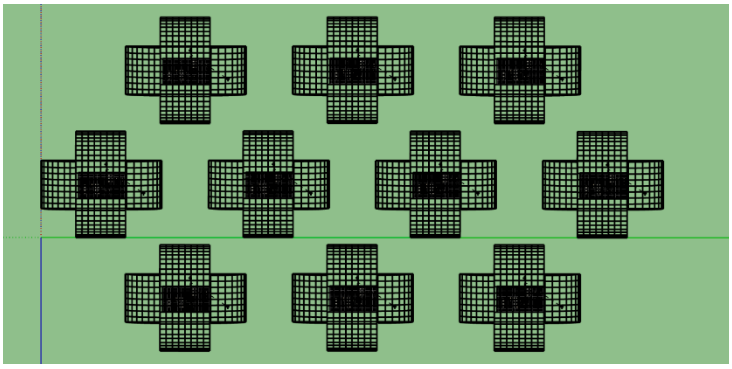


Figure 62 Cluster configuration 2

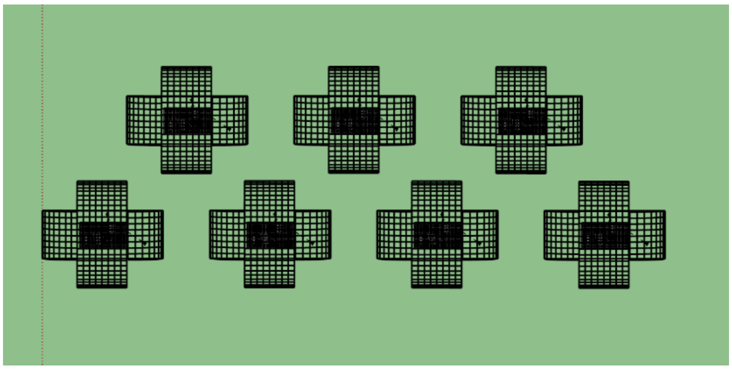


Figure 63 Cluster configuration 3

7.2. Design

Because of a limited pilot budget, it is not possible to provide a design for the protection of the total coastline of Tasikoki. The pilot budget is around 400 million IDR. This will approximately account for 100 m of Biorock submerged breakwater considering the most optimal configuration, spacing and size of the Biorocks. Advice on future development, when additional budget becomes available, will be given later in this chapter. The location of the Biorock submerged breakwater is parallel to the coastline at the southside of the coast with sufficient distance between the spit and the breakwater (Figure 64). The centreline of the breakwater has a distance of 50 m from the beginning of the beach (end of vegetation). As mentioned, the length of the breakwater is approximately 100 m which consists of three lines of Biorock with a horizontal spacing of 2 m and a vertical spacing between the outer lines of 5.5 m (Figure 65). The shape of the Biorock is a cross of arched steel frames with a 2 x 1 x 1 m gabion filled with rocks in the middle (Figure 66). The clusters, with anodes just in the centre of each cluster (Figure 65), are powered by solar panels. The solar panels will supply the central power source which will be placed on the dune crest half way of the Biorock structure (Figure 64). The power requirements are given to the electrical expert of Tasikoki in order to deliver sufficient power to the clusters.

Figure 64 Location of Biorock structure and central power source (red star)

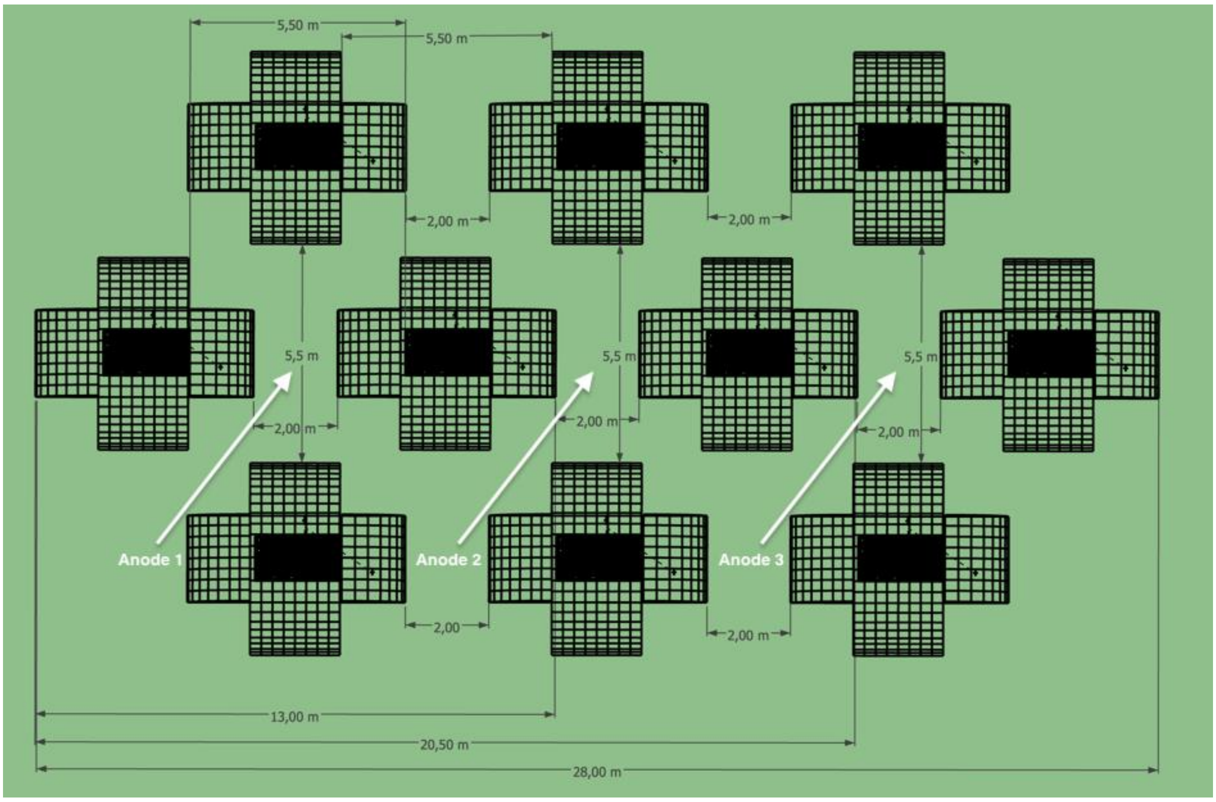


Figure 65 Configuration of Biorock structure

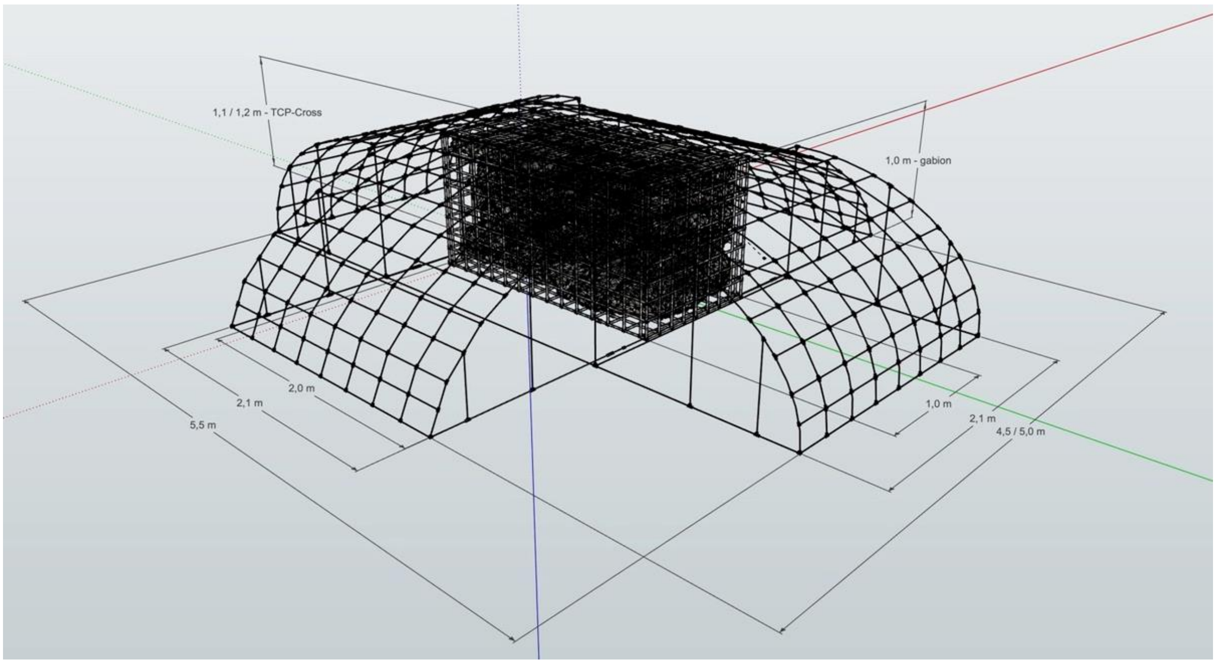


Figure 66 Design dimensions of a single Biorock module

A brief overview of the design dimensions and the exact location of the Biorock structure can be seen below.

Location of Biorock structure and anodes:

- Parallel to coastline
- Southside of the coastline with sufficient distance (50 m) to the spit
- Centreline 50 m from the start of beach (end of vegetation)
- Exact location can be depicted in Table 10
- Anodes are placed in the centre of each diamond-shaped cluster
- Central power source is placed on the dune crest, half way of the Biorock structure

Table 10 Exact location of boundaries of Biorock structure

Location Coordinates	Boundary North	Boundary South
Latitude	1°23'27.16"N	1°23'25.65"N
Longitude	125° 6'15.64"E	125° 6'12.71"E

Configuration of Biorock structure (Figure 65):

- Dimensions of Biorock structure: 100 m length, 15 m width
- Three rows of Biorocks, positioned in a diamond shape
- Internal spacing horizontally 2 m, vertically 5,5 m (between outer lines)

Size and shape of Biorock (Figure 66) (Figure 67):

- Cross shaped with pre-fab frames of 2.1 x 5.4 m arch shaped
- Gabion 2 x 1 x 1 m filled with rocks (long side parallel to coastline)

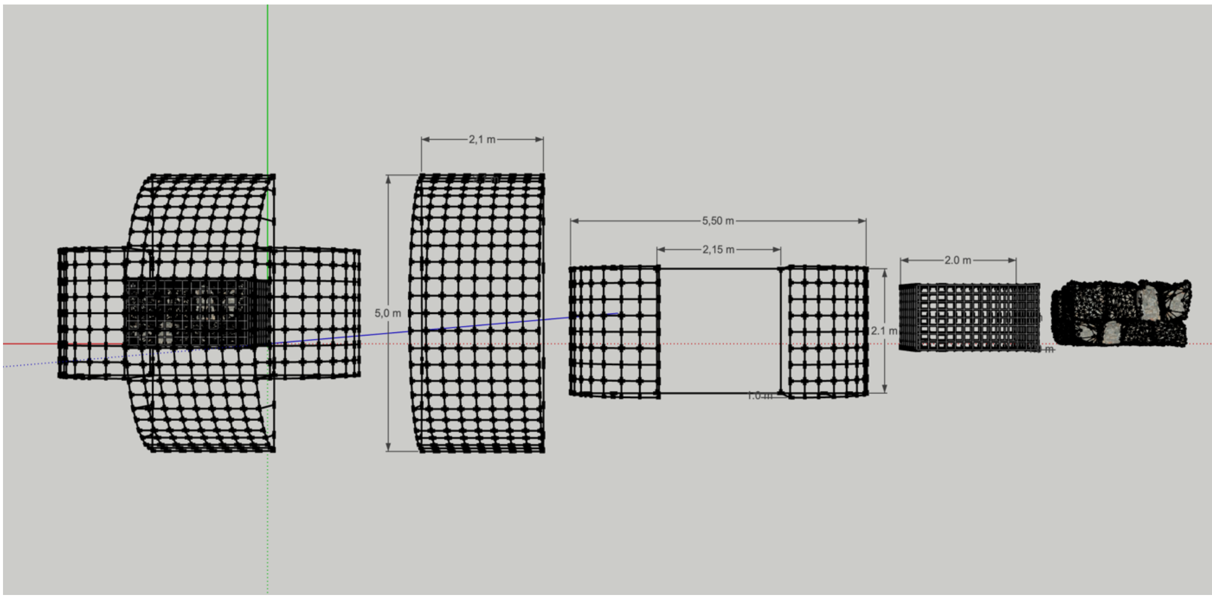


Figure 67 TCP-structure assembly line, from right-to-left: Rocks, gabion, frame A, frame B, TCP-structure

7.3. Nearshore processes

The Biorocks should mitigate various processes that cause erosion. Most design decisions are based on the four nearshore processes that cause most of the erosion at Tasikoki beach. These processes are already addressed in sub-paragraph 2.2.8. Coastal storm regimes namely, wave impact, long waves, turbulence and avalanching/sliding. The solution thus is designed such that all these processes should be mitigated.

7.3.1. Wave impact

According to wave data of ARGOSS (2019) the dominant wave direction comes from a direction of approximately 164˚. However, as depicted in 2.2.4. Wave climate waves from 90˚ to 225˚ are approaching the shore year-round. The Biorock should therefore protect the beach against this range of wave directions. To have a maximum impact on the incoming waves, the Biorocks should be positioned such that the long side of the gabion is positioned parallel to the shore. In this way the total wave spectrum can be dissipated. An additional side effect of positioning the Biorocks parallel to the shore is to ease the implementation of the Biorocks. The Biorocks can in this way be structured in a straight line along the coast and at the same time keep their diamond-shaped pattern. Besides, Tasikoki beach is naturally protected by the coral reefs in front of the coast. This means, the largest part of the waves will already break near the coral reefs. Nevertheless, waves can also break nearshore during high water and storm events. The Biorocks should thus be positioned close to the shore to make sure also these waves can be dissipated. Once they are located further offshore, the water depth would be too high, decreasing the dissipating effect of the Biorocks.

7.3.2. Long waves

To mitigate erosion effects due to long waves three lines of defence are considered. In this way waves are broken three times before entering the shore. No detailed research has been done on the impact of Biorocks against long waves. Therefore, further research should be considered to clarify what the effects of Biorocks are against long waves. Nevertheless, the longshore gaps between the Biorocks, which are 2 m in width, are small enough to dissipate the energy of the waves with the smallest wave length approaching the Tasikoki coast. For very shallow water, which is the case for the location of the Biorock, the wave length can be calculated by making use of Equation 4 (Holthuijsen, 2007, p. 124).

Equation 4 Wave length for very shallow water

$$L = T\sqrt{gd}$$

Where,

$$L = wave\ length$$
$$T = wave\ period$$
$$g = gravitation\ velocity$$
$$d = water\ depth$$

As laid out in sub-paragraph 4.2.3. Wave periods the wave period varies between 1 s to 20 s, with a mean of 7 s. This means, by using Equation 4, that the wave length varies between approximately 4 m and 80 m, while considering a maximum water depth of around 1.6 m. The waves with small wave lengths will be diffracted by the Biorocks. The diffraction is maximum when the width of the gaps equals the length of the waves. As the gaps between the Biorocks are 2 m, they are so small that the longer waves tend to reflect. However, due to the permeability of the Biorocks and the structure this process is prevented. Waves are thus dissipated, without the negative effects of reflection.

7.3.3. Turbulence

As is already explained in paragraph 7.3.1. Wave impact, the Biorocks are positioned parallel to the shore. This maximizes the mitigating impact of the Biorocks against undertow. According to Bosboom and Stive (2015, p. 188), "undertow is the large return current in the surfzone". Moreover, the undertow is largest in case of breaking waves. Hence, when a wave breaks a lot of sediment will be stirred up from the bottom and will eventually be transported seaward due to the undertow. The Biorocks, positioned parallel to the shore, are perfectly able to withstand the erosive effect of the turbulence combined with undertow. Namely, the Biorocks structure act more or less like a permeable submerged breakwater. Waves that break in front of the structure will turn into rollers, leading to a lot of turbulence. The stirred-up sediment, which is partly the eroded sediment of the Tasikoki beach, will thus be transported shoreward. Moreover, due to the mild wave climate behind the Biorocks sediment will be able to settle, resulting in an accreting beach. Besides, the undertow is partly interrupted by the Biorocks. However, due to permeable compaction the water is still able to flow through, but the sediment will be filtered by the Biorocks. In this way there is more sediment coming into the coastal cell than there is leaving. The beach will thus accrete. During storm events it is expected that this process is most significant, meaning most accretion will occur, and beach growth will be notable.

7.3.4. Avalanching/sliding

The last important nearshore process causing erosion is avalanching/sliding of the dune face. As the Biorocks decrease the wave impact of the waves entering the shore, they also decrease the wave run-up on the beach. Therefore, during storm events, the dune face becomes less wet, reducing the change in angle of repose of sand. This means the dune becomes less vulnerable for avalanching/sliding, which also decreases erosion. Accretion of sediment on the beach also naturally counteracts the impact of wave run-up on avalanching/sliding for it requires more energy for the wave to reach the dune face. With the rising sea level, a wider beach provides thus more protection by reducing the probability of avalanching/sliding. Thereby, the limestone on the Biorocks grow faster or at least in the same pace as SLR. The Biorocks thus maintain their mitigating impact and will endure climate change over time.

7.4. Additional design decisions

Apart from the design decision which are based on the near shore processes, there are some additional design decisions that further specify the design of the structure at Tasikoki. Specifics like location, distance, size, configuration and shape will be discussed in the next paragraphs. In total three different designs have been made and tested.

7.4.1. Distance from coastline

The 50 m distance from the coastline is based on bathymetry data. Due to the Biorock principle it is favourable to have the Biorocks submerged as much as possible in order to grow the limestone as protection for corrosion and erosion. The depth at 50 m distance provides approximately 10 cm of water at the bottom during mean lower low water. After consolidation of the Biorocks this number can increase. Thereby, the location of the Biorocks is chosen as close as possible to the coastline to mitigate nuisance for local fishermen. Also, it provides a near shore location for fishing year-round.

7.4.2. Location

By locating the submerged breakwater at the southside of the coastline it is aimed to create a so-called sand engine. Expected is that sediment will accrete behind the breakwater on the beach. The LST with a south to north direction will transport the accreted sediment to the northern direction (rest of the beach). Thus, the accreted sediment will be distributed along the shore over time. This process has been investigated by simulating the Biorock structure in an Unibest-model (Figure 68). What can be depicted from the model is the accretion until half way of the beach. Further downdrift of the coast the erosion is still not entirely mitigated. The Biorock structure should therefore either be extended or duplicated in order to recover the entire beach. Besides, a safe distance from the spit (100 m) is taken to assure that the local dynamics around the inlet mouth cannot affect the process of accretion.

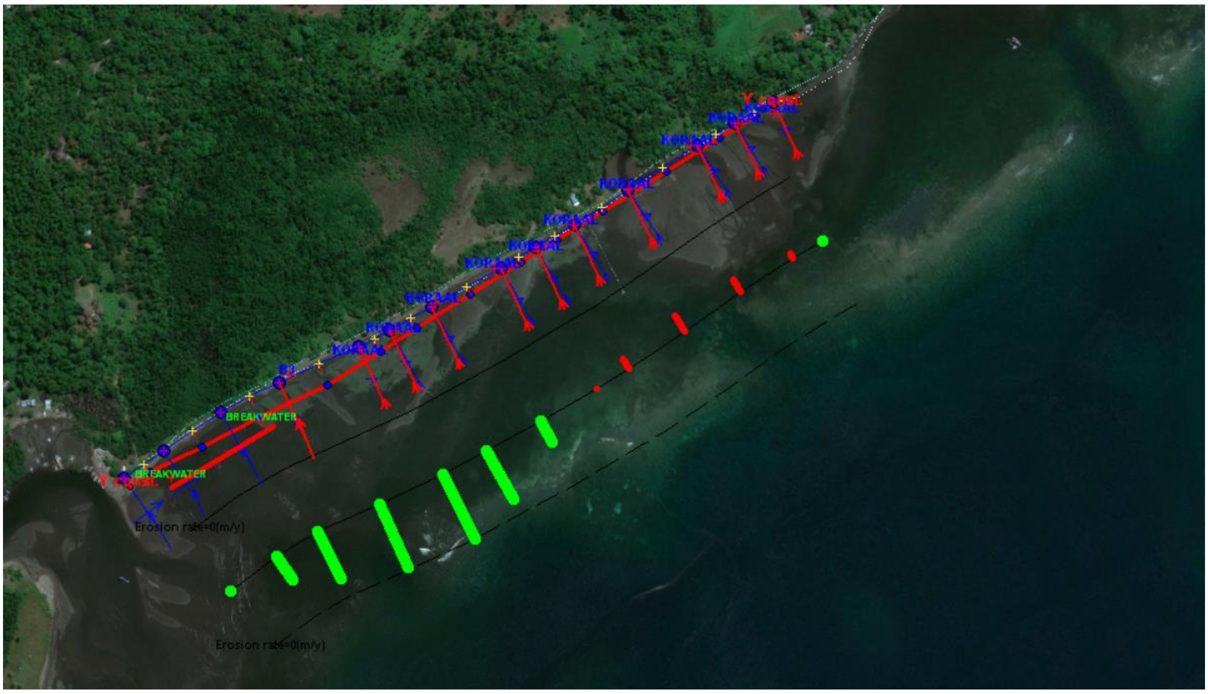


Figure 68 Unibest-model with the Biorock structure

If there is an additional budget available in the future, it is advised to assess the level of accretion. If the level is sufficient (disappearance of scarps and distributed sediment to the north), a similar submerged breakwater can be placed in the same parallel distance from the beach. Starting at the point where the distribution of the transported sediment becomes less significant. A similar breakwater then will function as a sand engine for the rest of downdrift part of the Tasikoki beach. Unibest has been used to investigate the effects of such a solution with two identical Biorock structures along the Tasikoki beach. In Figure 70 these effects are clearly visibly. The structures function perfectly well as a sand engine and cause accretion along the entire beach. It is thus advised to implement this solution in the future. Though, it should be mentioned that such a solution needs time to become fully effective. After implementation of the second structures it takes a while (months to couple of years) until it results in the accretion of the entire beach. This can be seen in Figure 69.

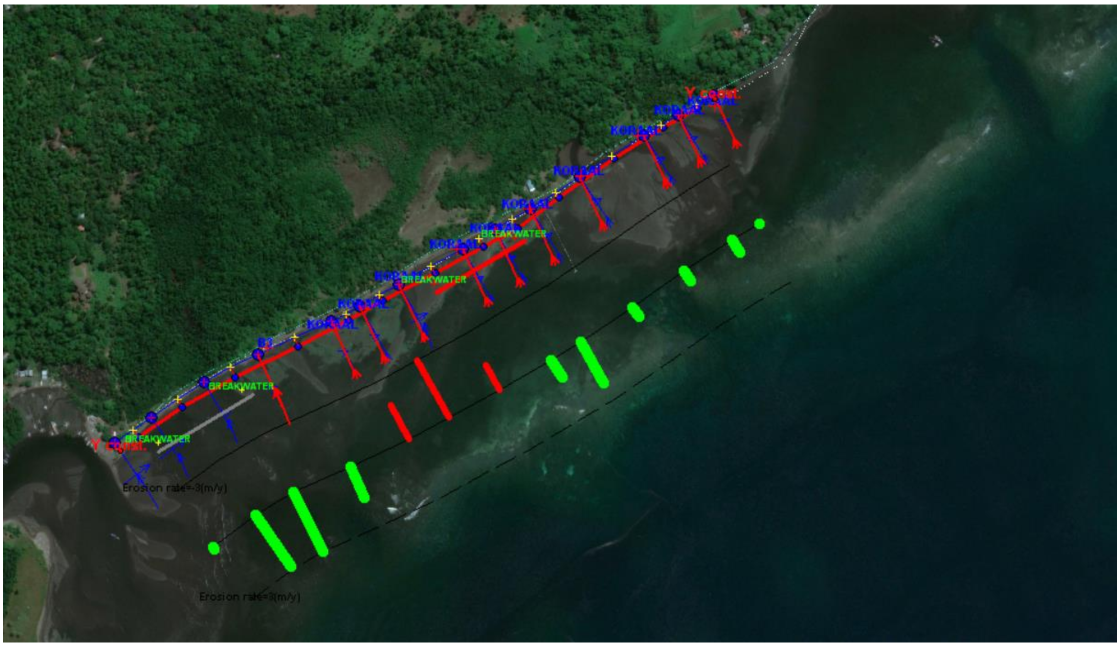


Figure 69 Unibest-model with two identical Biorock structures along the Tasikoki beach after a couple of years

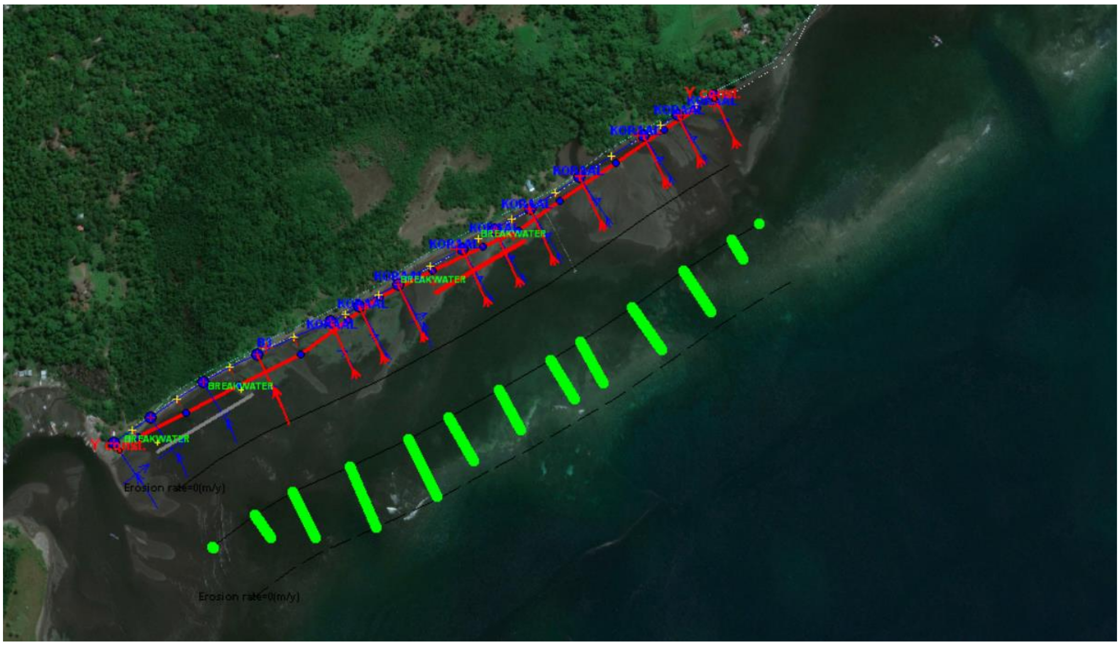


Figure 70 Unibest-model with two identical Biorock structures along the Tasikoki beach after 20 years

7.4.3. Biorock shape and size

Design of the individual structure is a rock-filled gabion with a cross of arc shaped frames, called TCP-Cross. This shape is chosen in order to dissipate waves from all relevant wave directions. A circle shaped frame has been investigated, but this design turned out to be less cost effective (material amount versus wave spectrum dissipation). All sizes of the Biorock elements are chosen for cost effectiveness. The size of the steel frames and the gabion are based on pre-fab elements.

7.4.4. Biorock configuration

A configuration of three diamond shaped rows is chosen to assure sufficient wave dissipation capacity during storms. During storms it is expected to have the most sediment accretion. The diamond shape ensures that each wave breaks three times. The internal spacing is a consideration between costs and significant density of breaking elements. Decided is for a spacing of 2 meters between each structure, that provides enough protection and delivers the longest length of the breakwater. The configuration is visible in Figure 62.

7.4.5. Power supply

It has been decided to use solar panels to provide power for the clusters. The main reason for this is a sustainable point of view. Also, constant input of power is required. Given the frequency of power outages in North Sulawesi, the safe option is solar panels in combination with batteries to ensure power supply during the night.

7.4.6. Electrical system

Given the use of solar panels and absence of a grid connection, the electrical system is an off-grid system. The 100 W PV cells convert the solar energy to an electrical current. Before the electrical current can be sent to the 12 V 100 Ah Battery, the current has to be reduced by using a step-down DC/DC converter. This step-down converter makes sure the battery does not get overcharged which causes a longer life time than one without. The constant power supply from the battery towards the TCP-cross structures has to consist of a very low current, approximately between the 1.5 V and 3 V. These low currents lead to the best growth rates of limestone, as using higher currents will lead to soft and porous limestone which will not attach properly to the steel structure. Switching from a 12 V battery current to 1.5 V going to the TCP-structures needs interposition of a resistor or multiple resistors in parallel. This is a cheap solution; however, power will be lost in the resistor. A different option could be a variable step-down-step-up DC/DC converter, this enables you to vary the number of volts and amperes going from the battery to the structures. Making it possible to experiment with different settings.

7.5. Implementation

The implementation will be done by a team made up of Tasikoki staff members and sub-contractors, managed by Alfonso Sianturi. In Appendix O the construction guide for the implementation is added. This guide provides a step-by-step manual for the construction of each individual part of the TCP-system, as well as additional information regarding electrical systems. A presentation of the concept and the guide has been given to the implementation team to explain different aspects of this project. This also gave the team the opportunity to ask questions or express concerns regarding the design/implementation. Concerns that came forward, after the presentation have been discussed and altered/added to the implementation plan.

7.5.1. Engagement plan

Involving the stakeholders by sharing the expectations throughout the lifecycle of the project is key for mutual understanding of interest. In order to smoothen this process and make the interaction between stakeholders and the project future proof, an engagement plan will be formulated. An overview of the stakeholder interests as shown in sub-paragraph 2.3.1. Stakeholders, shows that mostly local residents and fishermen will be influenced by the implementation of the TCP-cross structures as Tasikoki beach. It is therefore wise to set up a strategy in order to keep the attitude of local stakeholder’s positive towards the project.

Engagement of the local stakeholders consist of four phases:

1. Analysing the impact of the project on stakeholder’s interest
2. Creating a strategy to engage the stakeholders towards the project
3. Communicate the project plan to the stakeholders
4. Monitor, maintain and revise (if necessary) the engagement strategy

Per phase an explanation for the Tasikoki Project Staff will be provided in order to engage the local community in such a way that the chance of social conflicts will be limited. The engagement plan is presented to the Tasikoki staff, a copy can be found in Appendix M.

7.5.2. Monitoring & Maintenance plan

It will be essential to monitor the coastline development to determine the impact of the structure on the coastal evolution. Even so, ongoing maintenance will be required to make sure the TCP-cross keeps functioning properly. This work can be included in the routine of the volunteers (and staff) at Tasikoki Wildlife Rescue and Education Centre. Further explanation on performing the monitoring and maintenance is provided in Appendix K.

7.5.3 Measurement plan

A step-by-step measurement plan is included in Appendix L. This plan describes the method used by the team to obtain bathymetry data of the Tasikoki coast. The plan can be used by future research teams to obtain such data for different locations. For the Tasikoki beach it can be interesting to do such measurements in a few years' time, to see if any major changes have come to the Tasikoki beach.

7.6. Future scenarios

Implementation of the TCP-cross structure, as advised in the previous chapter, is expected to accrete sediment at the location of interest, with a high probability of distributing sediments along the downdrift coast. Erosion will thus be locally mitigated, in favour of the protection of the Tasikoki hinterland. Shoreline recession directly caused by SLR is however hard to mitigate. The growth of the beach will decrease the probability of flooding, but most likely eventually will succumb to the high sea level. Eventually the sea level will rise above the dune crest and the hinterland will flood.

To create an anticipative tendency for the project the following paragraph assesses three future scenarios based on different forecasts of climate change; present, moderate and extreme scenario. For each scenario a tipping point is calculated which is the year that the coastline most probably experiences an overwash or even an inundation coastal storm regime (Table 11)(2.2.8. Coastal storm regimes). The first tipping point will be in 2041 for the most extreme scenario. For the moderate and present scenarios, the tipping points will be 2052 and 2117, respectively.

Table 11 Tipping point calculation

Senario	Period	SLR rate	El Niño rise	Highest high tide	Max. Wave height	Critical crest height	Tipping point
Present SLR	2018-2050	0.0070 m/year	0.1 m	0.795 m	2,5 m	1.59 m	2117
Moderate SLR	2018-2050	0.0176 m/year	0.2 m	0.795 m	2,5 m	1.59 m	2052
Extreme SLR	2018-2100	0.0220 m/year	0.3 m	0.795 m	2,5 m	1.59 m	2041

Use is made of the three scenarios for SLR as laid out in sub-paragraph 2.2.7. Mean sea level. Rates of SLR for the present, moderate and extreme scenario are respectively 7.0 mm/yr, 17.6 mm/yr and 22.0 mm/yr. Other contributors to a high-water level are the tide, extreme climate events such as El Niña and storms. The highest tidal range at Tasikoki is 1.59 m (+0.795 m from MSL) and El Niña could cause a temporary SLR around 0.1 to 0.2 m (2.2.6. Tidal regime and Extreme climate events). Globally the tidal amplitudes change due to SLR, both increasing and decreasing the tidal range. Changes in mean high water (MHW) can exceed ±10% of SLR using a projection of 2 m SLR. Appendix P nevertheless shows that there is no change in MHW around North Sulawesi (Pickering, et al., 2017). Tidal changes are therefore not taken into account in the scenarios. Change in extreme climate events intensity is considered. The lower limit (0.1 m) of temporary SLR is used for the present scenario while the upper limit (0.2 m) is included in the moderate scenario. For the extreme scenario, an increase in intensity is expected. So, an upper limit is considered for this scenario (0.3 m).

The maximum wave height during storm surges is 2.5 m (ARGOSS, 2019). In the future, storm intensity and frequency are expected to increase (Ampou, et al., 2017). Most of the waves reaching maximum height will break at the coral reefs about 250 m offshore and will probably not cause any significant differences in sea level onshore. In other words, wave height will not be included in the tipping point calculation. Though, due to storm surges the sea level will probably increase significantly. However, because of a lack of viable data, storm surge water levels are left out in these scenarios. Besides, based on the bathymetry data, the lowest point of the crest (critical crest height) is located at B2 and is +1.59 m from MSL (4.5. Bathymetry).

Due to the fact that storm surge levels are left out in these scenarios, it is strongly recommended to reassess the situation multiple years prior to the tipping point. Also, an interim check is advised to see which scenario is witnessed and remeasure the critical crest height (could be increased due to the implemented solution). Reassessment of the situation prior to the tipping point should involve a new research on the Tasikoki coast. Either the current solution suffices for more years or there is need for a new solution. Hopefully there are new innovative solutions against shoreline recession to mitigate the probability of flooding in the future.

8. Conclusion

The beach owned by and located near Tasikoki Wildlife Rescue and Education Centre has been subject to severe shoreline recession over the past decades. In some parts of the Tasikoki coast a staggering 18 meters of coast has retreated over the past 16 years; creating an increased probability of flooding of the hinterland. It is therefore of the upmost importance that the Tasikoki hinterland will be protected against shoreline recession. Tasikoki Coastal Protection aims to achieve this goal by answering the following main question:

'What are viable BwN solutions to mitigate recession of the coastline of Tasikoki to protect the hinterland from flooding and how can the most optimal solution be implemented?'

In the process of answering the main question several sub-questions need to be answered after which a general conclusion will be presented.

Starting with the first sub-question, '***Which factors cause the shoreline retreat and coastal erosion?'***, an interdependent system of three main factors influence shoreline retreat, consisting of coastal conditions, societal system and ecosystem. One major disrupter of this system is climate change, especially SLR. Hydrodynamical processes that directly cause shoreline retreat are SLR, LST and CST. SLR causes direct coastal retreat. However, after approximation it is determined that it SLR is only partly responsible for the total coastline retreat. Regarding the coastal conditions, it can be concluded that the dominant wave direction is from 164˚ north. This determines that the dominant sediment transport direction is northward along the shore.

The two tidal inlets present at Tasikoki coast play an important role in the erosion pattern. Climate change (i.e. SLR) tends to disrupt the morphological equilibrium of the tidal inlets. To restore the equilibrium, it is assumed that both tidal inlets demand sediment. The southern larger inlet demands more sediment then provided, which causes erosion of the updrift coast and the ebb tidal delta. The northern smaller inlet demands less sediment then available, which results in less erosion down drift the coast.

The four main nearshore (CST) processes impacting the Tasikoki coast are wave impact, long waves, turbulence and avalanching/sliding. It is difficult to quantify the relative contribution of LST and CST to the erosion caused by these processes. However, given the erosion pattern at the Tasikoki coast, it is assumed that CST has a significant impact. This assumption is based on the fact that there is no coral reef present in front of the large tidal inlet. Considering the dominant wave direction of 164˚, waves from this direction are not dissipated by this gap in the coral reef, causing higher erosion rates in the extension of this direction.
Societal impact on the Tasikoki coast by the stakeholders is considered moderate, mainly due to the absence of a stakeholder possessing major blocking power. An engagement plan for the local inhabitants and fishermen is included to provide insights in the benefits of the solution and prevent unexpected resistance.
Human interference and climate change effects the ecosystem, especially coral reefs. Coral is very sensitive to these factors and it therefore expected to be harmed and to decrease. Absence of coral reef decreases its wave dissipating capacity which will lead to an increase of erosion.

The second sub-question is: ***'How can a UNIBEST model be used to simulate the coastal dynamics of the Tasikoki beach in order to predict the effects of possible solutions?'*** For this research a UNIBEST-model, with software provided by Deltares, has been created. The model can be used to test different scenarios and possible solutions. Furthermore, the ideal location of a solution can be determined. Due to several highly complex coastal characteristics, lack of (quality of) data and translating theory into practice, simplifications had to be made. Therefore, it is not possible to model trustworthy rates of erosion. However, the model has been verified using historical data; the model successfully recreated coastline regression over the past 16 years. It can thus be concluded that despite the simplifications the model is still a valuable asset for the project, as it gives good visual indications of what the effects are of certain solutions.

To answer the third sub-question ***'What are viable BwN solutions for coastal protection?'***, five different types of solutions are investigated, namely: Biorock, mangroves, seagrass, oyster reefs and hard structures. In order to challenge these solutions on all relevant aspects related to the project, a set of criteria has been drawn up. Protection of hinterland, costs, BwN, ecological, societal and operational aspects have been examined and compared between the proposed solutions. Based on these multiple criteria (MCA), the Biorock principle is concluded as the most optimal solution within the scope of the project for Tasikoki coast. In short, Biorock is a steel frame with a low current running through it to enhance coral growth and biodiversity at the same time.

Finally, the fourth sub-question '***What is an effective way to implement the solution at Tasikoki beach?'***. If the implementation is done incorrectly, the system might lose its effect and the results will most likely have a negative outcome. Limitations of the implementation are the budget and technical capabilities of the Tasikoki staff. In order to ensure a successful outcome of the project, construction, engagement, monitoring & maintenance and measurement plans are included. Multiple meetings with the project team and the supervising staff have ensured that these plans are clear without leaving any concerns. Brief explanations of the plans are as listed below:

- Construction plan: Step-by-step construction guide of the whole system
- Engagement plan: Plan to engage stakeholders to create support for the project
- Monitoring and maintenance plan: Basic methods to monitor effects and maintain effectiveness of the system
- Measurement plan: Step-by-step plan to investigate the coastal conditions at possible future project locations

To conclude, the Biorock-based solution is considered the most optimal for mitigating coastline recession at Tasikoki beach. The Biorock design is revised into TCP-cross modules, optimising it for Tasikoki beach. The solution is a 100 m long, 15 m wide submerged permeable breakwater consisting of 40 TCP-cross modules configured in diamond shape clusters (three lines of defence) for optimal wave dissipation. Using clusters provides a modular design, meaning that the length is variable (three structures can be added each time to extend the breakwater). The cross-shaped arched steel frames are designed to dampen waves from the entire wave spectrum while accreting limestone that stimulates biodiversity and enhances coral growth.

Length and configuration of the solution is mainly based on the available budget, along with other aspects such as size of the structures. A trade-off between coral growth and wave dampening resulted in the advised location. Verification in Unibest shows that this design causes accretion at the beach in front of the breakwater, resulting in sediment distribution downdrift. Therefore, it is decided to construct the TCP-system directly downdrift of the southern tidal inlet. If the structure functions as planned and more budget becomes available in the future, it is advised to implement a second 100 m TCP-cross structure more downdrift. According to simulations done in the Unibest model this should lead to accretion along the entire length of the coast.

9. Discussion

This discussion will address uncertainties regarding the performed research, decision making and future choices the project will face. Future research should focus on eliminating these uncertainties where possible. Other uncertainties can only be solved by the test of time. Coasts are very dynamic and it can take several years to observe permanent changes/results. Therefore, conclusions should not be drawn too soon.

SLR faster than accretion

A very important factor that should be taken into account, when reviewing the effect of the TCP-system, is that no accurate assumptions can be made on the amount or rate of beach accretion. If the structure is placed and the beach keeps retreating, it might seem like the system is not working at all. However, the SLR might counteract the accretive effect of the breakwater. So even though the net effect is negative, resulting in recession of the beach, the pace of recession might be decreased due to the breakwater.

Budget based decision

As the budget of this pilot is limited to 400,000,000 IDR (approximately 25,000eur), only 100 m of breakwater can be realized for the protection of a stretch of coastline of 1000 m. Efforts have been made to place the TCP-system in the most strategic location, where the most accretion is realized for the entire stretch of coast. However, if more budget would have been available for the project, the TCP-cross structure would have been bigger to enlarge the mitigating impact against erosion for the entire coast.

Extending or duplicating

If more budget becomes available, two options arise. Extending the first breakwater in northerly direction or placing a second breakwater at a second location. The model suggests that placing a similar sized breakwater just south of the jetty would result in accretion over the full length of the beach. However, as discussed before the model has been simplified to a certain degree; making it very difficult to draw conclusions on this topic. On top of this, it also depends on the amount of budget that becomes available and the effectiveness of the first breakwater. If the first breakwater is successful in accreting the beach and enough budget becomes available to create a similar second breakwater; it is advised to construct a second breakwater just south of the jetty. If the breakwater doesn't function properly or not enough budget becomes available to construct a second breakwater, it is advised to extent the first breakwater. However, this will depend on the impact the breakwater has had on the beach. A new thorough analysis will be required by that time, taking the erosion/accretion pattern into account.

Generic data sets

Due to the remote location of Tasikoki beach, a lot of data is not available on a variety of topics. Mostly generic (regional, national and global) data was used for this research. Efforts have been made to modify the data without compromising it too much, to adjust it to the Tasikoki beach. In order to do so, certain assumptions were made. For follow-up research, it is advised to first focus on improving the quality of the nearshore wind and wave climate data. This could be done by doing measurements for extended periods of time; something that did not fit into the scope of this research.

Protection of hinterland vs coral growth

The primary function of the TCP-system is to protect the hinterland of the Tasikoki area. However, one of the design characteristics is the growth of limestone on the structure; essentially creating an artificial reef. This reef can only grow when the TCP-cross is fully submerged, as this is the only way electrolysis will occur. A structure that is constantly submerged, will have the highest rate of limestone growth. A balance had to be found between coastal protection and coral enhancement, resulting in a partial submerged structure during low water. The bottom of the breakwater will be submerged at all times, whereas the top of the structure will only be submerged during higher tides. Hence, it is expected that less limestone will grow at the top compared to the bottom, or maybe even no limestone at all. However, the wave energy dissipating capabilities of the system have not been compromised, as waves still pas through the breakwater and not over it.

Simplification and assumptions

The shoreline recession of the Tasikoki coast has many influencing factors involved, like SLR, LST-processes and CST-processes. Each of these influencing factors are complex matters, which are not easy to solve straight away. They all need comprehensive data to eventually draw conclusions. Unfortunately, not all data was available or could not be gathered while conducting the project. Simplifications had to be made for some factors which lacked (viable) data; especially while setting up the Unibest-model. In the Unibest-model assumptions were made on six important topics, namely the wave climate, SLR, the spit evolution, the two tidal inlets present at the Tasikoki coast, the boundaries of the beach and the tidal current. It could be discussed whether these assumptions will give realistic outcomes of the model. Nevertheless, the model outcomes create a lot of value if they are used as visual indications, whether the coast will erode or accrete after implementation of certain solutions.

Storm surges

As storm surges are considered to be the most destructive for coastal environments, they are an important asset in the coastal erosion problem and should be incorporated at any time. Unfortunately, due to a lack of data and time to do proper analyses on storm surges (with Xbeach for example), they have not been considered quantitively. However, it is still the prediction that these storm surges will lead to the most accretion of sediment behind the TCP-cross structure. Further research on storm surges should clarify the effects of the TCP-cross structure during storm surges.

Limits of effectiveness

The TCP-cross structure functions as a permeable submerged breakwater. So, if the structure is effective, sediment will accrete behind the structure until a tombolo is formed. A tombolo is basically a bar of sand which connects the mainland with the breakwater. When a tombolo is created the structure has been 100% effective and no further accretion will be witnessed. This means the TCP-cross structure has a certain limit of effectiveness. However, no actual data can be provided on when the structure reaches this limit.

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Appendices

Appendix A

Barotropic energy flux directions

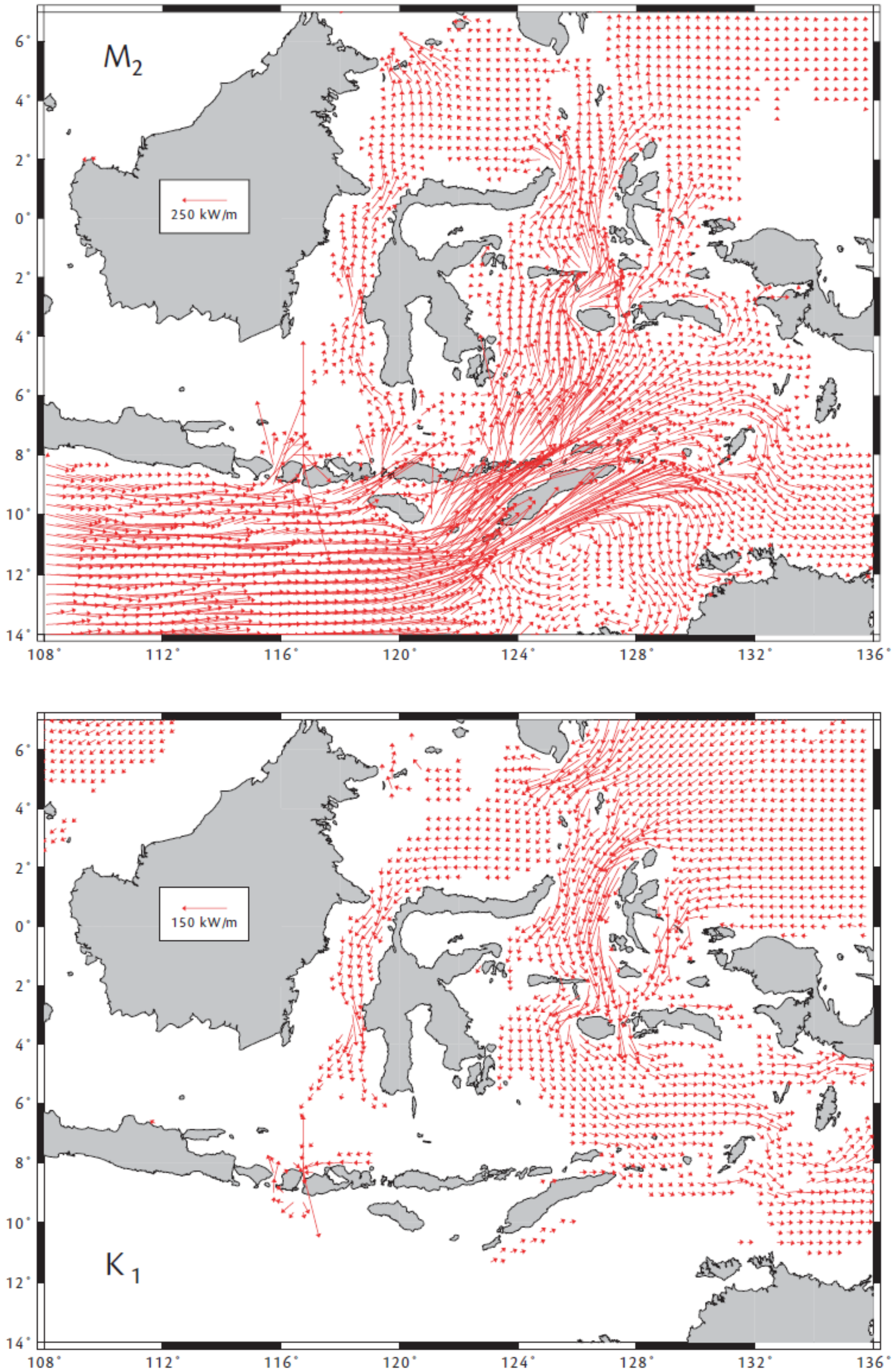


Figure 71 Mean barotropic energy flux directions for the M2 and K1 tides (Ray, Egbert, & Erofeeva, 2005)

Appendix B

Maximum current velocity of the M2 tide

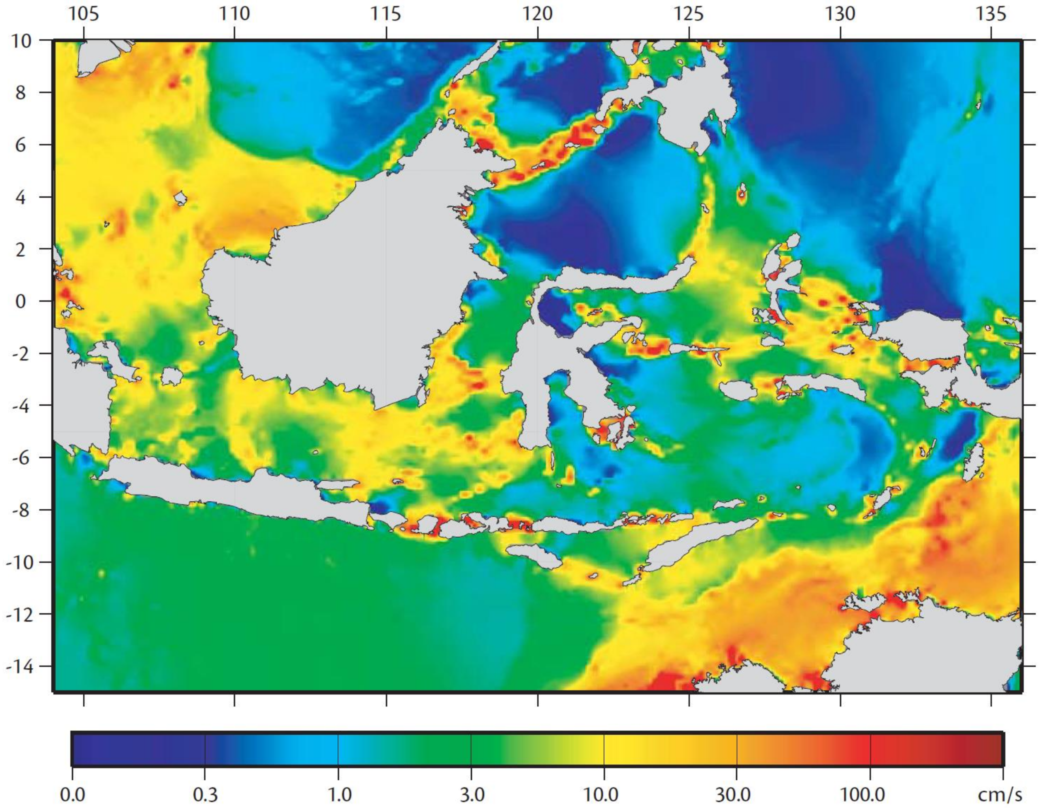


Figure 72 Maximum barotropic current velocity of M2 tide (Ray, Egbert, & Erofeeva, 2005)

Appendix C

Interview Yayha – Tasikoki Manager

The first interview was held with Yayha, a Tasikoki Program Manager who works already a long time for Tasikoki and comes from this area. Given his knowledge about the area and his seniority at Tasikoki, we asked him for an interview in order to get to know more about the historical developments of Tasikoki Beach.

Q: Dear Yahya, good morning! Thanks for coming over and making some time for us. We would like to start with an historical related question if that's ok. What was the state of the beach 10 years ago?

A: Over the last 10 to 20 years I have seen the beach changing significantly. One thing that is very clearly visible, is the high abrasion level of the shoreline. I remember from when I was young, the beach seemed to be much bigger and much more into the sea. Nothing like it is today.

Q: How did the vegetation look like on and around the beach?

A: The shoreline mainly consisted of just mangrove vegetation located near the shore.

Q: Can you explain us something about the average state of the sea? And have you seen some changes in the water level and sea behaviour over the last 10 years?

A: The water height depends on the season. October, November and December are characterized by low water. All other month's the water level is higher. Waves are mostly seen far from the beach and don't reach the shore with a significant height. I think they mostly break around 50 metres from the shore, which is probably near the coral reef. The waves seem in my opinion always to come from the same direction. Around two or three times a year we really have big storms which cause a lot of high waves and wind. You always see a lot of trash and other material on the shoreline after such an event. However, I have never experienced a tsunami here at Tasikoki, luckily!

Q: Where do the fishers normally go to fish? Do they ever fish in the sallow area in front of Tasikoki beach?

A: Fishers always fish behind the coral, which is quite far outside the of the shoreline. Only hand fishing is done in front of the beach. But not with the boat. In front of the beach, they catch small fish, crabs and squid. Currently there is an increasing problem for the fishermen, as they catch less fish. Fishers have to have a different job in order to live. Depends on the season.

Q: If nothing is done, what do you think that will happen with the beach and wildlife centre?

A: In my opinion, the beach will go away. In my village, the farmers lost a lot of trees to the sea. From what I've seen, the mangroves will survive in salt water. Only coconuts tree will go away. A lot used to be in front of Tasikoki beach, which are gone now.

Q: What about the lagoon next to Tasikoki, is that a lake made by the sea or fed by a river?

A: The lake is fed by the river but the flow rates are relatively small. The spit at the end grew bigger in the last few years.

Q: Than we still have a last question regarding the Bitung Harbour. We are investigating the effect of the development of the Harbour on the coastlines southwards of it. What can you tell about the development of the Harbour?

A: The local harbour was built a long time ago. However, the international harbour was built 7 years ago. This is a harbour for the container ships coming from several countries in South East Asia.

Appendix D

Interview with Paulus Prong – Program Manager Biorock Gangga Island

The second interview was held with Paulus Prong, the person who was responsible for the Biorock Project at the Gangga Island Resort and Spa. In contrast to the other Biorock projects, this project was the first with the goal of reducing the erosion by using the Biorock technology. Paulus, as the program manager, was responsible for all the project phases and currently maintains the structures on a weekly base besides his job as a diving instructor at the resort. We visited Paulus in order to get to know more about the principle of the Biorock technology and to get a better understanding about the possibility to implement the Biorock solution at Tasikoki. He provided us with an interview and an underwater tour around the Biorock structures.

Q: Good morning Pak Paulus. Thanks for inviting us over to this amazing place to discuss the Biorock project. Can you explain us about the coastal dynamics here around Gangga?

A: The current during low tide is going southward and a bit westward near the jetty, and during high tide the current is more northward and eastward near the jetty, observed from the beach. At this area, the low tide current is dominant. During the monsoon season, waves are coming from every direction. In my observations, I saw that the combination of waves from the north and wind from the west causes a lot of erosion

Q: What does the vegetation looked like before the Biorock and did you see any change after the installation of the Biorock?

A: Before placing the Biorocks, the sea bottom was covered with algae. After the Biorock installation, a lot of seagrass, soft and hard coral and other underwater life was attracted to the area.

Q: Where was the most beach lost around the resort?

A: At the quay wall the most erosion occurred

Q: How was the placement and formation of the Biorock determined?

A: No model has been used, it was based on the coastal dynamic observations over a long amount of time, like the dominant currents and wind directions which caused the most erosion over the years.

Q: In the report written by you and Thomas Goreau, the price range from the solutions differs a lot. How can the costs of making the blocks be in a range from 20$ - 1200$ per meter of coastline protected?

A: This was caused by several aspects:

- Costs are dependent on the materials;
- Anodes and cables are dependent on the dollar price;
- Anodes are made from metal;
- Transport costs are high;
- All materials are from Manado, rocks are volcanic material;
- Biorocks are connected to the beach houses

Q: Which other alternatives have been considered for this beach?

A: Bamboo poles have been used to protect the beach against erosion, but this solution failed because the structure was not strong enough during storms and because it would degrade a lot while being submerged in the sea.

Q: What kind of problems occurred during the construction of the project?

A: The main problem was perceived by delays caused by material supply.

Q: How are the developments of the Biorock structures checked?

A: As I check the structures, I see that the thicker wires are always covered with water, thinner ones are above the sea water. When I do my weekly check, I take out the plastic rubbish, as plastic rubbish destroys young corals and the growth of limestone. The volcanic rocks in the steel wire gabions are good for the growth of oysters and barnacles. When the structure becomes stronger, the Biorocks could potentially hold without any power supply. These structures show in a year already significant growth.

Q: What are the basic design characteristics of a cluster of Biorocks?

A: Every cluster is shaped as a diamond shape of four Biorock structures and iis connected to the land in series. Through the structures there is electricity flowing using Low voltages and low amperages. The anodes stay in the water for longer periods, so no corrosion occurs to them. The structures itself are not anchored, as they stay on their place by the weight of the stones.

Q: What are additional design specifics to take into consideration when we want to make a similar project?

A: When setting up a Biorock project, it should be taken into account that there need to be some space left between the structures. These openings should leave space for boats to go through and also sediment to pass. Thereby is most wave energy dissipated by the Biorocks that have their top crest above the sea level.

Q: What would you improve, if you could do the project again right now?

A: There are no real improvements I would like to suggest, only make sure delivery dates are better known so planning can be optimized.

Q: What have been the effects so far of the Biorocks?

A: Significant reduction of wave energy is realised and depending on the current the beach will accrete. Thereby we have noticed much more fish in the area. At low tide, they leave to deeper areas as the Biorocks are quite close to the beach. At high tide, they come back and can be seen swimming around the Biorocks in large numbers.

Q: Why are the Biorocks situated so close to the beach?

A: The location of the Biorocks have been chosen on practical grounds, while the electrical cables are 100m so the Biorocks are positioned 100 m from the electricity source.

Q: What were the details regarding the construction of the project?

A: The Biorock structures at Gangga Island took 3 months to construct, mainly due to the long transportation time of the materials. 6 to 10 people were involved in the installation of the structures. In total 40 Biorocks were placed at the structure near the jetty and 46 Biorocks were placed more to the north. The structures cover a width of 50 to 60 m. The construction costs of the structures are estimated on 250 million IDR for a single project.

Appendix E

Input Unibest model

In this appendix is explained how the sediment transport and corresponding coastal evolution of the Tasikoki beach, with varying circumstances, can be analysed with a model. This is done with the help of UNIBEST-CL+, a single line coastline modeling package developed by Deltares. The model will be used to substantiate potential solutions. The software package is introduced and the required input parameters and settings are described.

Model type

As 2.2.5. Mixed tide and wave dominated, Tasikoki beach is described as a mixed energy class beach with a slight wave dominated tendency. The UNIBEST-CL+ software is specialized in wave dominated cases. It can be applied for simulating the response of the nearshore zone of the shoreface where effects of wave breaking and wave-driven longshore currents in combination with alongshore directed tidal currents are predominant (Deltares, 2009).

Unibest-CL+ software package

The UNIBEST-software is an acronym of **Uni**form **Be**ach **S**ediment **T**ransport. UNIBEST-CL+ is designed to compute coastline changes due to longshore sediment transport gradients of an alongshore nearly uniform coast, on the basis of the single line theory. This has first been presented by Pelnard-Considère (1956). One-line models are often used in order to get a first insight in the basic behaviour of a coast, especially for long time scales. In this theory the coast is schematized into a single line and the displacement of this line is described as a function of time and longshore position. UNIBEST-CL+ consists of two integrated sub-modules:

- The Longshore Transport module (LT-module)
- The CoastLine module (CL-module)

The longshore sediment transport is computed and schematised with the LT-module separately for a number of cross-shore profiles along a coast. These schematized transports are then used in the CL-module to perform coastline evolution simulations in which effects of structures such as groynes, offshore breakwaters and revetments can be incorporated.

Setup of the Unibest-LT module

The setup of the LT module requires input parameters such as the cross-shore profile, transport parameters (including sediment characteristics) and wave data. Data has been acquired to determine the cross-shore profiles for 17 locations along the Tasikoki coast. However, Unibest is designed for long term simulations on large stretches of coast rather ignoring small wiggles and details. The coast in front of Tasikoki however is relatively short (1 km), which is almost beyond Unibest's boundaries. This means that in order to get realistic results the whole situation has to be simplified. The output of the LT-module will be used in the CL-module as RAY-files.

Cross-shore profile

The first topic issued in the LT-module is the cross-shore profile, which consists of bathymetry, active height, dynamic boundary and reference level. Firstly, to simplify the case the 17 measured cross-shore profiles have been reduced to one single cross-shore profile for the entire coast, assuming a uniform beach profile. This is rectified by the fact that the wave climate and transport parameters are more or less equal along the Tasikoki coast. In the coming sub-paragraphs, the model input will be further elaborated.

Bathymetry

The methodology to determine the bathymetry and coastal profile is explained in sub-paragraphs 3.3. Bathymetry and 3.4. Beach topography. This data is manually inserted in Unibest to create a cross-shore profile. The cross-shore profile used for the Tasikoki model is presented in Figure 73.

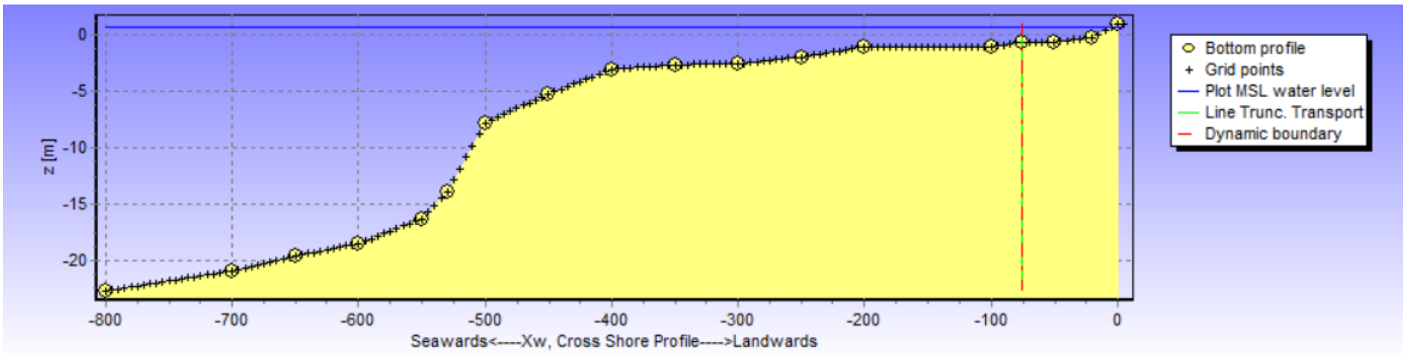


Figure 73 Cross shore profile in Unibest

Profile/Active height & Dynamic boundary

The dynamic boundary divides the profile in two parts, a static part (outside the transport zone) and a dynamic part (inside the transport zone). The profile/active height simulates the elevation of the shoreline in which sediment is dynamically active. The estimation of the active height depends on the local wave climate, local bathymetry and the timeframe. As a rule of thumb the active height is about 2 to 3 times the 1/1-year significant wave height (Deltares, 2009). Considering a H_s of 0.4 m in the Tasikoki region retrieved from sub-paragraph 4.2. Wave climate, the active height is determined to be 1.5m.

Reference level

The reference level basically simulates the MSL. The MSL is calculated as the mean average over all high and low tides. A value of 0,64 m was found for 2018 (2.2.6. Tidal regime).

Coast orientation

Secondly, the coast orientation had to be provided. Since only one cross-shore profile is considered, only one coast orientation has to be implemented. Unibest will automatically adapt the coast orientation for every grid point on the reference line in the CL module. The specified angle is used for the relation between the coast angle and the sediment transport. Unibest calculates the gradients in longshore sediment transport and consequently calculates the changes in coastline. These gradients in longshore sediment transport are based on gradients in wave climate, transport parameters and coast orientation. Since the wave climate and transport parameters do not change along the relative short coast, the coast orientation becomes very important. It is the only parameter that will result in different longshore sediment transport gradients for different grid points and will therefore lead to either erosion or sedimentation.

Transport & Wave Parameters

Transport parameters

Sediment transport parameters have to be specified in Unibest, as these coefficients are important in order to determine the behaviour of sediment. The most important parameters are the median and 90-percentile values for the grain diameter, the D_{50} and D_{90}. In paragraphs 3.5. Sediment characteristics and 4.6. Sediment is explained how the grain size distribution and the D_{50} and D_{90} have been determined. More detailled information is provided in Overview input Unibest LT-file**.**

Wave parameters

The wave parameters are used to define wave breaking, bottom friction and bottom roughness. More detailled information is provided in Overview input Unibest LT-file**.**

Wave Current

Last items that should be specified in Unibest are the schematized wave and tidal climate. In chapter 4. Data is explained how this data have been acquired. This sub-paragraph is called 'Wave Current', because the wave-driven longshore currents in combination with alongshore directed tidal currents transport the sediment along the coast.

Wave climate

The offshore wave data provided by Argos have to be translated to nearshore wave data. From examining the surroundings, it has been concluded that offshore waves coming from 0˚ - 90˚ and 180˚ - 225˚ north can only reach Tasikoki beach when they diffract. Hence, waves lose wave energy and wave height by a factor 2 when they arrive at the shore. (Bosboom & Stive, 2015, p. 166) Offshore waves from other directions were not adjusted to translate them to nearshore waves.

Tide information

The tidal regime in the Tasikoki region is mixed semi-diurnal as is explained in 2.2.5. Mixed tide and wave dominated and 2.2.6. Tidal regime. However, it becomes very complex to implement this regime in Unibest. Moreover, as explained before, the waves are dominant over the tides at Tasikoki beach, so the tidal regime relatively has less impact on the coastal evolution. Therefore, it has been decided to exclude the tide in the model.

Setup of the Unibest-CL module

In this paragraph, it is explained how the Coast Line module (CL-Module) is set up. First, a picture of the coast is imported from Google Maps on which the coastline position is modelled. The output of the LT-module (relation between coast angle and transport) for predefined cross-sections are used as an input in the CL-module. Detailed descriptions of these first steps, to create the basis of the model, are not relevant to present in this report. On the contrary, there will be elaborated on the influences of the tidal basins, jetty, coral and boundary conditions at Tasikoki beach and how they can be modelled.

Tidal basins

The hypotheses about the tidal basins and their interaction with the coast are presented in sub-paragraph 2.2.9. Tidal inlets and deltas and paragraph 4.7. Tidal basins affected by SLR. The interaction between tidal basins and the coast are very complex systems. At first, the tidal basins were modelled as a source term in Unibest. To verify this approach, Hans de Vroeg from Deltares has been contacted to consult on this case. He explained that it is almost impossible to model these tidal basins in the Tasikoki case, since there so little information available about them. Moreover, to simplify the case in Unibest it would also be better to ignore the tidal basins in the model. Therefore, it was decided to exclude the tidal basins.

Jetty

At first the jetty, introduced in sub-paragraph 2.2.13. Jetty, was modelled as a permeable groyne. After further research on historical aerial images of the beach it was concluded that the jetty is so permeable, that it does not influence the coast. This means the jetty is not incorporated in the model.

Coral

Coral reefs reduce the wave energy and therefore the wave height. Based on research, coral reefs reduce the average wave height with 64% (Ferrario F. , et al., 2014). So, a local wave climate file with reduced wave height was created and implemented to simulate the coral.

Boundary conditions

Boundary Conditions are the conditions that describe the behaviour of the coast at the two model boundaries in terms of the coastline position. The four possibilities are:

- Coastline position Y remains constant
- Coast angle remains constant
- Sediment transport Qs is a user-defined constant value
- Sediment transport Qs is a user-defined function of time

Based on aerial images obtained from Google Earth, was concluded that the coastal position of the boundaries of Tasikoki have not changed (significantly) over the years. Therefore, it was decided to set the coastline position Y constant in the model.

Sea level rise

As described in previous chapters, sea level rise is a major cause of shoreline recession. In a first attempt, the sea level rise (SLR) was simulated by increasing the reference level over a period of time. Unfortunately, this did not lead to the desired results. After verifying this approach with Hans de Vroeg form Deltares, it was concluded that it is not possible to simulate SLR in Unibest. Hans recommended us to use the Bruun's rule to determine the effect of the SLR on the beach, this is performed in 4.4. Coastal recession through SLR.

Overview input Unibest LT-file

Table 12 Input Unibest LT-file

Category	Input	Unit	Number	Source
Coast angle	Coast angle	°	155	Google Earth
Active height	Active height	m	1.5	Unibest manual Deltares page 11
Cross shore profile	Uniform beach profile	-	-	Created in Surfer model
Cross shore profile	Reference level	m	MSL: 0.64	Wave climate; Tide charts
Transport parameters	Formulae	-	Bijker	Coastal Dynamics 1 book page 278
Transport parameters	D50, grain diameter	µm	431	Performed sieve analysis
Transport parameters	D90, grain diameter	µm	852	Performed sieve analysis
Transport parameters	Sediment density	kg/m^3	2650	Fixed number in Unibest
Transport parameters	Seawater density	kg/m^3	1025	Fixed number in Unibest
Transport parameters	Porosity	-	0.4	Fixed number in Unibest
Transport parameters	Bottom roughness	m	0.035	Coastal Dynamics 1 book page 266 figure 6-5
Transport parameters	Sediment's fall velocity	m/s	0.032	Calculation, see next table
Transport parameters	H_{sig}/h - 1/20	-	0.07	Unibest Manual Deltares page 49
Transport parameters	Coefficient b deep water	-	2	Coastal Dynamics 1 book page 279
Transport parameters	H_{sig}/h - 1/2	-	0.6	Unibest Manual Deltares page 49
Transport parameters	Coefficient b shallow water	-	5	Coastal Dynamics 1 book page 279
Wave parameters	Coefficient for wave breaking (gamma)	-	0.78	Coastal Dynamics 1 book page 169
Wave parameters	Coefficient for wave breaking (alfa)	-	1	Unibest manual Deltares page 85
Wave parameters	Coefficient for bottom friction (f_w)	-	0.01	Unibest manual Deltares page 85
Wave parameters	The value of the bottom roughness (k_b)	m	0.035	Coastal Dynamics 1 book page 266 figure 6-5
Wave current	Wave climate	-	-	Argos
Wave current	Normalization scenario duration	days	365	Unibest manual Deltares page 26

Table 13 Parameters to calculate sediment's fall velocity

Input	Abbreviation	Unit	Number	Source
Fall velocity	W_s	m/s	0.032	Coastal dynamics 1 book page 260 eq.6.4
Median grain diameter	D50	m	0.000431	Performed sieve analysis
Relative mass density	s	-	2.585	Sediment density / Seawater density
Acceleration of gravity	G	m/s^2	9.81	
Drag coefficient	C_d	-	9	Coastal dynamics 1 book page 262
Reynolds number	Re	-	0.035	Coastal dynamics 1 book page 266 Fig. 6-5

Appendix F

Impact of SLR on shoreline recession

All meaurements have been done by hand
Coastal erosion rate is retrieved from source see Unibest input excel sheet
Google earth coastal retreat has been retrieved by analysing historical photos from 2002 and 2018

Scenario Actual SLR 2002 - 2018

		A1	**A2**	**A3**	**A4**	**B1**	**B2**	**B3**	**B4**	**B7**	**B9**	**B11**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
L	m	55.00	30.00	30.00	35.00	30.00	30.00	75.00	35.00	20.00	35.00	35.00	35.00	25.00	15.00	25.00	30.00	20.00
H	m	1.29	1.57	1.69	1.70	1.90	1.57	2.23	2.03	1.39	1.71	1.52	1.60	1.43	1.38	1.33	0.97	1.72
Slope	-	0.02	0.05	0.06	0.05	0.06	0.05	0.03	0.06	0.07	0.05	0.04	0.05	0.06	0.09	0.05	0.03	0.09
Retreat	m/year	0.30	0.13	0.12	0.14	0.11	0.13	0.24	0.12	0.10	0.14	0.16	0.15	0.12	0.08	0.13	0.22	0.08
Retreat past 16 years	m	4.77	2.13	1.99	2.31	1.77	2.14	3.77	1.93	1.61	2.29	2.58	2.44	1.96	1.22	2.10	3.47	1.30

Scenario Moderate SLR 2018 - 2050

		A1	**A2**	**A3**	**A4**	**B1**	**B2**	**B3**	**B4**	**B7**	**B9**	**B11**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
L	m	55.00	30.00	30.00	35.00	30.00	30.00	75.00	35.00	20.00	35.00	35.00	35.00	25.00	15.00	25.00	30.00	20.00
H	m	1.29	1.57	1.69	1.70	1.90	1.57	2.23	2.03	1.39	1.71	1.52	1.60	1.43	1.38	1.33	0.97	1.72
Slope	-	0.02	0.05	0.06	0.05	0.06	0.05	0.03	0.06	0.07	0.05	0.04	0.05	0.06	0.09	0.05	0.03	0.09
Retreat	m/year	0.30	0.13	0.12	0.14	0.11	0.13	0.24	0.12	0.10	0.14	0.16	0.15	0.12	0.08	0.13	0.22	0.08
Retreat in 2050	m	9.54	4.27	3.98	4.62	3.54	4.28	7.54	3.86	3.23	4.58	5.15	4.89	3.92	2.43	4.20	6.95	2.59

Scenario Extreme SLR 2018 - 2050

		A1	**A2**	**A3**	**A4**	**B1**	**B2**	**B3**	**B4**	**B7**	**B9**	**B11**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
L	m	55.00	30.00	30.00	35.00	30.00	30.00	75.00	35.00	20.00	35.00	35.00	35.00	25.00	15.00	25.00	30.00	20.00
H	m	1.29	1.57	1.69	1.70	1.90	1.57	2.23	2.03	1.39	1.71	1.52	1.60	1.43	1.38	1.33	0.97	1.72
Slope	-	0.02	0.05	0.06	0.05	0.06	0.05	0.03	0.06	0.07	0.05	0.04	0.05	0.06	0.09	0.05	0.03	0.09
Retreat	m/year	0.75	0.34	0.31	0.36	0.28	0.34	0.59	0.30	0.25	0.36	0.41	0.38	0.31	0.19	0.33	0.55	0.20
Retreat in 2050	m	23.99	10.72	10.01	11.61	8.89	10.75	18.95	9.71	8.11	11.52	12.96	12.29	9.85	6.11	10.55	17.47	6.52

Figure 74 Shoreline retreat due to SLR per section per scenario

Appendix G

Overview of bathymetry profiles

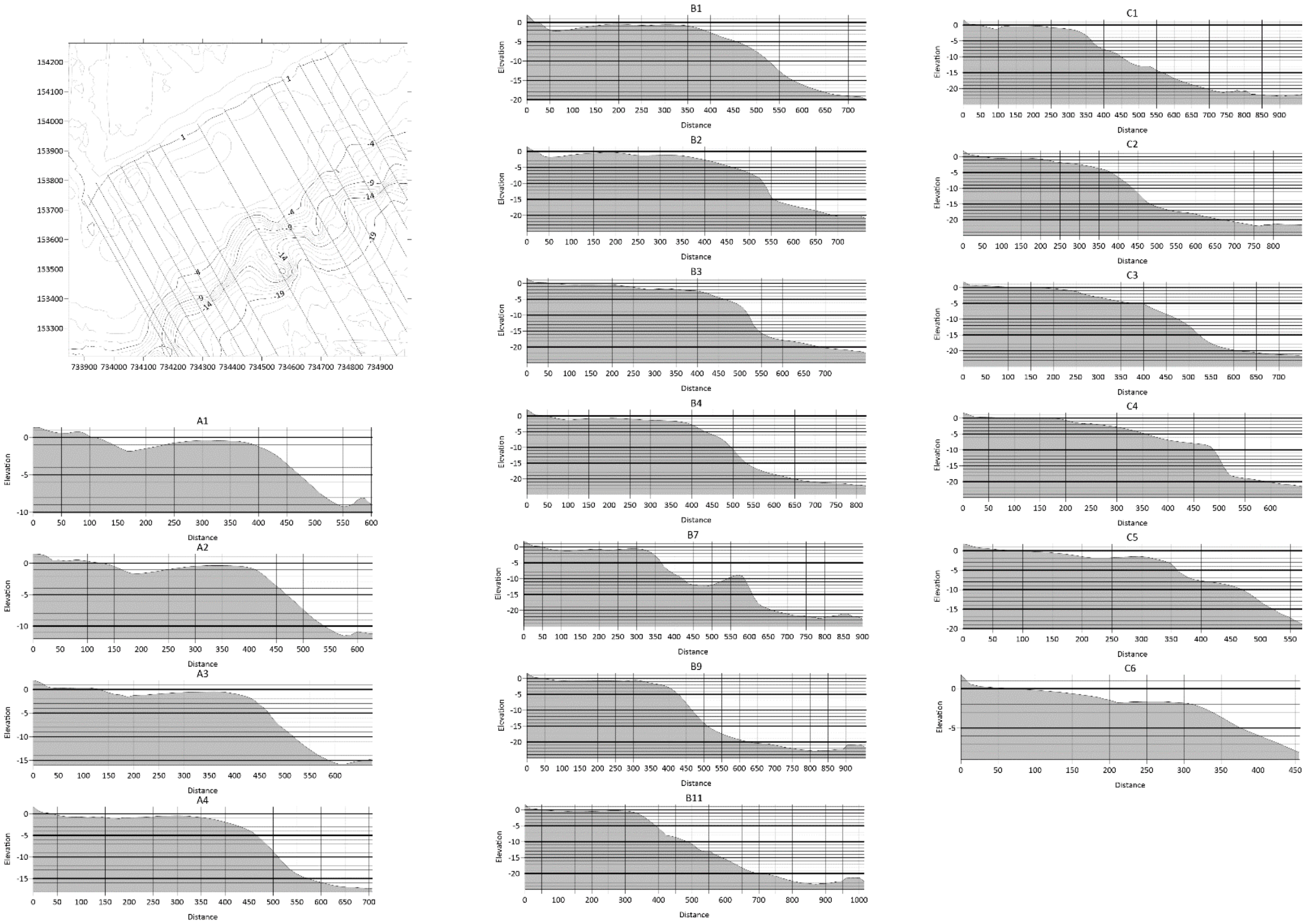


Figure 75 Bathymetry profile overview

Appendix H

Sediment sample grainsize distribution data

Table 14 Sediment sample overview

	Offshore sample 1		Offshore sample 2		Offshore sample 3		River sample 1		River sample 2		Shore sample 1	
Diameter (mm)	Weight (g)	Percentage	Weight (g)	Percentage	Weight (g)	Percentage	Weight (g)	Percentage	Weight (g)	Percentage	Weight (g)	Percentage
2	25.2	7%	0.8	0%	1.8	0%	17.4	3%	20.3	4%	15.2	2%
1.5	43.5	13%	3.6	1%	6.4	2%	38.2	8%	74.3	15%	75.6	12%
0.8	76.5	22%	7.1	1%	13.2	3%	114.8	23%	140.4	28%	165.5	26%
0.5	97.8	28%	30.8	6%	30.9	8%	227.8	45%	172.5	34%	188.5	30%
0.315	65.5	19%	112.5	23%	60.9	16%	99.3	20%	80.6	16%	126.3	20%
0.2	24.4	7%	210.8	43%	161	42%	9.3	2%	13.6	3%	46.8	7%
0.165	8.7	3%	99.3	20%	92.7	24%	0.4	0%	1.2	0%	8.2	1%
0.08	1.9	1%	15.2	3%	10.5	3%	0	0%	0	0%	1.3	0%
0.05	0.2	0%	6.4	1%	5.8	2%	0	0%	0	0%	0.3	0%
0.01	0	0%	1.4	0%	0.5	0%	0	0%	0	0%	0.1	0%

Appendix I

Tidal basin area specifics

Category	Year	Input	Unit	Number	Source	Comment
Big basin	2018	Total area of channel	m2	286.478	Google earth pro	Area is estimated by using a polygon in google earth pro
Big basin	2018	Area island 1	m2	6.647	Google earth pro	Area is estimated by using a polygon in google earth pro
Big basin	2018	Area island 2	m2	67	Google earth pro	Area is estimated by using a polygon in google earth pro
Big basin	2018	Area island 3	m2	3.351	Google earth pro	Area is estimated by using a polygon in google earth pro
Big basin	2018	Area channel	m2	276.413	Google earth pro	Area is estimated by using a polygon in google earth pro
Big basin	2002	Area delta	m2	141.544	Google earth pro	Area is estimated by using a polygon in google earth pro
Big basin	2018	Area delta	m2	168.229	Google earth pro	Area is estimated by using a polygon in google earth pro
Little basin	2002	Area delta	m2	27.199	Google earth pro	Area is estimated by using a polygon in google earth pro
Little basin	2018	Total area of little basin	m2	223.468	Google earth pro	Area is estimated by using a polygon in google earth pro
Little basin	2018	Area channel	m2	5.298	Google earth pro	Area is estimated by using a polygon in google earth pro
Little basin	2018	Area flats	m2	218.170	Google earth pro	Area is estimated by using a polygon in google earth pro
Little basin	2018	Area delta	m2	41.195	Google earth pro	Area is estimated by using a polygon in google earth pro
Little basin	2002	Area delta	m2	27.199	Google earth pro	Area is estimated by using a polygon in google earth pro
Big basin	2018	Area flats	m2	786.867	Google earth pro	Area is estimated by using a polygon in google earth pro
Hydrodynamics		Sea Level Rise	cm/year	0,71	ICCSR	
Hydrodynamics	2002-2018	Sea Level Rise	m	0,11	ICCSR	
Hydrodynamics		Sea Level Rise	cm/4yr	2,86	ICCSR	

Figure 76 Area specifics

Appendix J

Feasibility study mangrove breakwater

Table 15 Required conditions to grow mangroves

An X indicates that a condition will (most probably) be a limiting factor to create a mangrove breakwater at Tasikoki beach. A checkmark means a condition is met.

Required condition	**Source** (Hoek, Applying the 'Building with Nature' philosophy for sustainable port development, 2018)	**Situation at Tasikoki beach**
Climate: mangroves can only grow in tropical or subtropical climate	(Ecoshape Building with Nature Guidelines, sd)	✓ Tropical climate, mangroves are present
Inundation time mangroves: should be between 7 and 13 hours a day	(Ecoshape Building with Nature Guidelines, sd)	Unknown, data about yearly tide levels is not available
Grade of the bed slope: mangroves grow at wide flats with mild slopes	(Ecoshape Building with Nature Guidelines, sd)	✓ The cross shore profile consists of a mild slope (see 4.5. Bathymetry)
Width of mangrove forest: 150m width is required to grow a sustainable forest and to effectively dampen waves	(Ecoshape Building with Nature Guidelines, sd)	✓ Enough width is available
Wave energy: maximum wave height should not exceed 1.5m to protect seedlings and juvenile mangrove trees	(Ecoshape Building with Nature Guidelines, sd)	✓ As described in 4.2. Wave climate, this wave height is not, or very rarely, exceeded
Type of soil: mangroves preferably grow in muddy soil but can also grow in sand. Generally speaking, when the coast is not muddy, the wave energy might be too high	(Ecoshape Building with Nature Guidelines, sd)	X Tasikoki beach is sandy, but mangroves are growing onshore (probably because there is a higher profile height and they are less subjected to the waves), might be a limiting factor to grow them offshore
Sedimentation rate: mangroves need sediment to keep up with sea level rise	(Ecoshape Building with Nature Guidelines, sd)	Unknown, detailed sedimentation rates are unavailable
Tidal currents: mangroves cannot establish if the tide-induced currents exceed a few dm/s	(Ecoshape Building with Nature Guidelines, sd)	✓ Tidal current is probably too high (2.2.11. Current), but this risk is mitigated by installing the permeable dam
Salinity: this is considered to be the most important factor. Mangroves have the competitive advantage that they can grow in salty water, they don't need it. Fresh water remains very important input for them	(Ecoshape Building with Nature Guidelines, sd)	X There is no fresh water source, like an outflowing river, salinity is too high to grow mangroves offshore
No pollution to water and soil: mangroves are sensitive to (oil) pollution	(Ecoshape Building with Nature Guidelines, sd)	✓ No contamination at present
Living organisms: organisms are important for the ecosystem for mangroves, they impregnate soil and support the flushing of salt	(Ecoshape Building with Nature Guidelines, sd)	✓ Since there are mature mangroves, these organisms are expected to be present

Appendix K

Monitoring and maintenance plan

Monitoring

Coast

Since advanced measuring equipment is not available, it is advised to monitor the coast by taking pictures. Preferably aerial pictures to have a good overview, which can be obtained from Google Earth or taken with a drone. A disadvantage of using Google Earth is the fact that it is not possible to correct for tides. Moreover, the map is only (on average) updated between one to three years. So it is not possible to completely rely on Google Earth, but it can be used additionally. Furthermore, coastlines are always dynamic, which makes it difficult to determine on the short term whether a change in the coastline is due to an implemented structure or just a natural occurrence. Also, a coastline can change per season, so it is preferred to compare shorelines from same seasons to estimate the annual variations.

Taking all these factors into consideration it is advised to take pictures at Tasikoki beach as follows:

- frequently, if possible weekly (during the maintenance routine)
- take pictures from fixed locations (they are described below)
- take pictures during low-tide (and if possible, also during highest tide)
- store the pictures on google drive for example

<u>Fixed locations:</u>

- from the beginning of the TCP-cross structure looking towards the jetty
- from the end of the TCP-cross structure looking towards the jetty
- the mangrove that grows in the middle of the beach (it is the only one), including the scarps at the vegetation line, an example is presented in Figure 77.

Finally, it is advised to perform yearly beach topography and nearshore bathymetry measurements in collaboration with ITM Tomohon. The required hand-made measuring equipment has been provided to ITM Tomohon. An explanation on how to perform these measurements is provided in

Appendix L. There will be human-errors in this data, nonetheless it will give insight into the coastal evolution.

Figure 77 Mangrove on Tasikoki beach and scarps in front of the vegetation line

Nature
To determine whether nature is indeed being enhanced, it is advised to also take close-up pictures from a fixed couple of TCP-cross structures. These pictures will reveal the growth of coral, oysters and limestone. Likewise, the amount of seagrass growth can be based on a picture of the area around a TCP-cross. The increase in biodiversity is not objectively measurable. However, it can subjectively be determined based on the fishers' observations and experiences.

Maintenance

It is essential to inspect and maintain the TCP-cross structure on a weekly basis and always after a storm. The following elements should be inspected:

- The TCP-cross structures will trap plastic, this should be removed. The plastic will cause friction when moving and loosen the limestone or even coral
- The cables and connections should be checked if they are still in place
- The amount of rust on the steel frame and gabion should be inspected. If all goes well, the steel that is always under water should be less rusty than the parts that are more exposed to the sun and air. Critical parts (that are about to rust through) should be registered and repaired
- Check the current that should be running through the steel frames of the TCP-cross structures and anodes
- Observe how stable the gabions are, they might tilt due to irregular subsidence or wave action

Appendix L

Measurement plan

Goal

Indonesia is suffering severe erosion all across the country, leading to high risks of flooding. Erosion is never caused by a single event; it is always a combination of events and circumstances which lead do changes in the coastal profile. In order to understand the coastal dynamics of a coastal zone, it is necessary to gain insights and collect as much data as possible. As the word already mentions, coastal dynamics are about the dynamics changing the coastal environment over years. Analysis regarding the development of a coastline is divided in multiple aspects, investigating different elements which encounter the full spectrum of the coastal dynamics. One of the main aspects, which directly shows the effects of certain developments, is the bathymetry of the beach and the sea in front of it.

In order to draw conclusions on the effects that happened to a coastline over a couple of years, it is key to map the area. In this booklet, the steps of creating a bathymetry map will be discussed. As all steps consist some hard and software to support the mapping process, some appendices are added to further elaborate on the process in more detail. By following these steps, it should be possible to create a bathymetry map of all beaches that need further investigation.

The process

Making a bathymetry map is an intensive process which requires sufficient preparation and a broad set of tools. In this paragraph, the whole process is explained. Starting by the initiation phase up to the creation of the bathymetry map. The process to collect the bathymetry data and make a full 3D map of it, consist of the following steps:

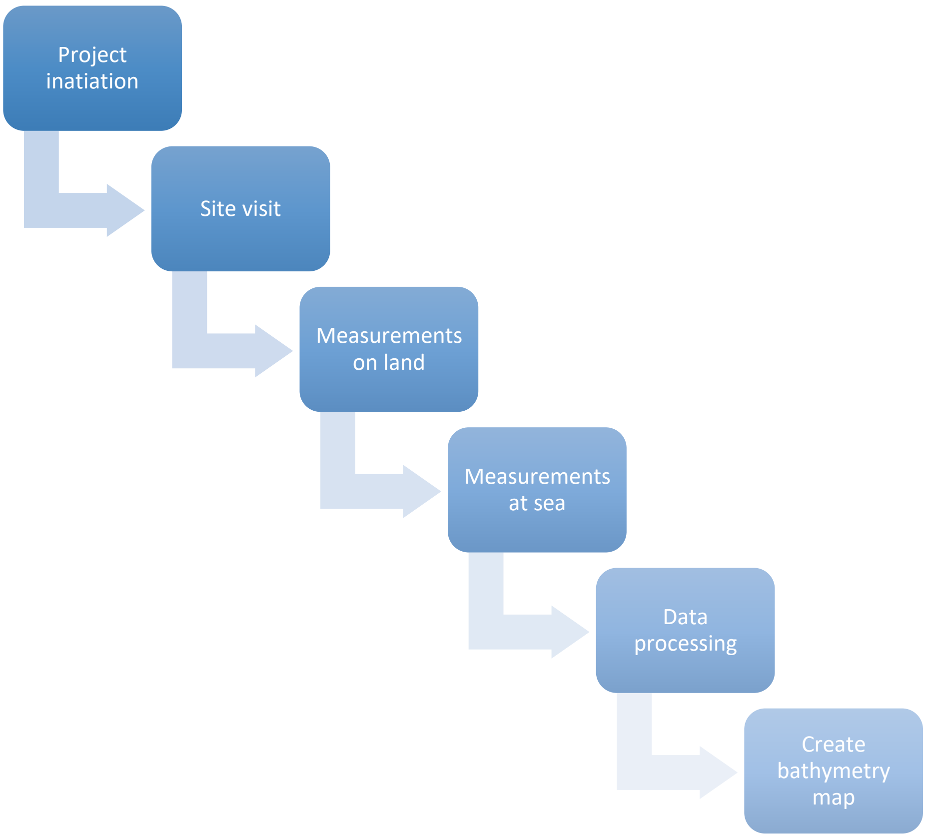


Figure 78 Process overview

Project initiation

- Select the research area
- Determine the size of the research area
- Investigate the area with satellite images from Google Earth
- Determine the accuracy of the bathymetry mapping
    - Given a research area that is 1000m wide, it is impossible to do the measurements every metre. Determine given the satellite images the distance between the measurement points. To create an accurate map, it is recommended to conduct measurements every 1/20th of the total size of the area.
- Analyse the tidal movements of the location on: https://www.tide-forecast.com to check when it is low tide.
- Build the beach measurement tool (See sub-appendix 1 and read the free article: A Simple Method of Measuring Beach Profiles by Francisco Andrade† and Maria Adelaide Ferreira (2006)

Site visit

- See project site during low tide to observe the bathymetry briefly
- Define the area by placing bamboo piles every X metre. Set a GPS point on ViewRanger at every starting point.

Measurements on land (See sub-appendix 1-4)

- Start using the beach measurement tool on all set measurement points
- Track all different height differences until reaching the water line.
- Note the time, current tidal height and number of last tracking point and set GPS points at every beginning and end point of a single track.

Measurements at sea

- Install the GPS monitor, GPS satellite receiver and transducer on the boat and connect the GPS monitor to a power source.
- Check the GPS monitor before sailing out, to make sure everything is installed properly. The depth should be shown and there should be sufficient GPS satellites in order to collect accurate data.
- Check the settings of for the data collection. You want the data to be as accurate as possible. Make sure data is tracked every 5 seconds and sail with an easy speed. This will make your final data output very detailed which will benefit your bathymetry mapping afterwards. Most fish finders track their route automatically when you turn on the device.
- Write down the height of the water level every 15 minutes by checking https://www.tide-forecast.com
- Sail the total area in a way that the full area will be saved. This should be done by sailing different patterns like parallel to the shoreline, perpendicular on the shoreline and a zig-zag pattern. As can be seen in Figure XX, we did all these three things at Tasikoki Beach to create as much detail as possible.
- After the full area has been sailed, make sure the track sailed that day is saved on the external SD card. By doing so, the data can be read out on a PC.

Data processing

After collection of all the data, it is time to process it in order to work towards the bathymetry map. A brief overview of the data processing is visualized in Figure 79. Both the land and sea measurements are coming together in an Excel file, where the data has to be fine-tuned in order to merge both measurement data. After the data is merged into one file, consisting both land and sea data, it is converted to Surfer, which can be used to make all different kind of maps. Having 2D and 3D maps of the bathymetry of a coastline can already tell a lot about the dynamics around a coastline. Thereby, these maps can be used as an input for the Unibest model, which analyses the sediment transport over a longer period. The Unibest modelling will however not be a part of the measurement plan, as this software is used to test certain solutions and only uses the bathymetry as an input.

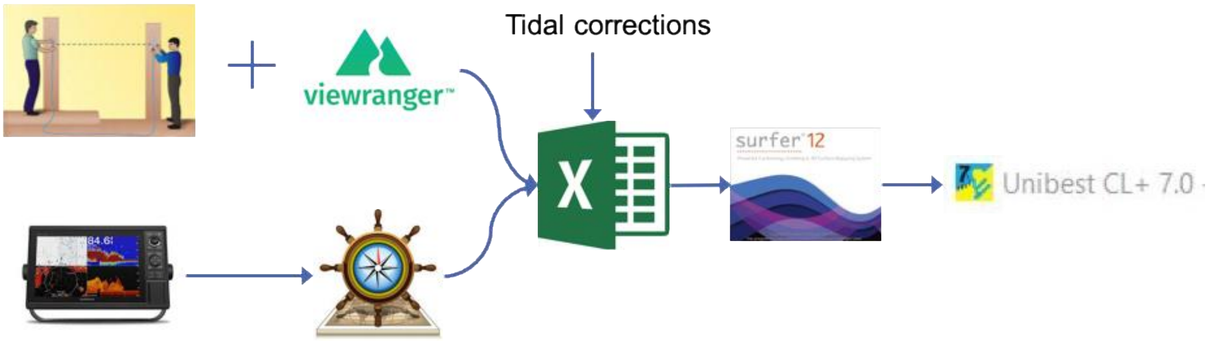


Figure 79 Overview of the data processing

Processing the data consist of the following steps:

- Filling in all hand measurements in an Excel file (as shown in sub-appendix 5)
- Correcting all the data given the tidal conditions at a certain time. This can be done by carrying out the following steps:
  1 - Sea measurements:
    - Check the time a measurement and the related height of the water level at that point.
    - Deduct the height of the water level at that time of the height measured.
    - Check the total tidal range of that day. Divide the total tidal range by two and add that value to the deducted measured value. Now you have the water depth at the mean sea level of that day.

  2 - Land measurements:
    - Check the noted time of the measurement and the water height at that point.
    - Sum all deltas measured between the tubes until reaching the water line and deduct the noted water level of that time of this summation value. Now you have the height of the starting reference point.
    - Starting from the reference point, add the delta from that point every time to get the height of each measurement point. Continue until the water line value is reached.
- All GPS locations from the ViewRanger app have to be opened in Google Earth and combined with the manually conducted measurement data in Excel (see sub-appendix 6).
- The data from the sea measurements are saved as a GPX file, consisting of many data points created every 5 seconds. This data first has to be opened in the Homeport | Garmin software, before it can be copied to Excel.
- In Homeport, an overview of the route and a table of all conducted data can be created. This table has to be copied to Excel, in order to merge it with hand measurements. Altogether, the main document encompasses all coordinates and depths of both the hand and fishfinder measurements, which is necessary for creating the bathymetry map.

Create bathymetry map

As both the manual and the Fishfinder data is now present in a single Excel file, this can be imported in Surfer to create a wide range of maps. The basic map to check the bathymetry of the whole coastline would be a 3D map. Besides a 3D map, an overlay of the Google Earth images can be made, initiating the water depths at the map which gives an improved insight in the situation at the analysed area.

The final result should look like Figure 80 and Figure 81:

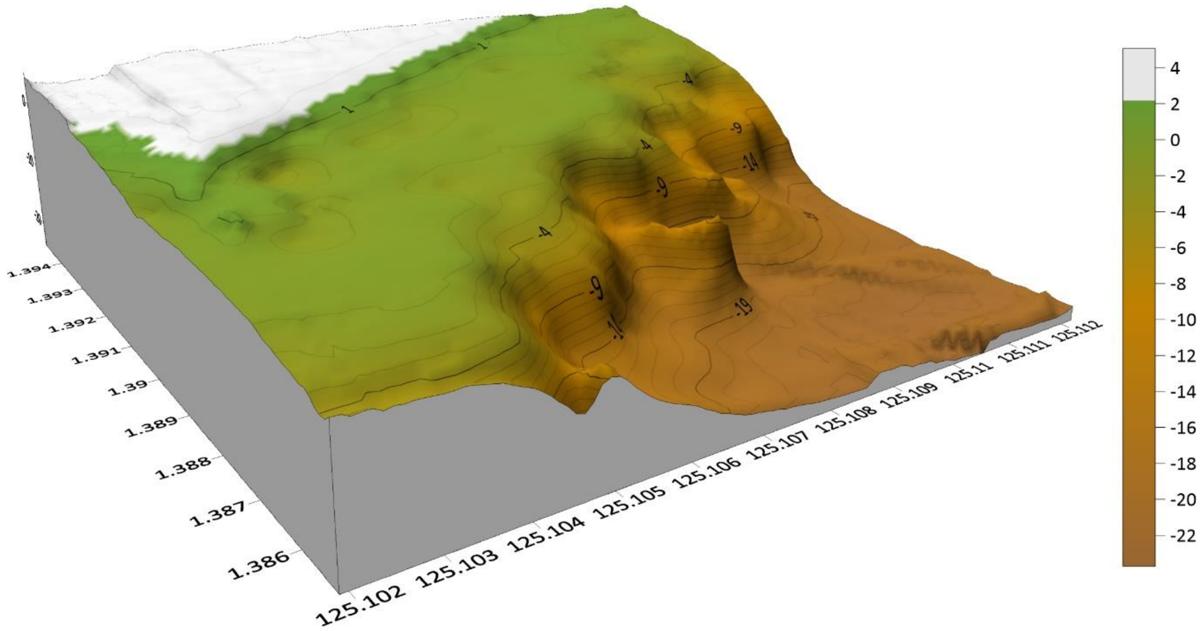


Figure 80 3D bathymetry map of Tasikoki Beach

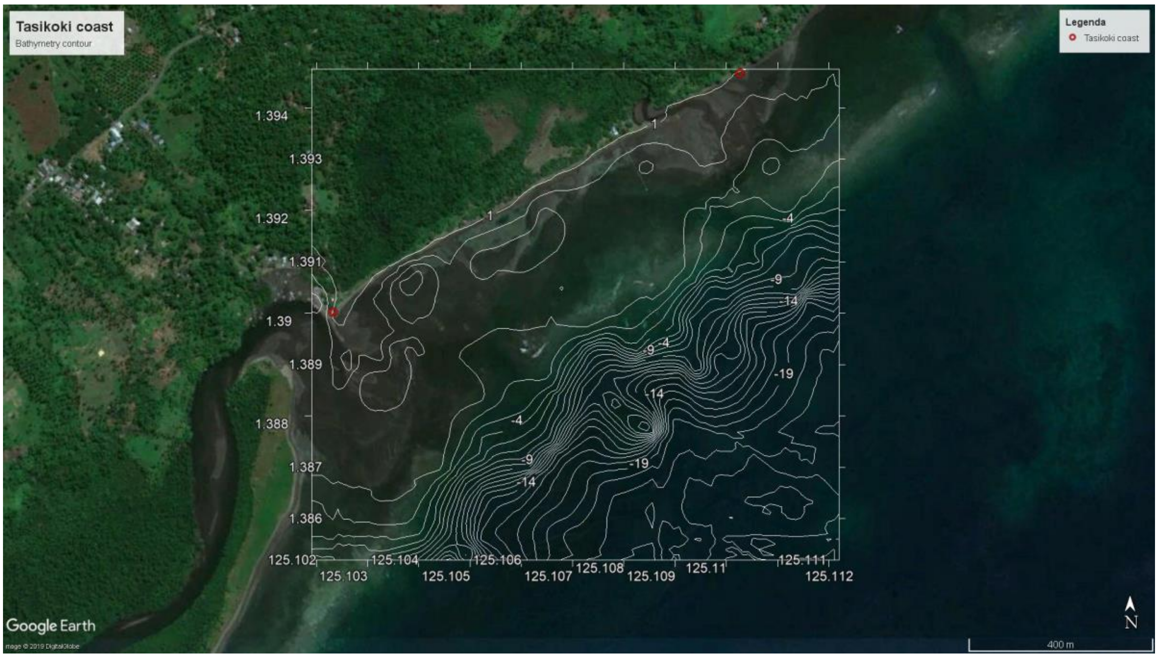


Figure 81 Depth contour overlay of Tasikoki Beach

Sub-appendix 1 - Equipment

Hardware:

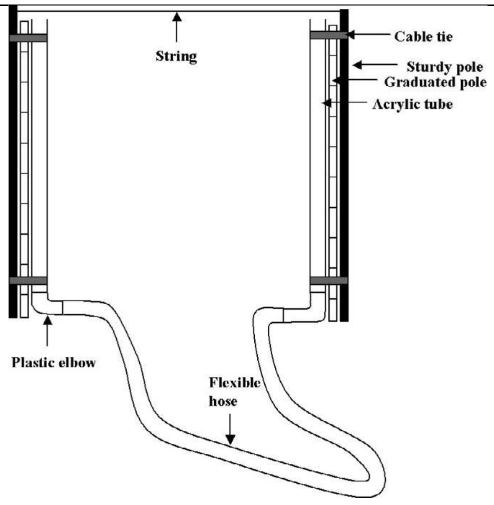
- GPS Fishfinder (or any other tool that measures depth and tracks the GPS location at the same time) including:
    - Monitor
    - Ability to save tracks to a MicroSD device
    - GPS satellite receiver
    - Transducer
- Beach measurement tool
- Location marks
- Notebook
- SD Card
- Measuring tape
- Boat
- Energy source
    - Remote battery if boat lacks power supply

Software:

- GPS Tool
    - Preferably ViewRanger on smart phone for data sharing
- Google Earth
- Surfer Pro
    - Or any other program that can draw xyz figures with GPS data
- HomePort | Garmin
    - Software of Garmin to visualize FishfFnder data
    - Every brand has its own software, depends on Fishfinder

In Table 16, a full overview of the equipment needed is provided including a picture, price and elements overview.

Table 16 Overview of the equipment

NAME	PURPOSE	PICTURE	ELEMENTS	PRICE
BEACH MEASUREMENT TOOL	Measuring the beach topography on areas that are never submerged		• 2x PVC Tube (3m) • 1x plastic transparent hose (11m) • 1x simple string (5m) • 2x plastic elbows (should fit the Ø of plastic hose) • 2x level (waterpas) • Tie wraps	600.000 IDR

LOCATION MARKS	Starting point for all beach measurements		• Bamboo • Coloured tape • Saw	50.000 IDR
NOTEBOOK	Writing down measurement results		• Pen • Notebook	50.000 IDR
MEASURING TAPE	Determine distances between location marks		• 1 x 100 m measuring tape	250.000 IDR
SMARTPHONE WITH THE VIEWRANGER APP (ANDROID & APPLE SUPPORTED)	Tracking GPS locations of the measurement locations	viewranger™	• ViewRanger App	Free

FISHFINDER	Measuring depth at the sea linked to GPS the locations	  	• Monitor • Transducer • GPS receiver	7.000.000 IDR
SD CARD	Saving the tracks sailed with the boat.		• 1x USB stick suitable for fishfinder GPS	200.000 IDR
ENERGY SOURCE (+ LOADING EQUIPMENT IF REMOTE)	Energy source to connect the monitor of the Fishfinder		• Remote battery • Charger • Cables	800.000 IDR

BOAT	Sailing the research area and collecting data		• Preferable a boat with minimal water depth to operate in shallow waters	200.000 IDR / day

Sub-appendix 2 – Overall land measurement process

1: Start by putting the levelling tool next to a starting point

2: Move the levelling tool in a straight line to the waterline

3: Make sure the water in the tube is not moving and is fully levelled out:

4: Note the height values of both tubes

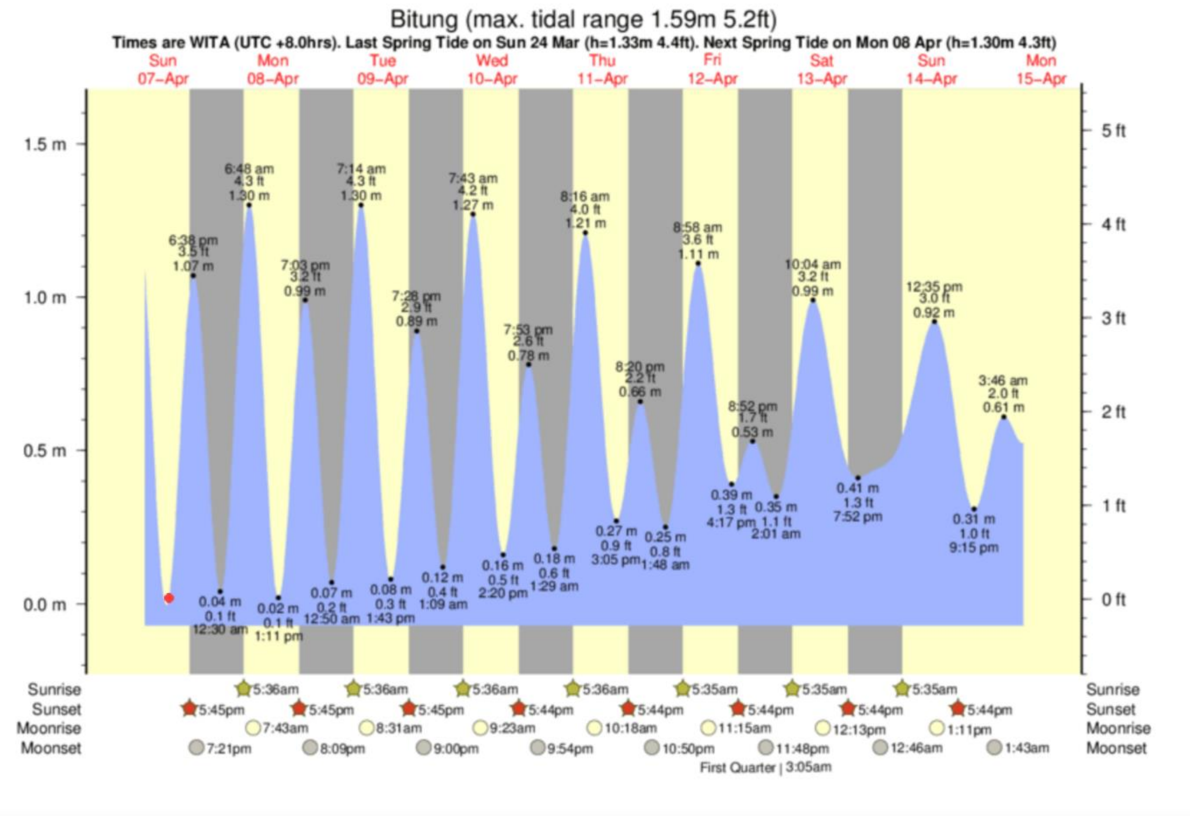
5: Move the tube along its own axis. Continue this process until reaching the water line.

6: Note the info & set GPS Location

- Last point before W(ater) L(evel) (number):
- water level in cm L(ast) P(oint) B(efore) WL:
- water level in cm WL:
- Delta
- Time of this measurement:
- Water level at ref point: (check https://www.tide-forecast.com)

Sub-appendix 3 – Select measurement times

Mapping the bathymetry will be done both manually, on the locations where the boat cannot sail, and on the deeper areas. In order to do the most accurate measurements, it is recommended to do this at the lowest possible tide as the largest area will then be dry. To get the information regarding the tides at a certain location, this can be found at: https://www.tide-forecast.com and then search for the specific location. This chart provides all the data for the tidal range for the upcoming week, including the time of the low and high tides. For the boat measurements, it is easiest to do this at high tide, as the chance of the boat getting stuck is the lowest.

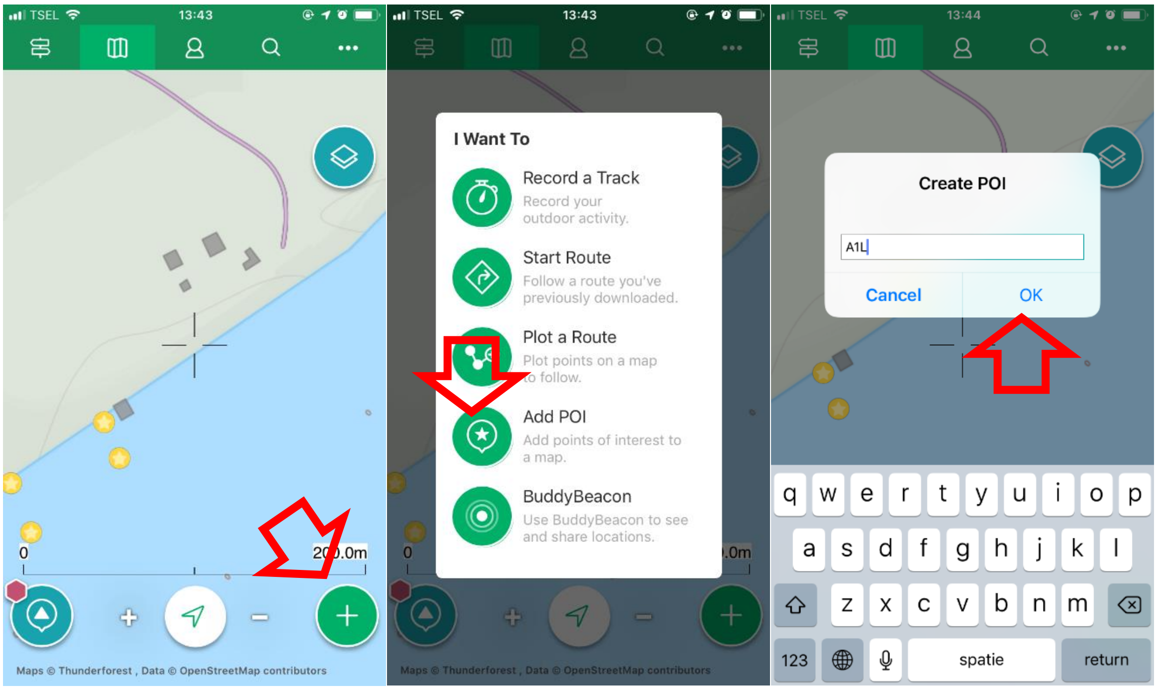


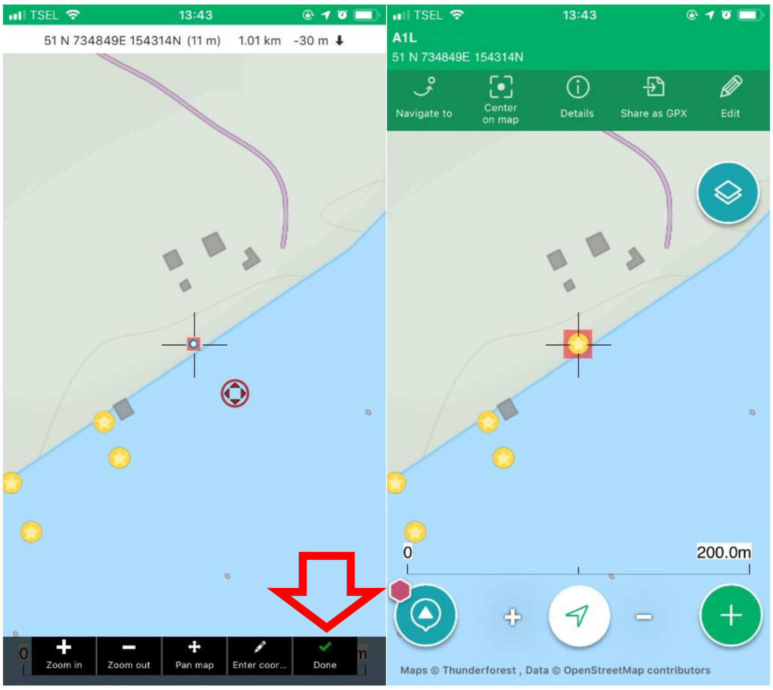
Sub-appendix 4– Set GPS Locations

In order to create a computer model afterwards, it is necessary to save all GPS points where the measurements have taken place. The easiest way to do this, is by using the ViewRanger App. In the following visualizations, it is shown step-by-step on how to save and export the data points.

On shore – beginning point:

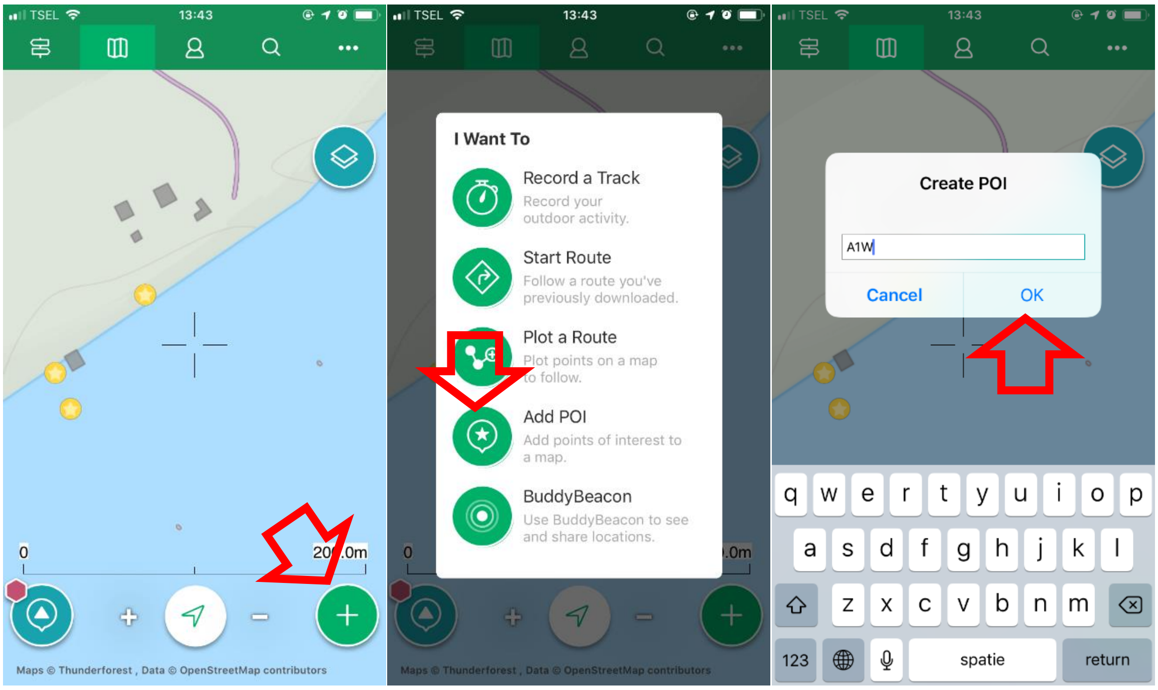
At the start of every manual measurement, it is key to set a GPS point. Afterwards, it can be seen as the starting point of a series of measurements, all carried out by hand. As the measurements start on land, all points are characterized by the letter L (land) at the end.

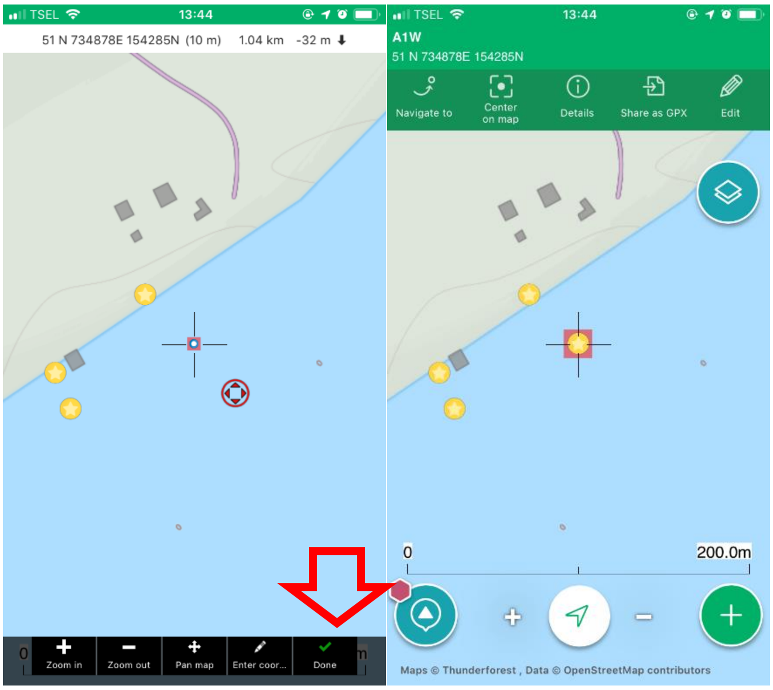




On the water line – end point:

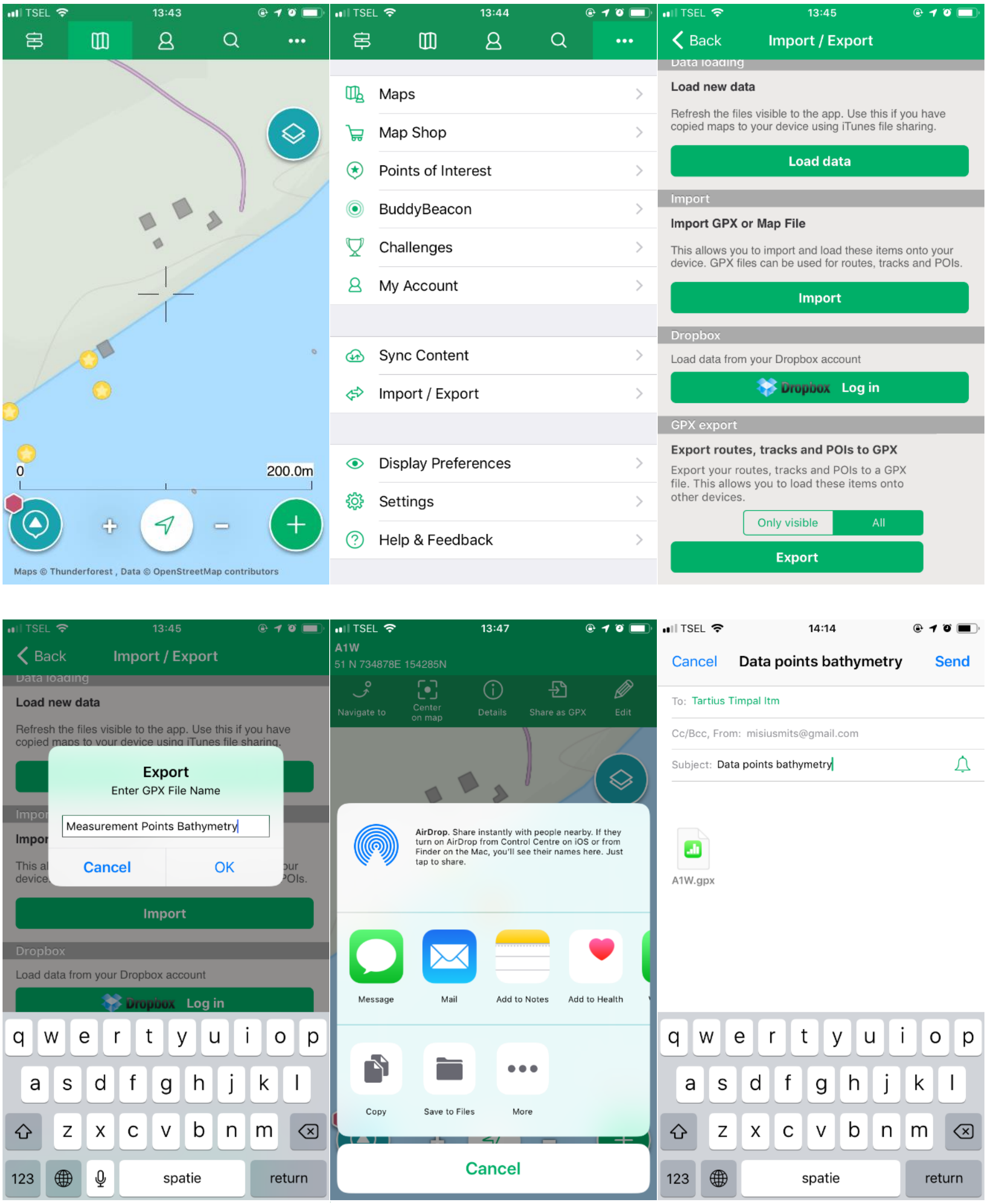
Once the waterline is reached, it is key to set a GPS point as well. By doing so, a clear line of the measurements can be drawn, which can be subdivided in part of 5 metre (which is the length of a single manual measurement. As all point are characterized by reaching of the waterline, they are given the letter W (water) at the end. Setting a data point on the water line can be done by following the steps below:





Export data

When all the GPS points are places, they can be exported as a GPX file to a computer with Google Earth running on it. The POI's can be exported by carrying out the following steps:



Sub-appendix 5– Filling in manual measurements

! Make sure you print all the forms which should track down all of the manual measurements before starting!

Keeping track of all manual measurements has to be done in the following way:

- Write down coordinates of starting point and save it in the Viewranger app as a A(X)L point.
- Write down the time of the first measurement
- Write down the heights of the water in both tubes (delta will be calculated afterwards by the computer)
- Move the beach measurement tool after each measurement around the axis of the pole which is the closest to the waterline. By doing so, no space remains unmeasured. Figure 82 shows an example of how the process should be carried out.

Figure 82 Manual measurement movement process

- Write down the heights of the water in the beach measurement tool after every time the pole has moves.
- Continue this process until the waterline is reached.
- Write the values in the main table + fill in the bottom table showing the values:
    - Last point before W(ater) L(evel) (number):
    - water level in cm L(ast) P(oint) B(efore) WL:
    - water level in cm WL:
    - Delta
    - Time of this measurement:
    - Water level at ref point: (check https://www.tide-forecast.com) on mobile device.
- Set a GPS point in Viewranger on the waterline, naming it the A(X)W point.
- Move to the next starting point.

Table 17 Example of a filled in hand measurement form

Base-line A				
	A1	A2	A3	A4
Latitute (N)	1°23'23.80"N	1°23'24.35"N	1°23'25.62"N	1°23'26.74"N
Longitute (O)	125° 6'8.57"E	125° 6'8.95"E	125° 6'10.00"E	125° 6'11.20"E
Time (hh:mm)	09:45	10:05	10:35	11:00
1	85,3	69,1	54,3	93,7
2	71,6	15,5	45,4	26,6
delta	-13,7	-53,6	-8,9	-67,1
2	83,8	33,3	75,8	83,6
3	72,5	51,5	24,3	36,3
delta	-11,3	18,2	-51,5	-47,3
3	78,7	46,9	75,7	80
4	78	37,6	24	39,8
delta	-0,7	-9,3	-51,7	-40,2
4	85,2	58	71,3	63,8
5	71,2	27	27	55,7
delta	-14	-31	-44,3	-8,1
………	……….	…………	……….	…………
29		43,7		
30		41,8		
delta	0	-1,9	0	0
30				
Last point before WL (number):	17	29	25	5
water level in cm LPB WL:	79,9	43,7	61,2	62
water level in cm WL:	76,6	41,8	58,6	57,7
Delta	-3,3	-1,9	-2,6	-4,3
Time of this measurment:	10:03	10:22	10:58	11:15
Water level at ref point:	0,36	0,16	0,08	0,05

Sub-appendix 6 – Convert GPS coordinates to input data

In order to link the GPS locations to the height differences measured on the land, the GPS locations first have to be opened and adjusted in Google Earth. This has to be done in the following steps:

- Send the GPX files from the ViewRanger app to your e-mail.
- Open the GPX files in Google Earth, this will result in the following image:

Figure 83 Google Earth view when data points are loaded

This picture shows the locations of the starting points and the water line of each individual manual measurement, as saved with the GPS ViewRanger app.

- Draw a path in Google Earth from, for example, the land GPS point (B2) to the water GPS point (B2W) and set a Placemark for every hand measurement that is made (every 5 metres, as this is the size of a single measurement).

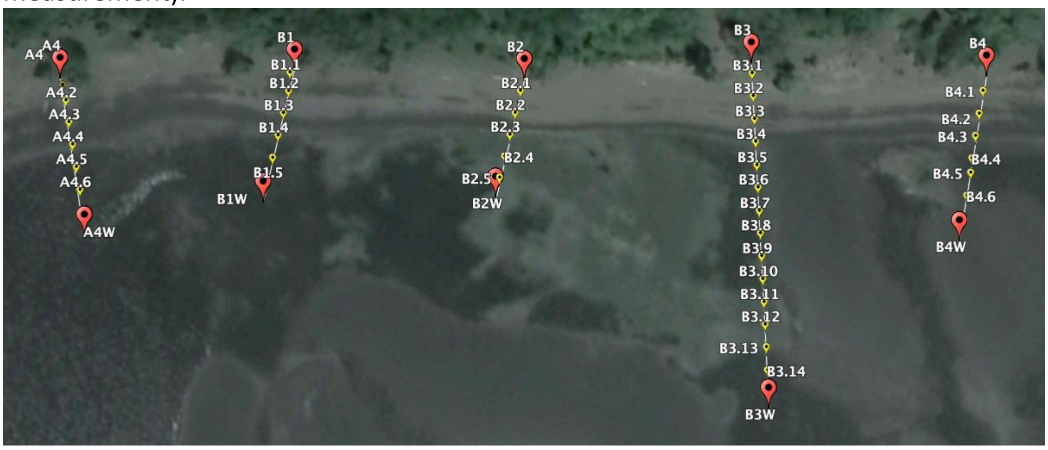


Figure 84 Paths and placemarks located on the hand measured area

This will provide each measurement point with coordinates, which otherwise had to be done every 5 metres by hand on the beach. The chance of making mistakes while using this method is relatively small and works much faster.

- Export all set measurement points out of Google Earth by File > Save > Save my places > Save as KML file.

- Convert the KML file to an Excel file by using GPS Visualizer (http://www.gpsvisualizer.com). Convert the KML file to a plain text file.

- Open the plain text file and copy the data in Excel. Make sure all measurement points and the coordinates are in separate columns and order it in a chronological way. Copy the related depths of all measurement points into this Excel. Now you should have on Excel file consisting of all measured points, its coordinates and their depth.

An example of our own measurements can be found in table XX, showing all needed data for a complete overview to create a bathymetry map.

Table 18 Example of the data from the Tasikoki measurements

time	latitude	longitude	name	height (cm)
21/02/2019 01:46	1.389.945.000	125.102.381.000	A1	165,1
	1.389.913.798	125.102.414.224	A1.1	151,4
	1.389.883.499	125.102.447.131	A1.2	140,1
	1.389.852.496	125.102.479.819	A1.3	139,4
	1.389.823.390	125.102.510.695	A1.4	125,4
	1.389.791.289	125.102.544.667	A1.5	102,9
	1.389.760.886	125.102.576.790	A1.6	85,7
	1.389.732.154	125.102.608.079	A1.7	63,8
	1.389.698.565	125.102.643.181	A1.8	54,7
	1.389.667.686	125.102.675.926	A1.9	42,9
	1.389.636.697	125.102.709.055	A1.10	37,1
	1.389.606.606	125.102.740.870	A1.11	36
	1.389.576.026	125.102.773.534	A1.12	43,7
	1.389.544.975	125.102.806.529	A1.13	60,1
	1.389.514.432	125.102.839.229	A1.14	60,1
	1.389.484.123	125.102.871.491	A1.15	51,4
	1.389.452.657	125.102.905.111	A1.16	39,3
21/02/2019 02:02	1.389.431.000	125.102.928.000	A1W	36

Appendix M

Engagement plan

Involving the stakeholders by sharing the expectations throughout the lifecycle of the project is key for mutual understanding of interest. In order to smoothen this process and make the interaction between stakeholders and the project future proof, an engagement plan will be formulated. An overview of the stakeholder interests as shown in chapter 2, shows that mostly local residents and fishermen will be influenced by the implementation of the TCP-cross structures as Tasikoki beach. It is therefore wise to set up a strategy in order to keep the attitude of local stakeholder's positive towards the project.
Engagement of the local stakeholders consist of four phases:

5. Analysing the impact of the project on stakeholder's interest
6. Creating a strategy to engage the stakeholders towards the project
7. Communicate the project plan to the stakeholders
8. Monitor, maintain and revise (if necessary) the engagement strategy

Per phase an explanation for the Tasikoki Project Staff will be provided in order to engage the local community in such a way that the chance of social conflicts will be limited.

Phase 1 – Check interference of interest between stakeholders and project
Main element of conflict between the project and the interest of the local community will be the interference with the fishing zones used daily by the locals and the locals who use the beach as a recreational zone. As the location is not in line with the route of the fishing boats, it will be most likely that the TCP-cross system will only interfere with the fishermen who operate individually and search for shellfish and other species which are catchable during low tide. Possible risk caused by the locals is overharvesting of the attached shellfish and other species around the structures, as this is key for the development of the hydrosphere around the structures.

Phase 2 & 3 – Create a strategy and communicate it to engage stakeholders towards the project
In order to prevent misunderstandings from local community regarding the project, it is key to inform them about it. Program manager Alfonso Sianturi together with someone from Tasikoki which is well known by the local people should visit the locals and explain the following:

- Creating awareness for the current problem
    - Explain which process is currently harming the coastline
        - Concept of SLR
        - The effect of SLR on the coastline
    - Explain in an easy way that will happen if nothing is done
        - Flooding of the hinterland
        - Disappearing of the beach

- Explaining the advantages of the project
    - Explain the effects of the TCP-Cross
        - Protection of the hinterland
    - Explain the positive side effects of the TCP-Cross
        - Increase of biodiversity
        - Growing back the beach

- Showing the impressions of the project
    - Explain the process of electrolysis which will make the structures grow

- Use of artist impressions showing the form and size of the TCP-cross
- Show the location where the TCP-Crosses are going to be placed
- Explain that the structures need to be left alone and no one can touch them, as this harms the growth process.

By explaining the cause, consequences of the project and showing the locals what it actually will look like, respect and understanding for the project will hopefully be raised. By letting the people know what to expect and showing the upsides for the community, their personal interest and the area.
As it will be hard to reach everyone involved, it is recommended to make an information panel consisting all above-mentioned aspects. By placing the information panel on the beach in front of the TCP-cross system, visitors can read all important information as the unknown structures will raise probably some questions. During the weekends, when most of the recreants are present at the beach, it would be useful to have someone from Tasikoki around to explain the interested people about the project. Verbal explanation is often much easier for local people and provides an opportunity for them to ask questions about the project. In this way, everyone will know the purpose of the project, the way it must be threated and what the effects are on their personal interests.

Phase 4 - Monitor, maintain and revise (if necessary) the engagement strategy
As the relation between the TWREC and the local community has been very good over the past decades, it is not expected that the project will lead to a huge conflict. However, compliance of the explained rules and acceptance of the project by the local community is not guaranteed after carrying out phase one to three. Locals may not like the looks of the system, still have problems with the presence in “their” water near “their” beach, do not understand the added value of such a system or any other which causes their resistance against the project. In order to be updated about the presence such conflicting interest, it is key to monitor this. By staying in contact with the local community, any dissatisfaction towards the project can be taken care of in an early stage. By giving the people a voice and by asking for their opinion regarding the project, hopefully a positive attitude will maintain. If not, it is key to convince the local people about the necessity of the project in order to protect the hinterland and maintain the shoreline. An open attitude and showing willingness to discuss with locals should temper the negative attitude and hopefully even switch it to a positive attitude.

Appendix N

Material and price calculations for each structure and total projects costs

Table 19 Material calculations for each structure

TCP-Basic

Gabion		
Height	1	m
Width	2	m
Depth	1	m

Mesh	1x
Length	5.4 m
Width	2.1 m

Frame for mesh		Total number	Total m per part	Totaal per BioRock	Margin
Bottom length	5 m	2	10		
Bodem width	2.1 m	2	4.2 m	20 m	22
Verticals	1.5 m	4	6 m		
			0 m		
			0 m		

TCP-Cross

Gabion		
Height	1	m
Width	2	m
Depth	1	m

Mesh	2x
Length	5.4 m
Width	2.1 m

Frame for mesh		Total number	Total m per part	Totaal per BioRock	Margin
Bottom length	5 m	2	10 m	51 m	56.1
Bodem width	2.1 m	2	4.2 m		
Verticals	1.5 m	2	3 m		
Bottom length extra frame	5.5 m	2	11 m		
Bottom width extra frame	2.1 m	6	12.6 m		
Stabilization gabion	1 m	4	4 m		
Verticals	1.5 m	4	6 m		
			0 m		
			0 m		
			0 m		

TCP-Circle

Gabion	
Heigth	1 m
Width	1 m
Depth	1 m

Mesh	4x straight panel	4x tilted panel	Can be made from 1 standard panel
Length	2 m	2	
Width	1.1 m	2	
		2.1	

Frame for mesh		Total number	Total m per part	Totaal per BioRock	Margin
Bottom length	4 m	4	16	61	67.1
Bottom tilted	2.1 m	4	8.4		
Bottom width	1.1 m	4	4.4		
Top width	1.1 m	4	4.4		
Tilted part (connect top with bottom)	2 m	8	16		
Verticals gabion	1 m	4	4		
Verticals stabilization	1 m	8	8		

Table 20 Price calculation per structure

TCP-Basic

Material	Specification	Number	Price per unit [IDR]	Total price [IDR]	Biorock per cluster	Total Biorock [IDR]	Total Biorock [EUR]	Total cluster [IDR]	Total cluster [EUR]	Total Biorock + cluster [IDR]	Total Biorock + cluster [EUR]
Gabion	2 x 1 x 1 m	1	780,000	780,000	4	2,930,000	183	21,690,500	1,356	5,422,625	339
Volcanic rock	m^3	2	100,000	200,000							
Construction rebar mesh	m8 2,1 x 5,4 m	1	750,000	750,000							
Rebar	10 IBD SNI	20	60,000	1,200,000							

TCP-Cross

Material	Specification	Number	Price per unit [IDR]	Total price [IDR]	Biorock per cluster	Total Biorock [IDR]	Total Biorock [EUR]	Total cluster [IDR]	Total cluster [EUR]	Total Biorock + cluster [IDR]	Total Biorock + cluster [EUR]
Gabion	2 x 1 x 1 m	1	780,000	780,000		5,540,000	346	32,130,500	2,008	8,032,625	502
Volcanic rock	m^3	2	100,000	200,000							
Construction rebar mesh	m8 2,1 x 5,4 m	2	750,000	1,500,000							
Rebar	10 IBD SNI	51	60,000	3,060,000							

TCP-Circle

Material	Specification	Number	Price per unit [IDR]	Total price [IDR]	Biorock per cluster	Total Biorock [IDR]	Total Biorock [EUR]	Total cluster [IDR]	Total cluster [EUR]	Total Biorock + cluster [IDR]	Total Biorock + cluster [EUR]
Gabion	1 x 1 x 1 m	1	400,000	400,000		5,660,000	354	32,610,500	2,038	8,152,625	510
Volcanic rock	m^3	1	100,000	100,000							
Construction rebar mesh	m8 2,1 x 5,4 m	2	750,000	1,500,000							
Rebar	10 IBD SNI	61	60,000	3,660,000							

Cluster

Material	Specification	Number	Price per unit [IDR]	Total price [IDR]	Total cluster [IDR]	Total cluster [EUR]
Titanium mesh (Anode)	1 roll 1 x 10 m	0.2	12,000,000	2,400,000	9,970,500	623
Power cable	roll 100 m	5	1,365,000	6,825,000		
PVC pipe	4 meter pipe 15"	0.25	400,000	100,000		
DC power source		0.5	1,291,000	645,500		

Table 21 Total project cost calculation

TCP Basic

Number of Clusters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Configuration 1	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Costs	21690500	43381000	65071500	86762000	108452500	130143000	151833500	173524000	195214500	216905000	238595500	260286000	281976500	303667000	325357500	347048000	368738500	390429000	412119500	433810000	455500500	477191000
Configuration 2	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49	52	55	58	61	64	67
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Costs	21690500	39086000	56481500	73877000	91272500	108668000	126063500	143459000	160854500	178250000	195645500	213041000	230436500	247832000	265227500	282623000	300018500	317414000	334809500	352205000	369600500	386996000
Configuration 3	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Costs	17395500	30496000	43596500	56697000	69797500	82898000	95998500	109099000	122199500	135300000	148400500	161501000	174601500	187702000	200802500	213903000	227003500	240104000	253204500	266305000	279405500	292506000

TCP Cross

Number of Clusters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Configuration 1	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Costs	32130500	64261000	96391500	128522000	160652500	192783000	224913500	257044000	289174500	321305000	353435500	385566000	417696500	449827000	481957500	514088000	546218500	578349000	610479500	642610000	674740500	706871000
Configuration 2	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49	52	55	58	61	64	67
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Costs	32130500	57356000	82581500	107807000	133032500	158258000	183483500	208709000	233934500	259160000	284385500	309611000	334836500	360062000	385287500	410513000	435738500	460964000	486189500	511415000	536640500	561866000
Config 3	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Costs	25225500	43546000	61866500	80187000	98507500	116828000	135148500	153469000	171789500	190110000	208430500	226751000	245071500	263392000	281712500	300033000	318353500	336674000	354994500	373315000	391635500	409956000

TCP Circle

Number of Clusters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Configuration 1	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Cost	32610500	65221000	97831500	130442000	163052500	195663000	228273500	260884000	293494500	326105000	358715500	391326000	423936500	456547000	489157500	521768000	554378500	586989000	619599500	652210000	684820500	717431000
Configuration 2	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	49	52	55	58	61	64	67
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Cost	32610500	58196000	83781500	109367000	134952500	160538000	186123500	211709000	237294500	262880000	288465500	314051000	339636500	365222000	390807500	416393000	441978500	467564000	493149500	518735000	544320500	569906000
Config 3	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Costs	25585500	44146000	62706500	81267000	99827500	118388000	136948500	155509000	174069500	192630000	211190500	229751000	248311500	266872000	285432500	303993000	322553500	341114000	359674500	378235000	396795500	415356000
Config 4	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46
Anodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Costs	32610500	51171000	69731500	88292000	106852500	125413000	143973500	162534000	181094500	199655000	218215500	236776000	255336500	273897000	292457500	311018000	329578500	348139000	366699500	385260000	403820500	422381000

Table 22 Structure length calculations (based on project cost)

Length of total TCP-struture in meter

Biorock Basic

Number of Clusters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Configuration 1																						
Spacing 4 m	8.2	18.4	28.6	38.8	49	59.2	69.4	79.6	89.8	100	110.2	120.4	130.6	140.8	151	161.2	171.4	181.6	191.8	202	212.2	222.4
Spacing 5 m	9.2	20.4	31.6	42.8	54	65.2	76.4	87.6	98.8	110	121.2	132.4	143.6	154.8	166	177.2	188.4	199.6	210.8	222	233.2	244.4
Spacing 6 m	10.2	22.4	34.6	46.8	59	71.2	83.4	95.6	107.8	120	132.2	144.4	156.6	168.8	181	193.2	205.4	217.6	229.8	242	254.2	266.4
Configuration 2																						
Spacing 4 m	8.2	14.3	20.4	26.5	32.6	38.7	44.8	50.9	57	63.1	69.2	75.3	81.4	87.5	93.6	99.7	105.8	111.9	118	124.1	130.2	136.3
Spacing 5 m	9.2	16.3	23.4	30.5	37.6	44.7	51.8	58.9	66	73.1	80.2	87.3	94.4	101.5	108.6	115.7	122.8	129.9	137	144.1	151.2	158.3
Spacing 6 m	10.2	18.3	26.4	34.5	42.6	50.7	58.8	66.9	75	83.1	91.2	99.3	107.4	115.5	123.6	131.7	139.8	147.9	156	164.1	172.2	180.3
Configuration 3																						
Spacing 4 m	8.2	14.3	20.4	26.5	32.6	38.7	44.8	50.9	57	63.1	69.2	75.3	81.4	87.5	93.6	99.7	105.8	111.9	118	124.1	130.2	136.3
Spacing 5 m	9.2	16.3	23.4	30.5	37.6	44.7	51.8	58.9	66	73.1	80.2	87.3	94.4	101.5	108.6	115.7	122.8	129.9	137	144.1	151.2	158.3
Spacing 6 m	10.2	18.3	26.4	34.5	42.6	50.7	58.8	66.9	75	83.1	91.2	99.3	107.4	115.5	123.6	131.7	139.8	147.9	156	164.1	172.2	180.3

Biorock Cross

Number of Clusters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Configuration 2																						
Spacing 1 m	12	18.5	25	31.5	38	44.5	51	57.5	64	70.5	77	83.5	90	96.5	103	109.5	116	122.5	129	135.5	142	148.5
Spacing 2 m	13	20.5	28	35.5	43	50.5	58	65.5	73	80.5	88	95.5	103	110.5	118	125.5	133	140.5	148	155.5	163	170.5
Spacing 3 m	14	22.5	31	39.5	48	56.5	65	73.5	82	90.5	99	107.5	116	124.5	133	141.5	150	158.5	167	175.5	184	192.5
Configuration 3																						
Spacing 1 m	12.2	18.9	25.6	32.3	39	45.7	52.4	59.1	65.8	72.5	79.2	85.9	92.6	99.3	106	112.7	119.4	126.1	132.8	139.5	146.2	152.9
Spacing 2 m	13	20.5	28	35.5	43	50.5	58	65.5	73	80.5	88	95.5	103	110.5	118	125.5	133	140.5	148	155.5	163	170.5
Spacing 3 m	14	22.5	31	39.5	48	56.5	65	73.5	82	90.5	99	107.5	116	124.5	133	141.5	150	158.5	167	175.5	184	192.5

Biorock Circle

Number of Clusters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Configuration 2																						
Spacing 1.2 m	9.2	14.4	19.6	24.8	30	35.2	40.4	45.6	50.8	56	61.2	66.4	71.6	76.8	82	87.2	92.4	97.6	102.8	108	113.2	118.4
Spacing 2 m	10	16	22	28	34	40	46	52	58	64	70	76	82	88	94	100	106	112	118	124	130	136
Spacing 3 m	11	18	25	32	39	46	53	60	67	74	81	88	95	102	109	116	123	130	137	144	151	158
Configuration 3																						
Spacing 1.2 m	9.2	14.4	19.6	24.8	30	35.2	40.4	45.6	50.8	56	61.2	66.4	71.6	76.8	82	87.2	92.4	97.6	102.8	108	113.2	118.4
Spacing 2 m	10	16	22	28	34	40	46	52	58	64	70	76	82	88	94	100	106	112	118	124	130	136
Spacing 3 m	11	18	25	32	39	46	53	60	67	74	81	88	95	102	109	116	123	130	137	144	151	158
Configuration 2 - 45˚																						
Spacing 1.2 m	8.4	13.2	18	22.8	27.6	32.4	37.2	42	46.8	51.6	56.4	61.2	66	70.8	75.6	80.4	85.2	90	94.8	99.6	104.4	109.2
Spacing 2 m	9.2	14.8	20.4	26	31.6	37.2	42.8	48.4	54	59.6	65.2	70.8	76.4	82	87.6	93.2	98.8	104.4	110	115.6	121.2	126.8
Spacing 3 m	10.2	16.8	23.4	30	36.6	43.2	49.8	56.4	63	69.6	76.2	82.8	89.4	96	102.6	109.2	115.8	122.4	129	135.6	142.2	148.8
Configuration 3 - 45˚																						
Spacing 1.2 m	8.4	13.2	18.4	23.6	28.8	34	39.2	44.4	49.6	54.8	60	65.2	70.4	75.6	80.8	86	91.2	96.4	101.6	106.8	112	117.2
Spacing 2 m	9.2	14.8	20.8	26.8	32.8	38.8	44.8	50.8	56.8	62.8	68.8	74.8	80.8	86.8	92.8	98.8	104.8	110.8	116.8	122.8	128.8	134.8
Spacing 3 m	10.2	16.8	23.8	30.8	37.8	44.8	51.8	58.8	65.8	72.8	79.8	86.8	93.8	100.8	107.8	114.8	121.8	128.8	135.8	142.8	149.8	156.8

Appendix O

Construction guide for the implementation

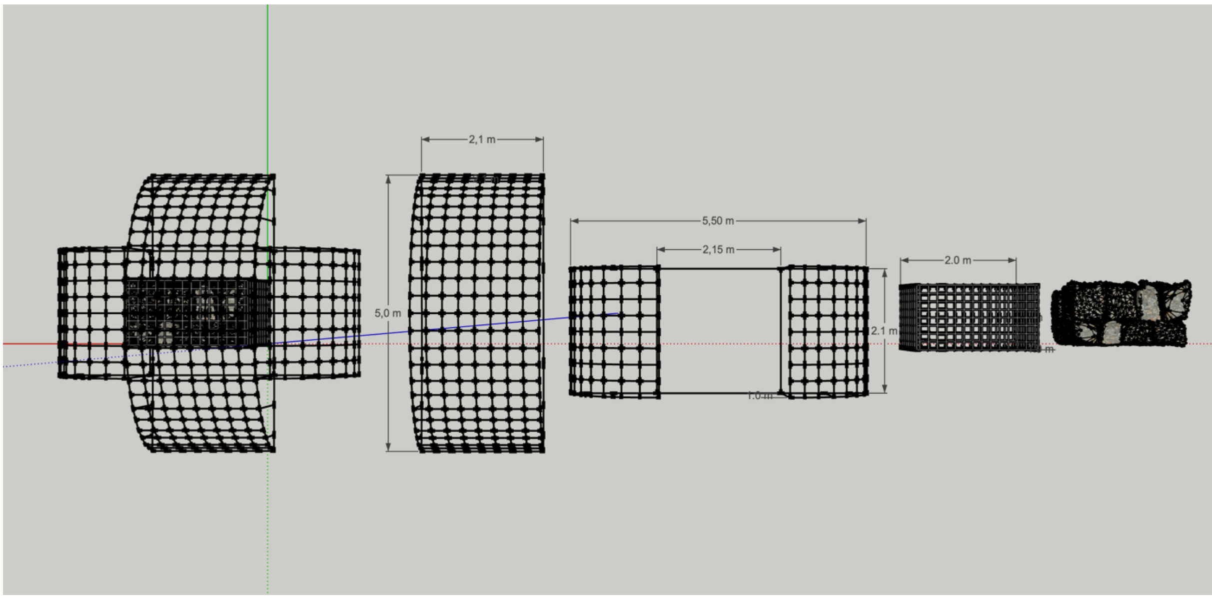
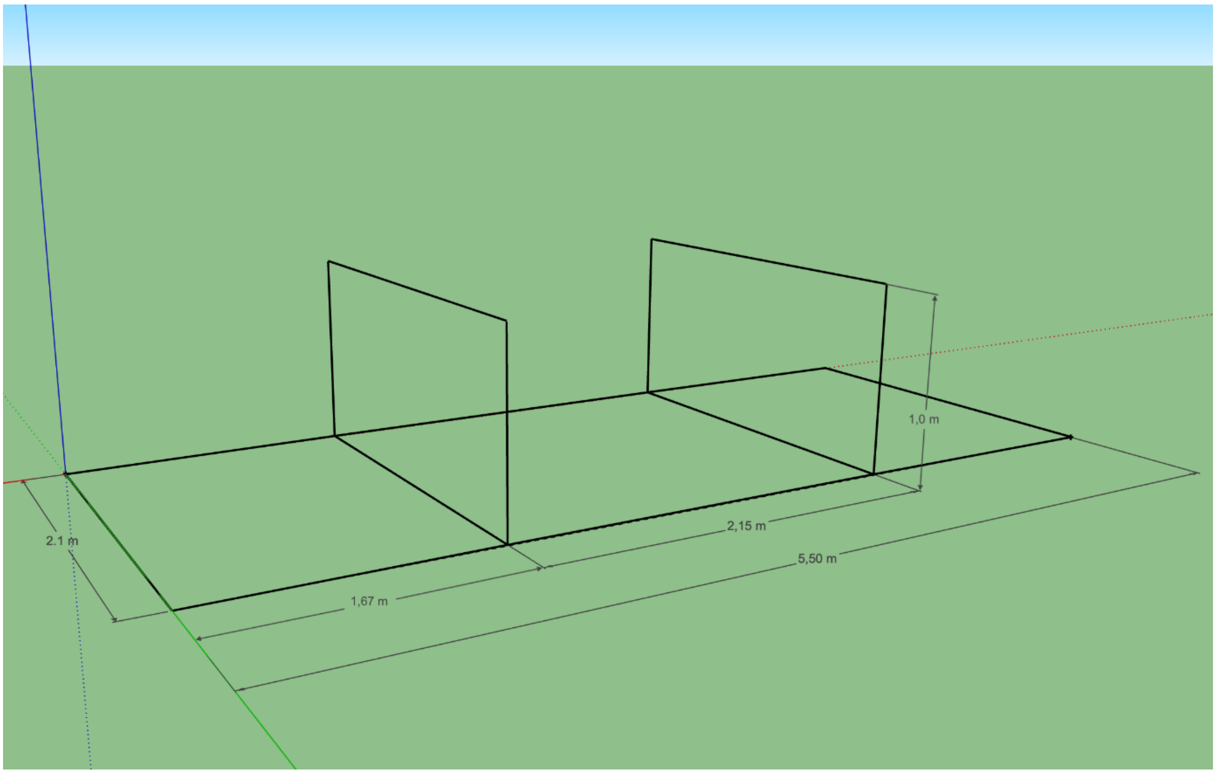


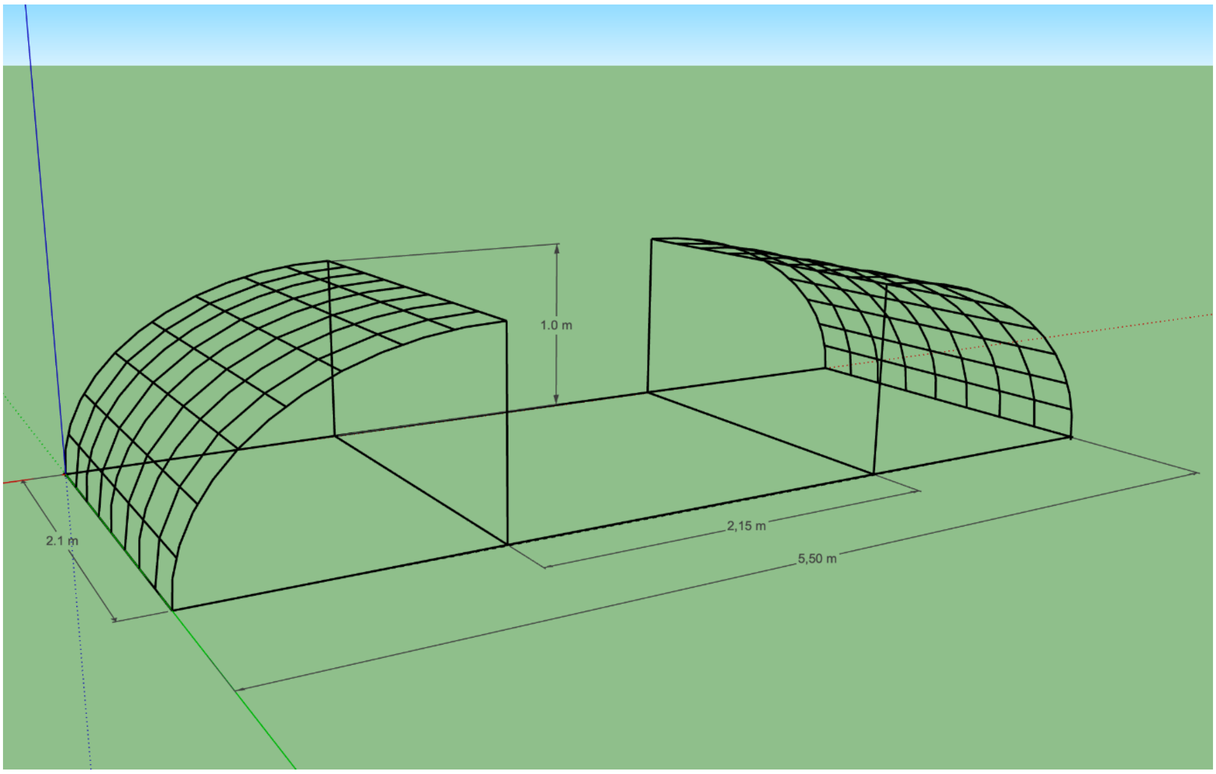
Figure 85 TCP-structure assembly line, from right-to-left: Rocks, gabion, frame A, frame B, TCP-structure

TCP-structure frame A

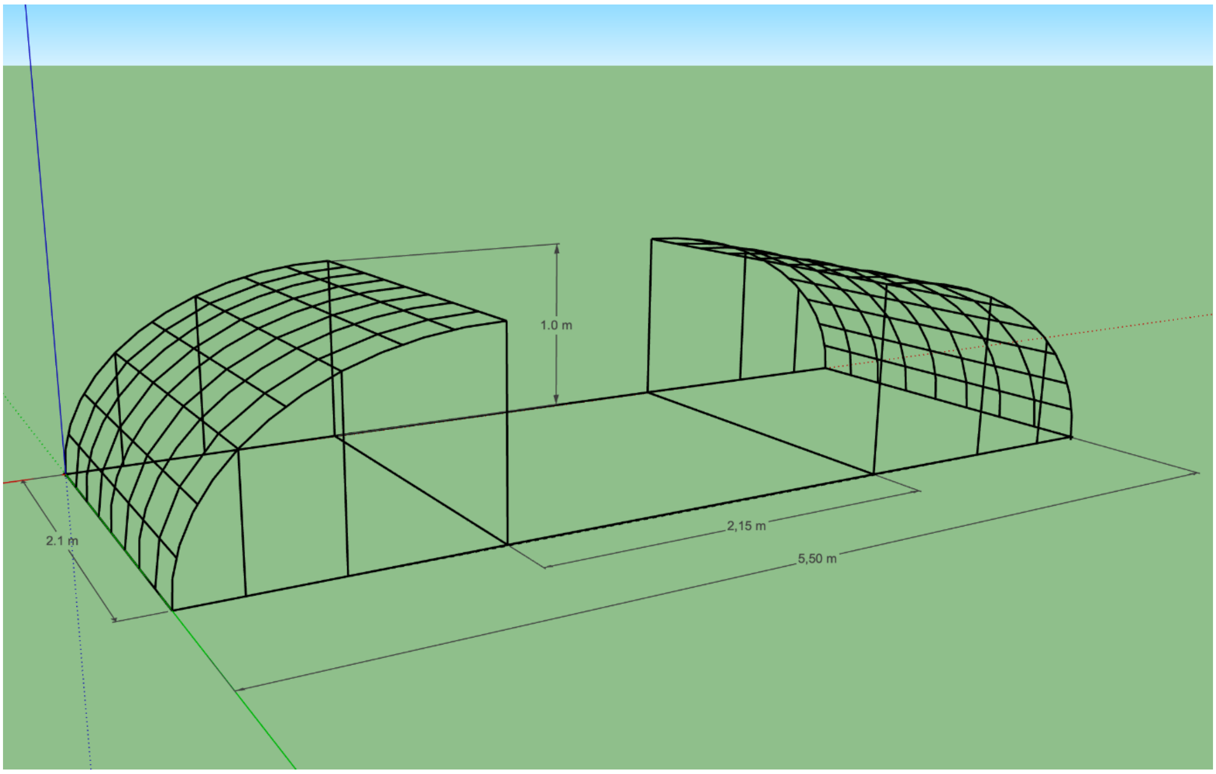
Step 1: Weld base frame 2,1 x 5,5 m and add vertical frames 1 m high



Step 2: Take construction mesh split in two, bend into curve and weld to base frame

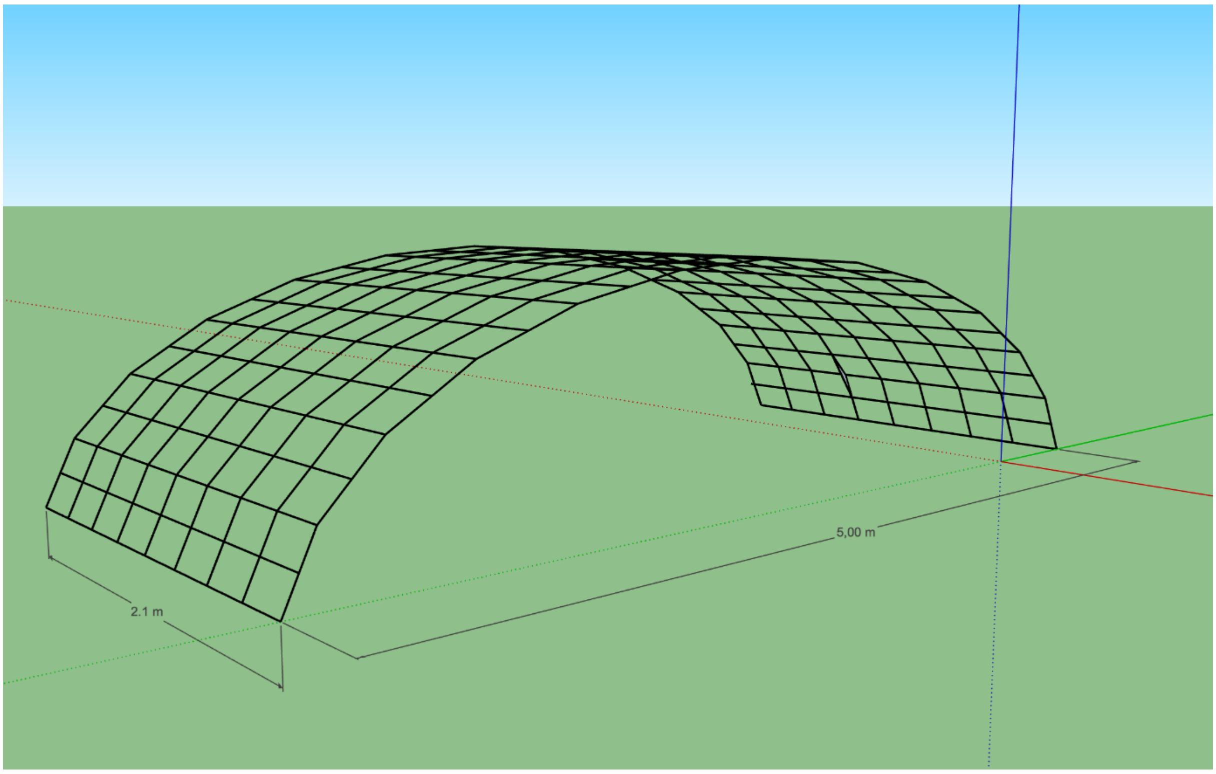


Step 3: Add vertical support studs four on each side

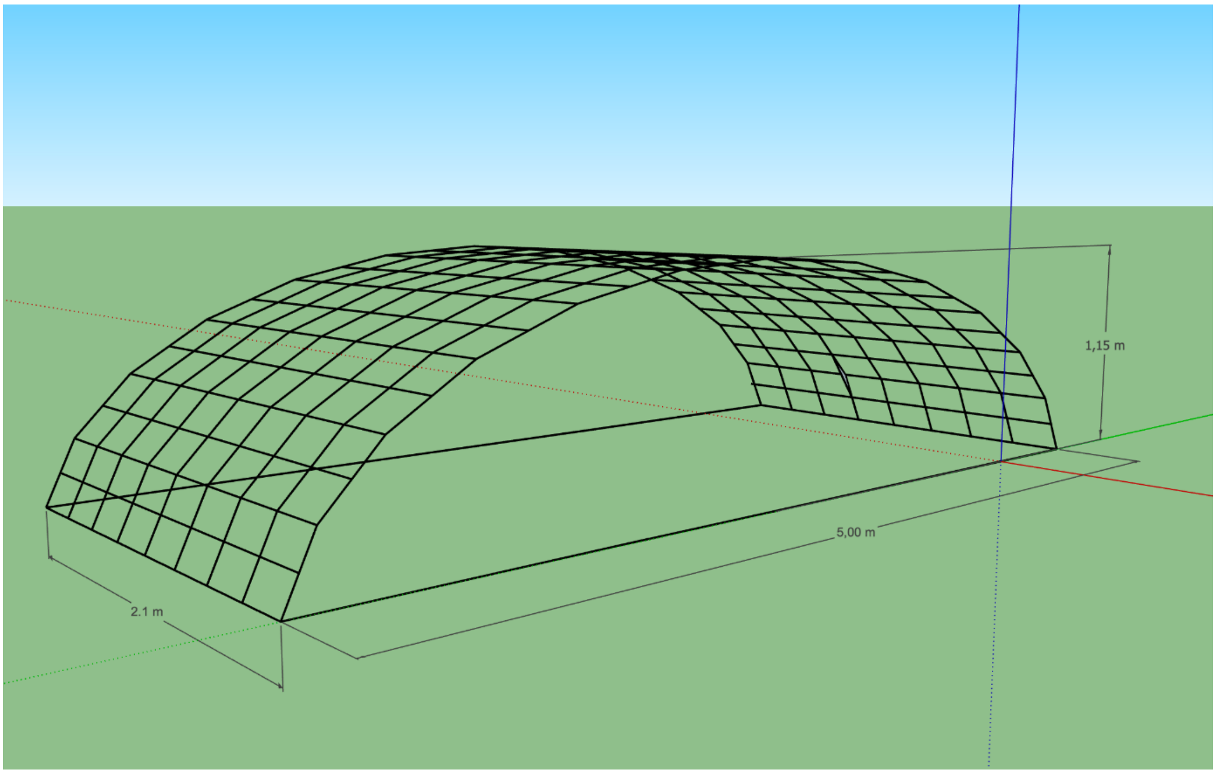


TCP-structure frame B

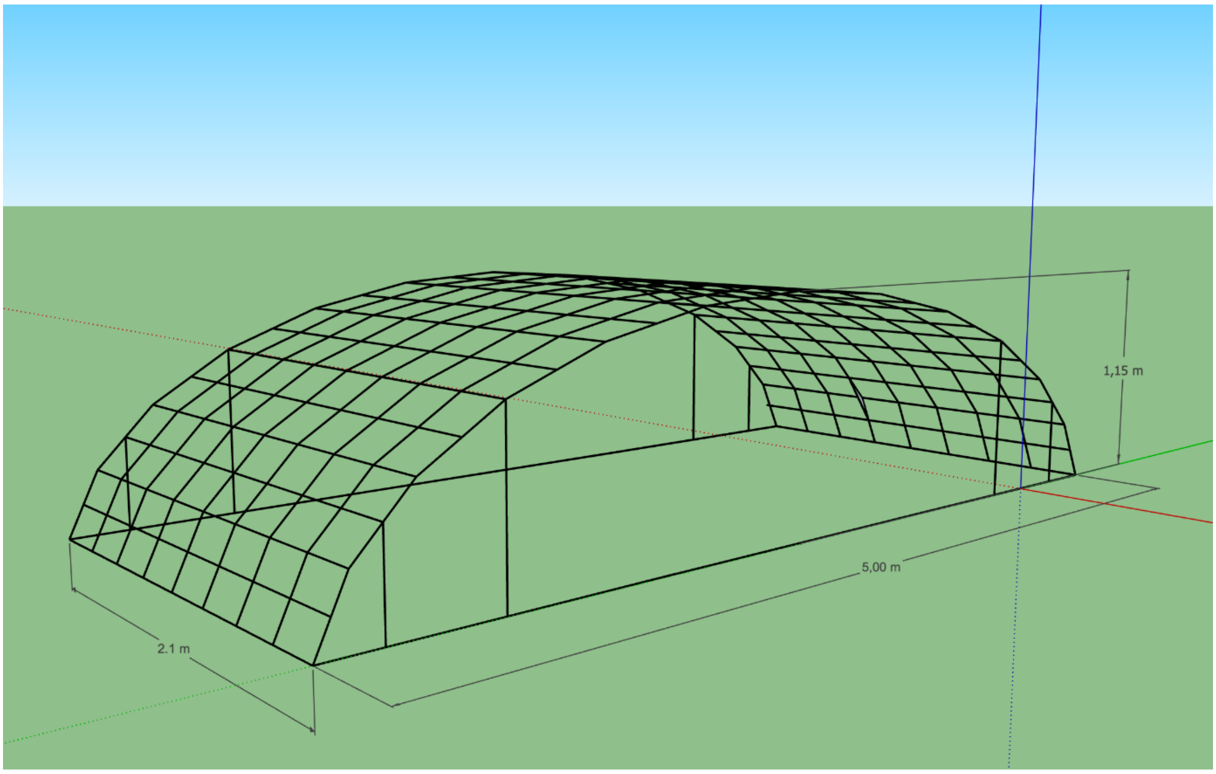
Step 1: Bend construction mesh over gabion on land



Step 2: Weld support rebar over length to create a frame (2x 5,5m) , add support rebar over the width at the base (2x 2,1 m)

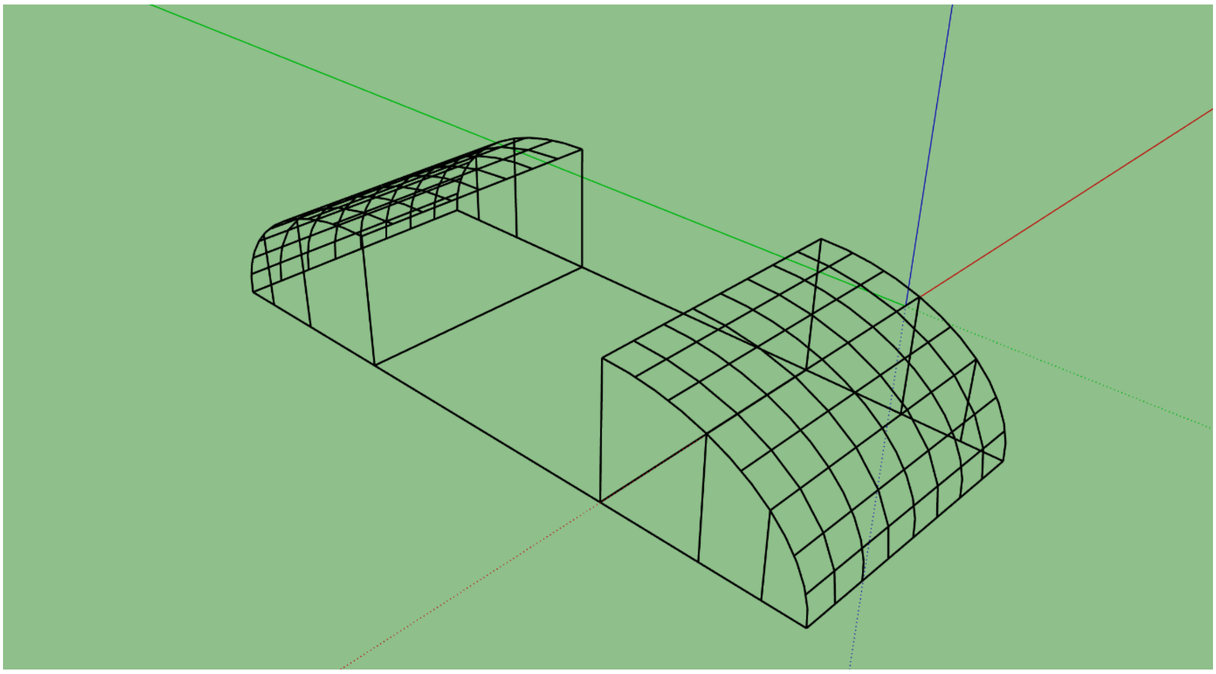


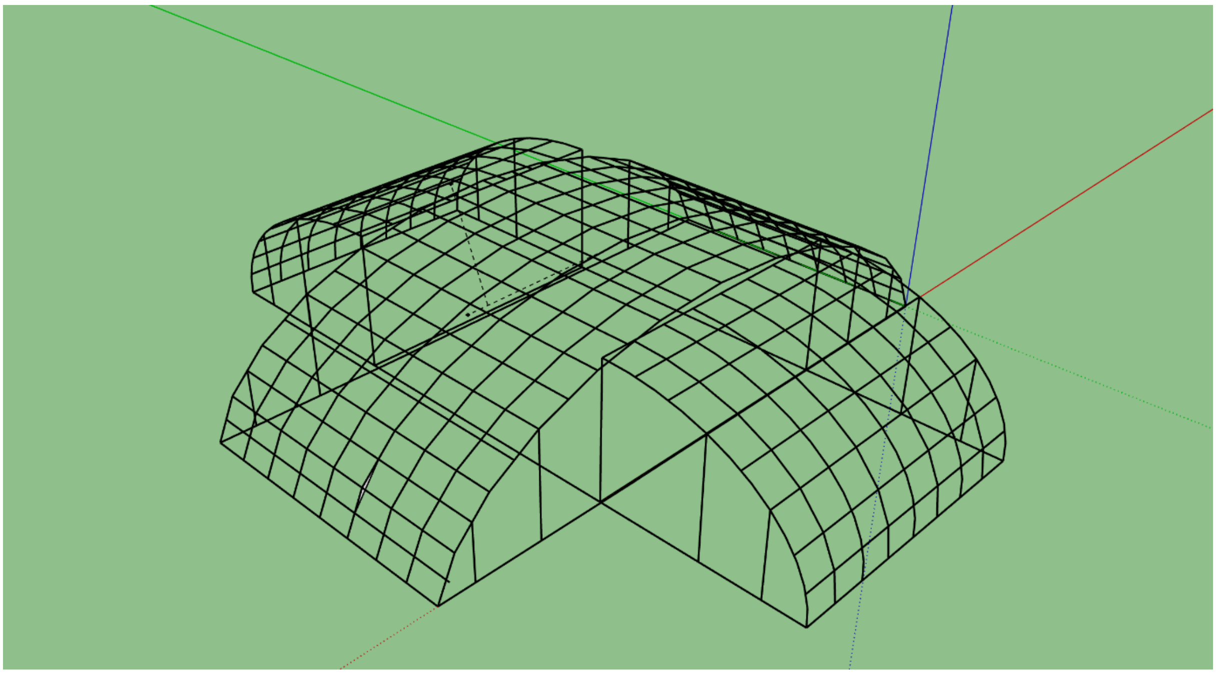
Step 3: Add vertical support studs, four on each side



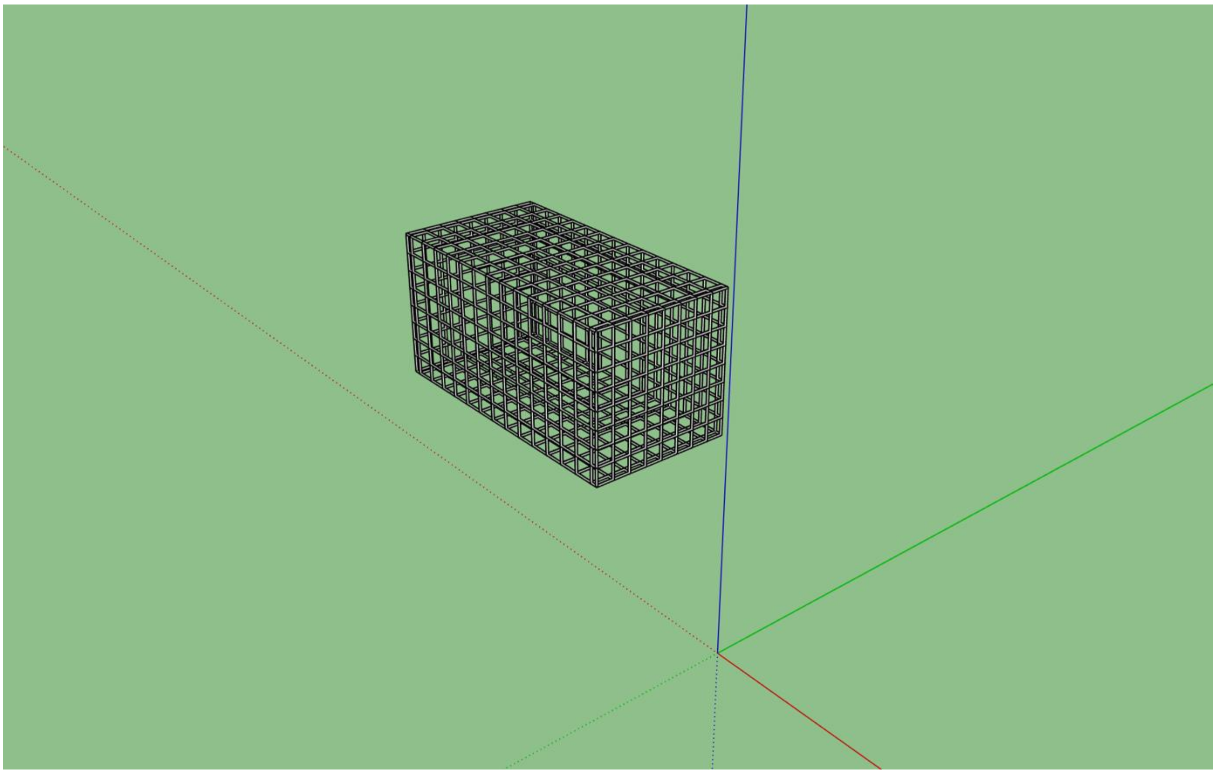
TCP-structure assembly

Step 1: Place frame A and frame B over each other, and weld together, to make solid frame

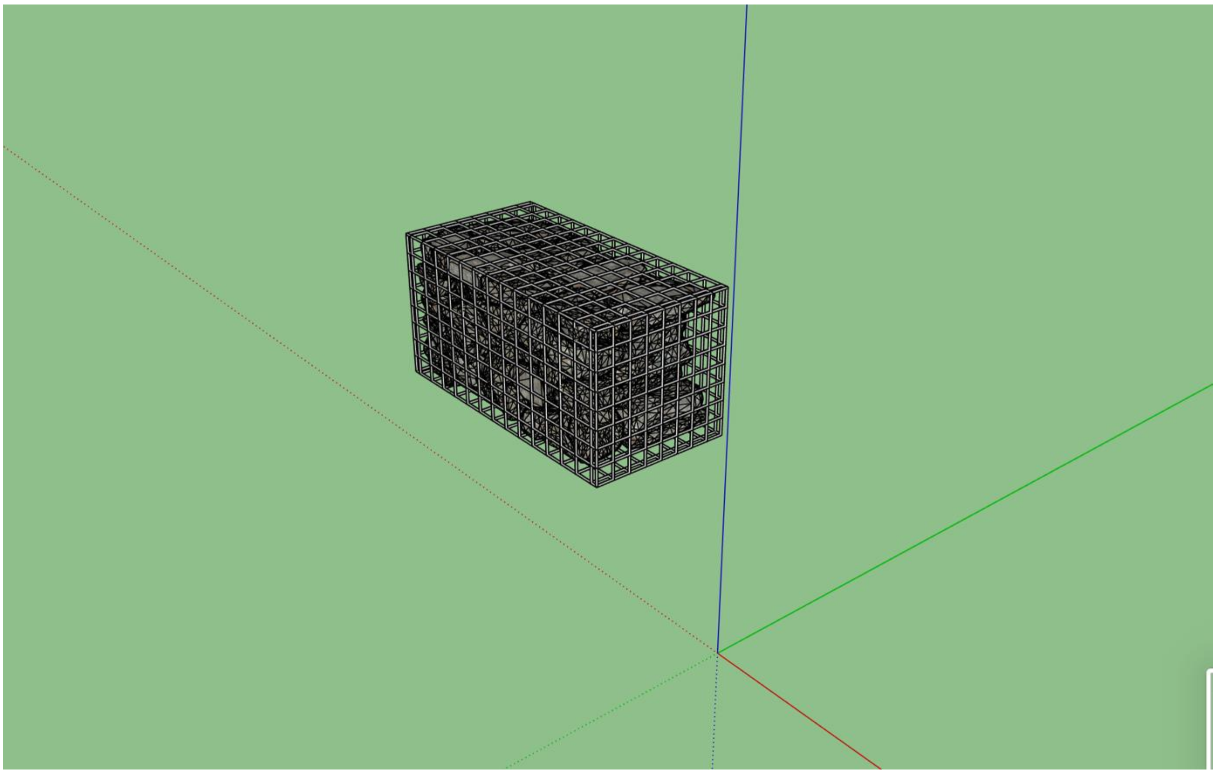




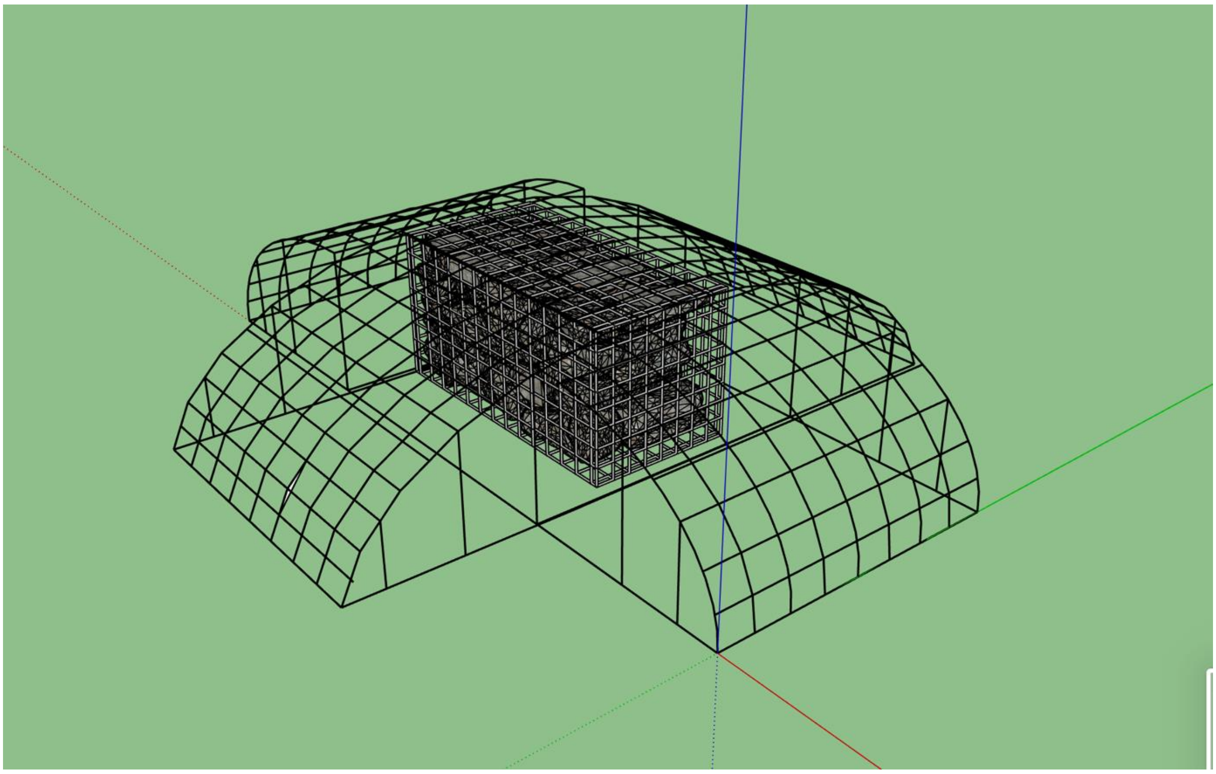
Step 2: place gabion in the water at designated location



Step 3: Fill gabion with football size stones (25cm diameter)

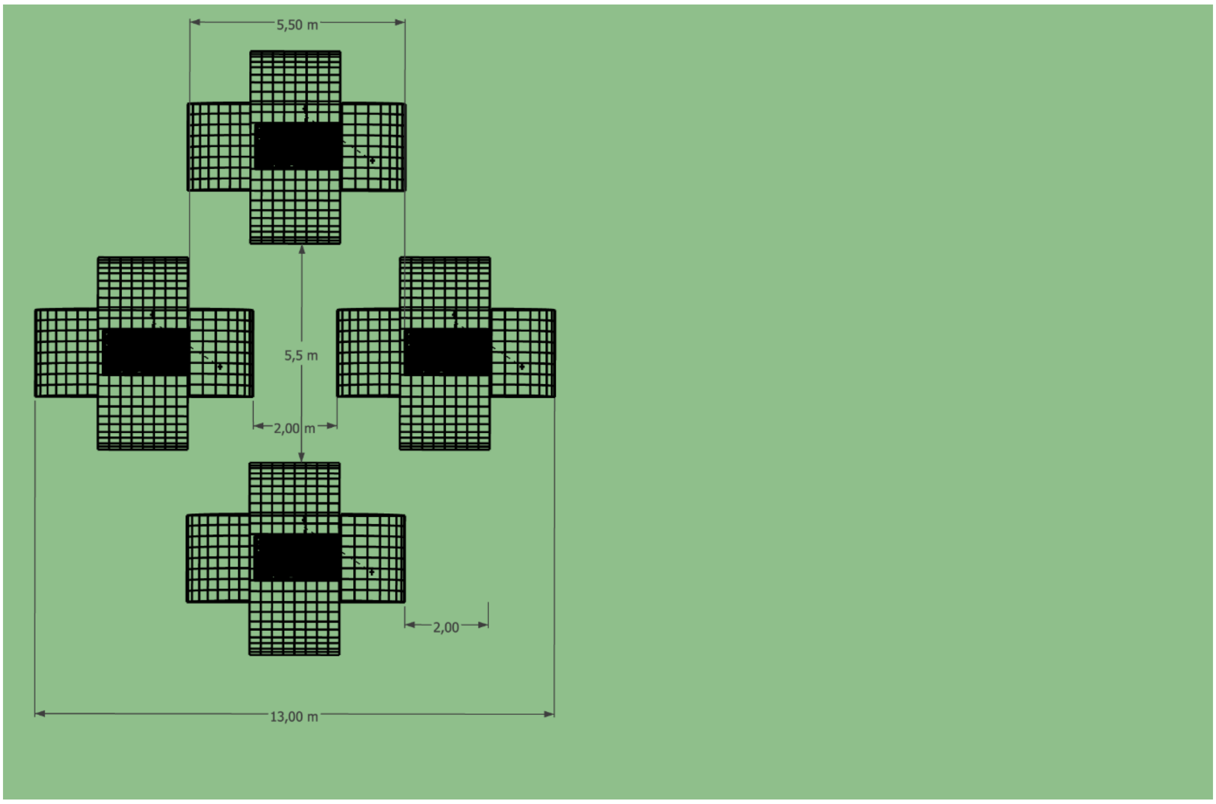


Step 4: Place solid frame over gabion and secure with hose clamps

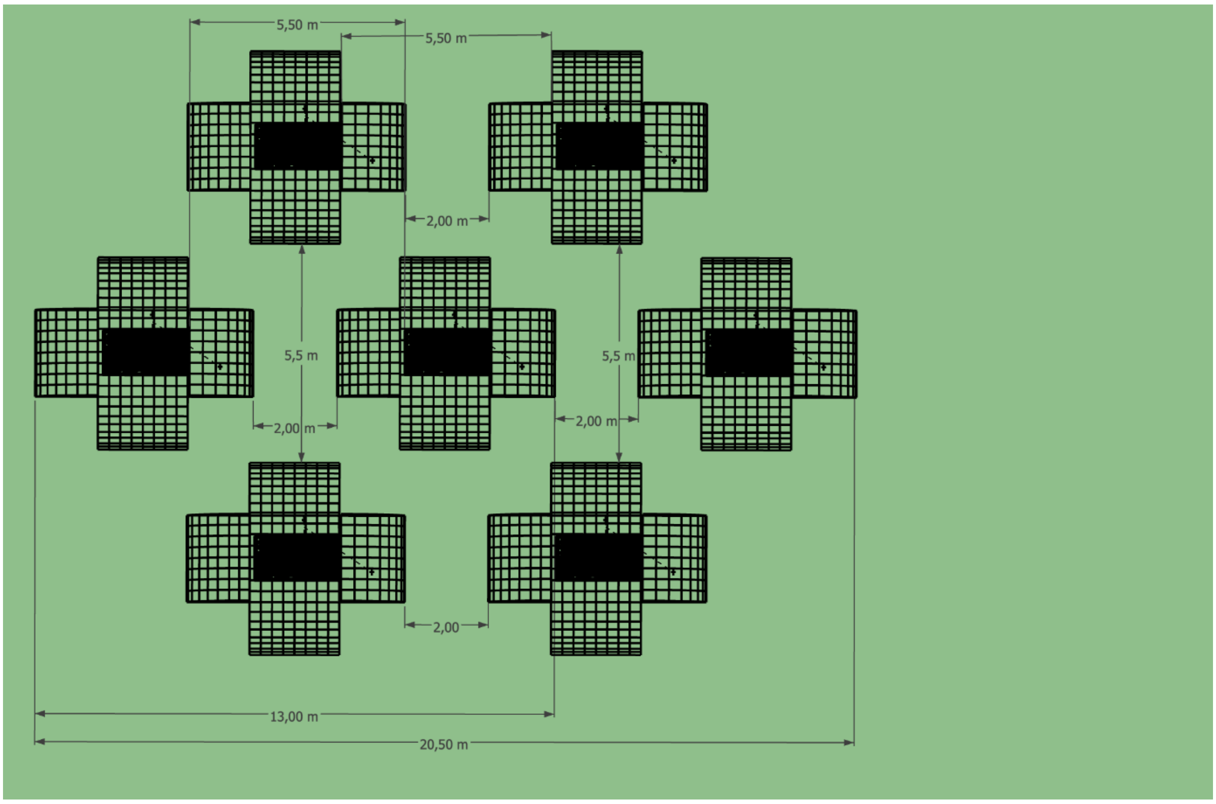


TCP-cluster assembly

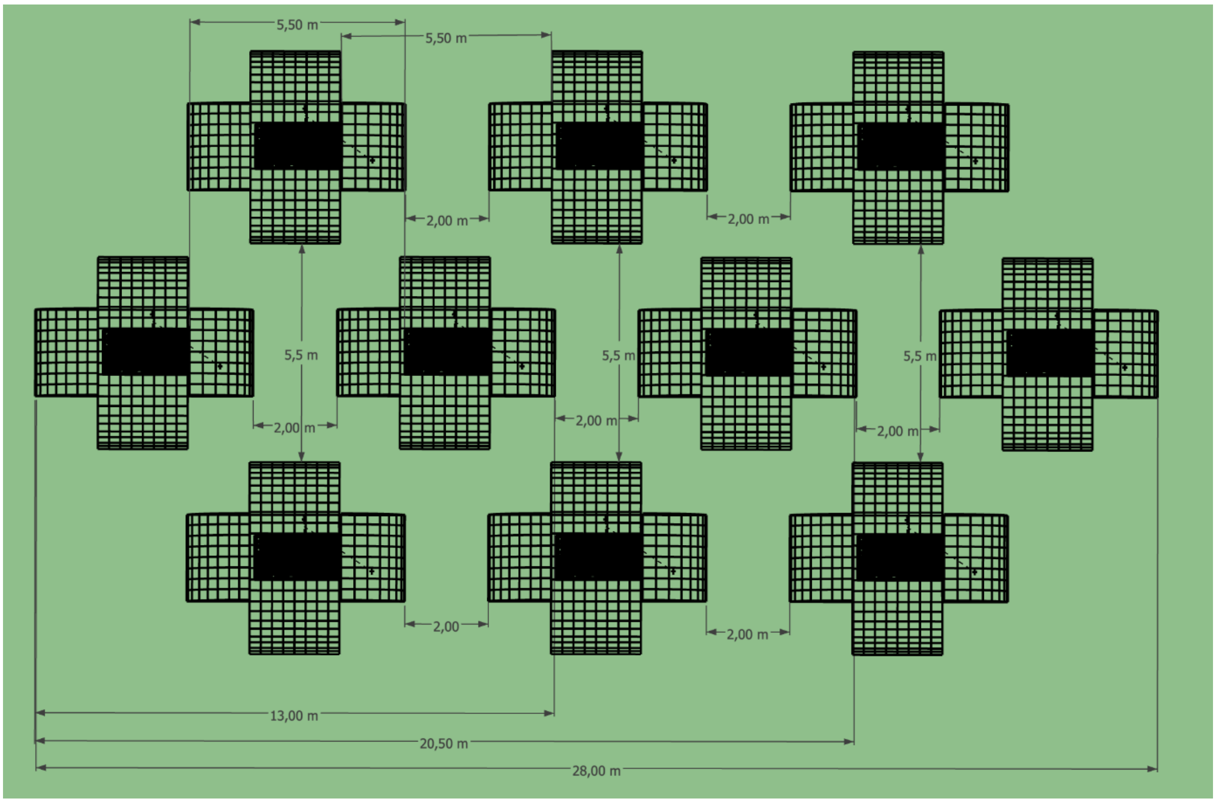
Step 1: place first cluster of 4 TCP-structures at designated location, place anode in the middle (look at figure: Anode locations)



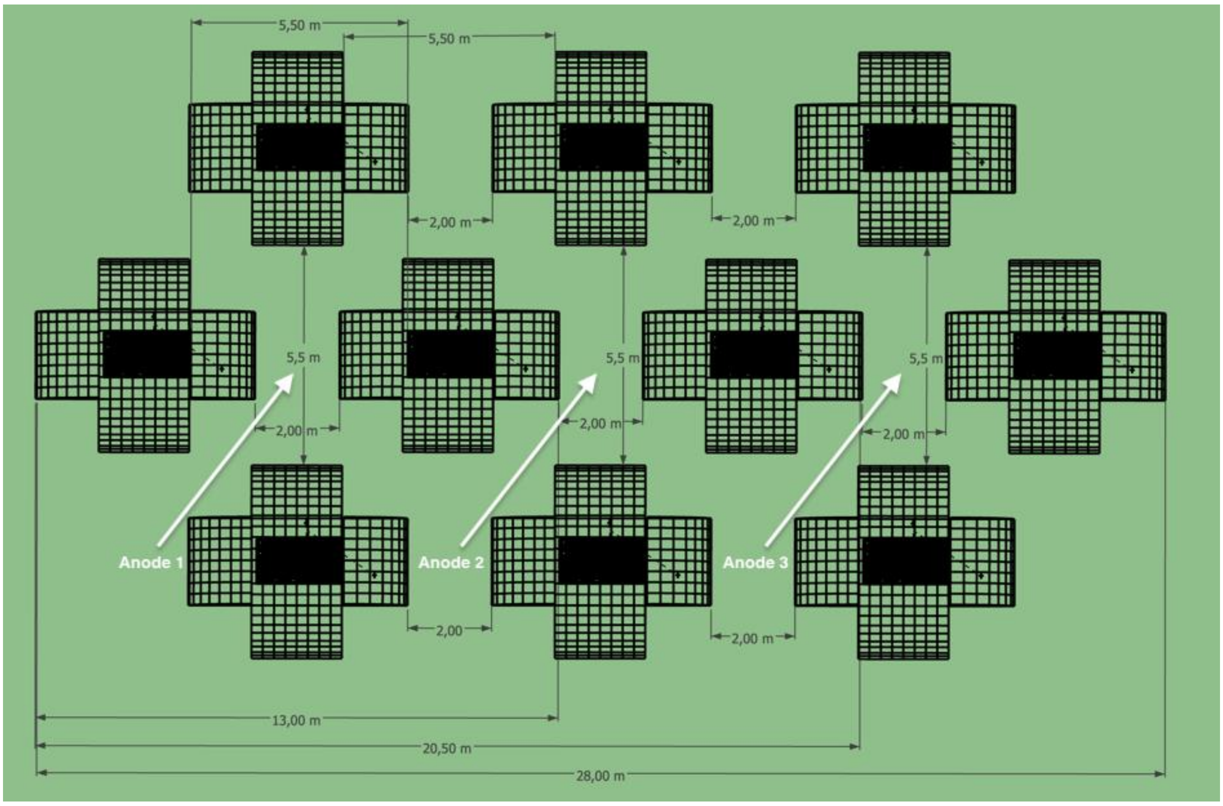
Step 2: Add second cluster of 3 TCP-structures, anode location as in figure: Anode locations



Step 3: Add third cluster of 3 TCP-structures, anode location as in figure: Anode locations

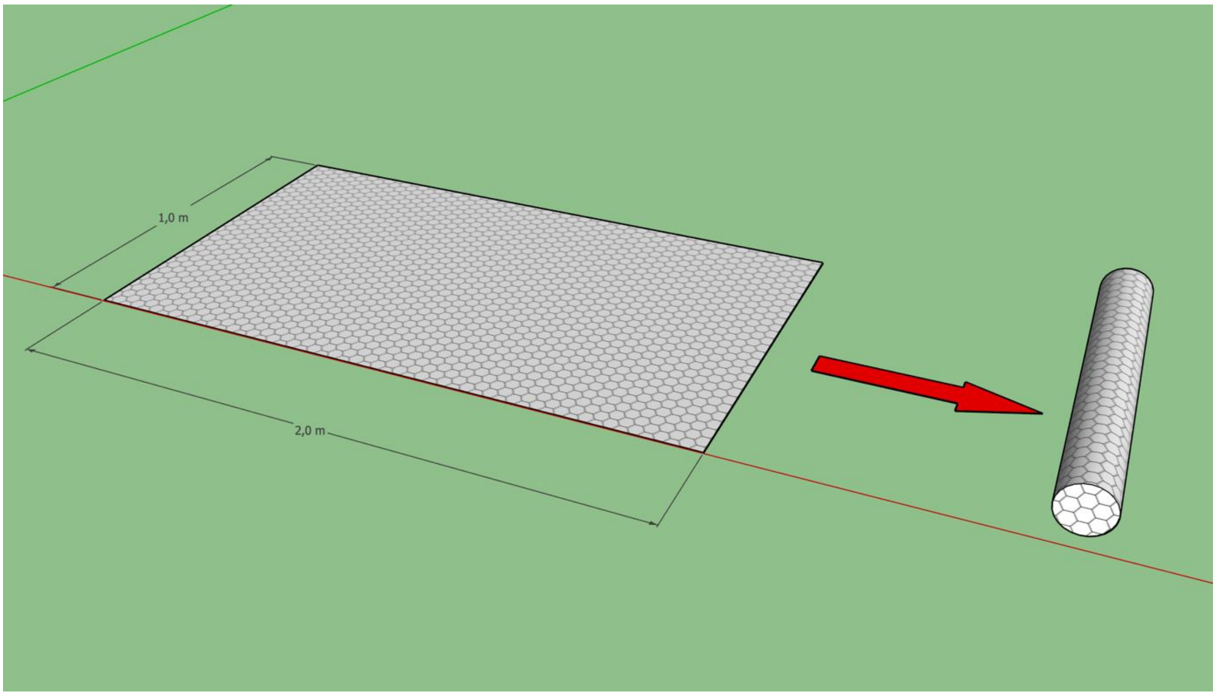


Anode locations

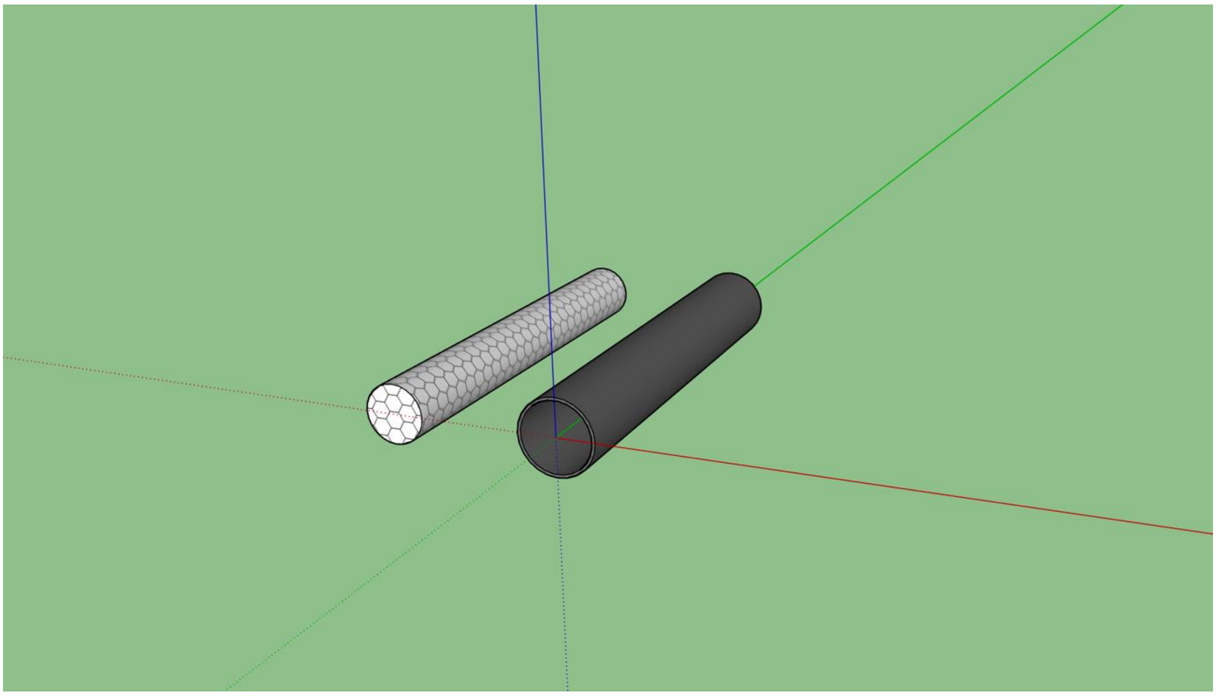


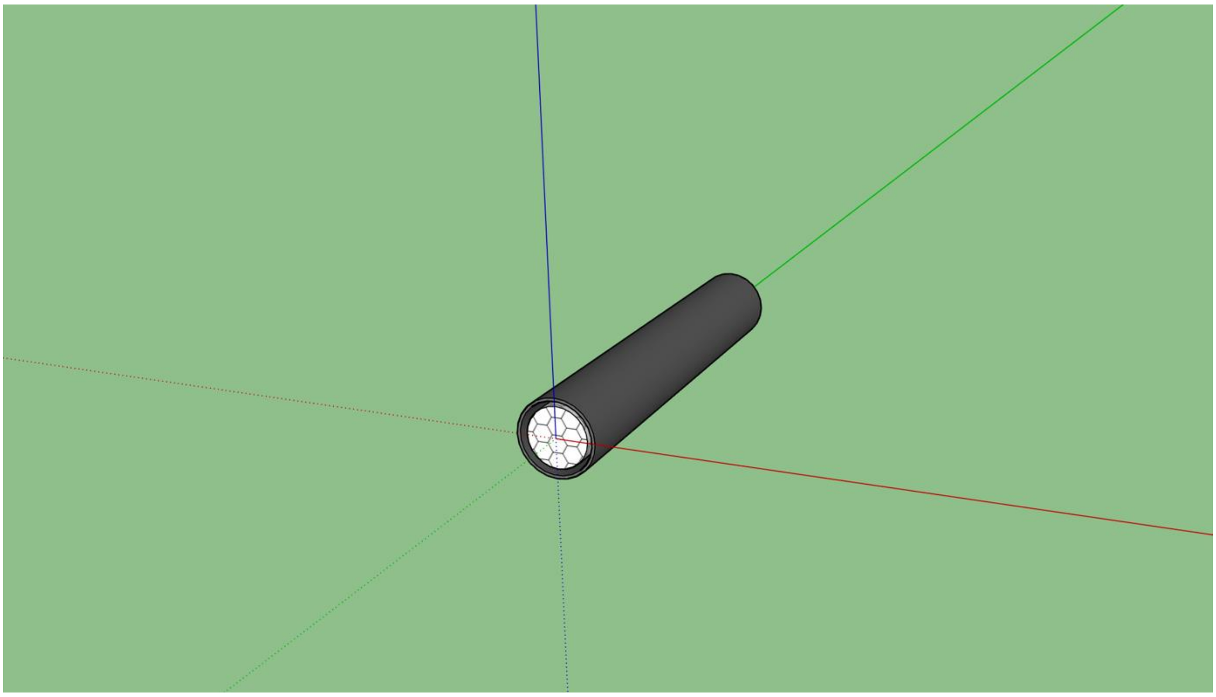
Anode assembly

Step 1: roll titanium mesh into a roll of ±10 cm diameter, this is the anode. Fixate the roll, so it can't roll open after a while

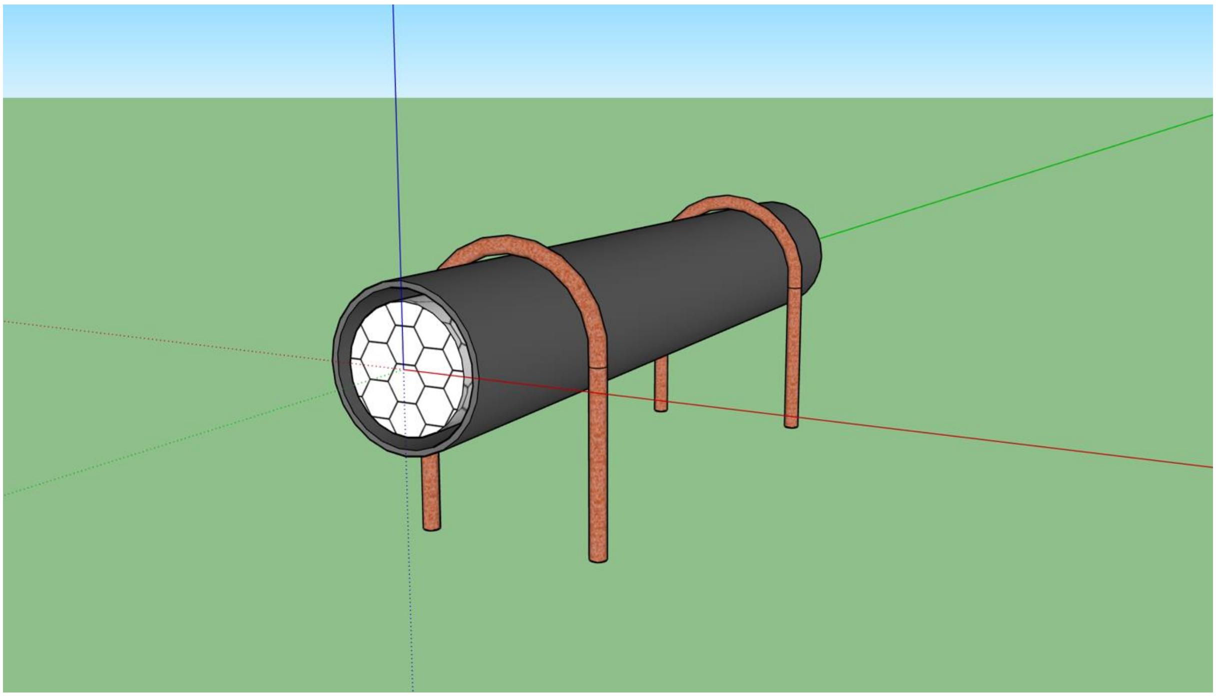


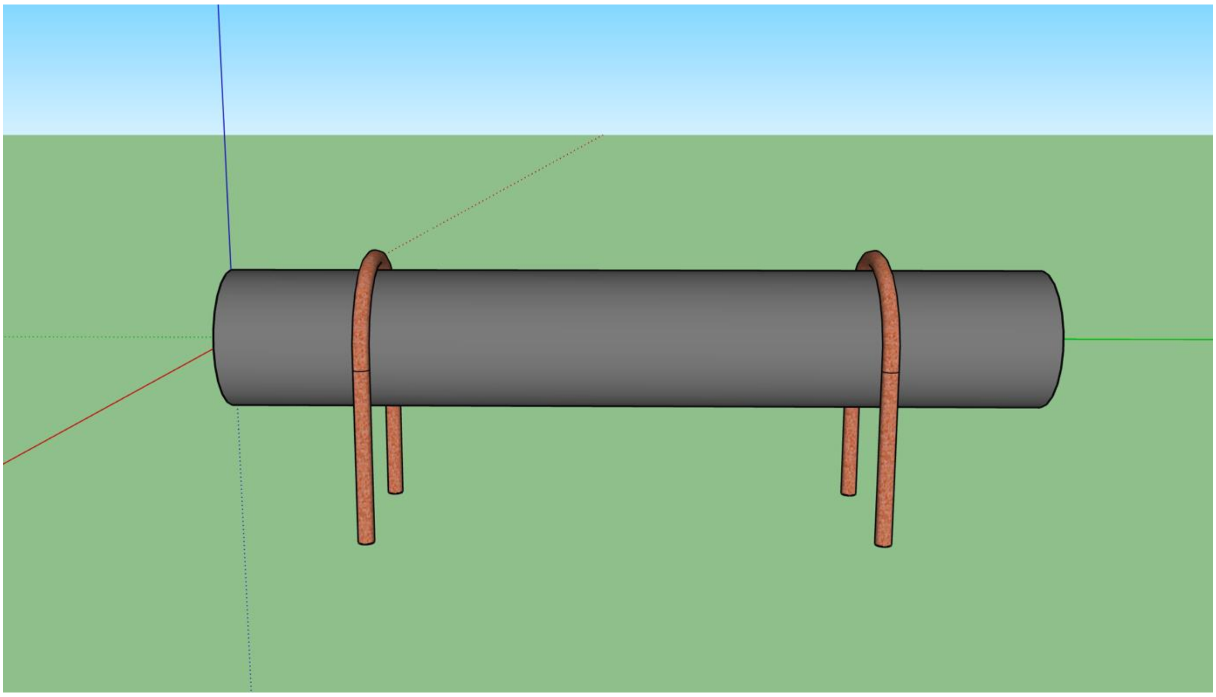
Step 2: place anode roll into PVC pipe 15 cm diameter for protection



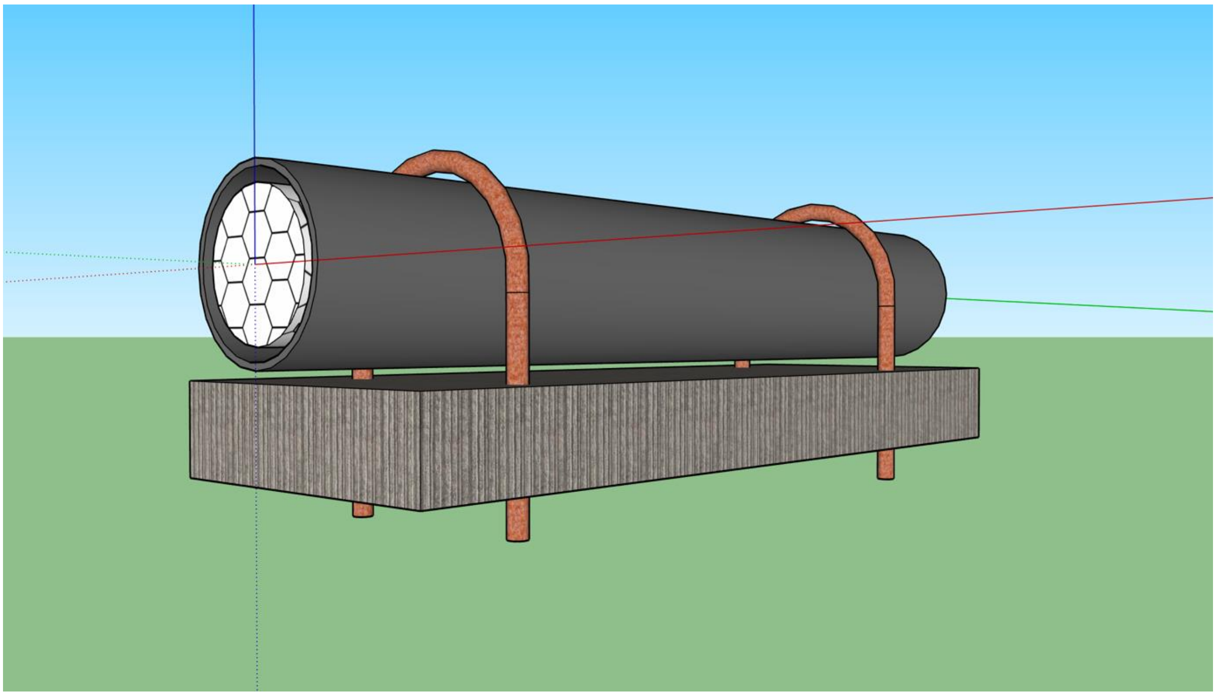


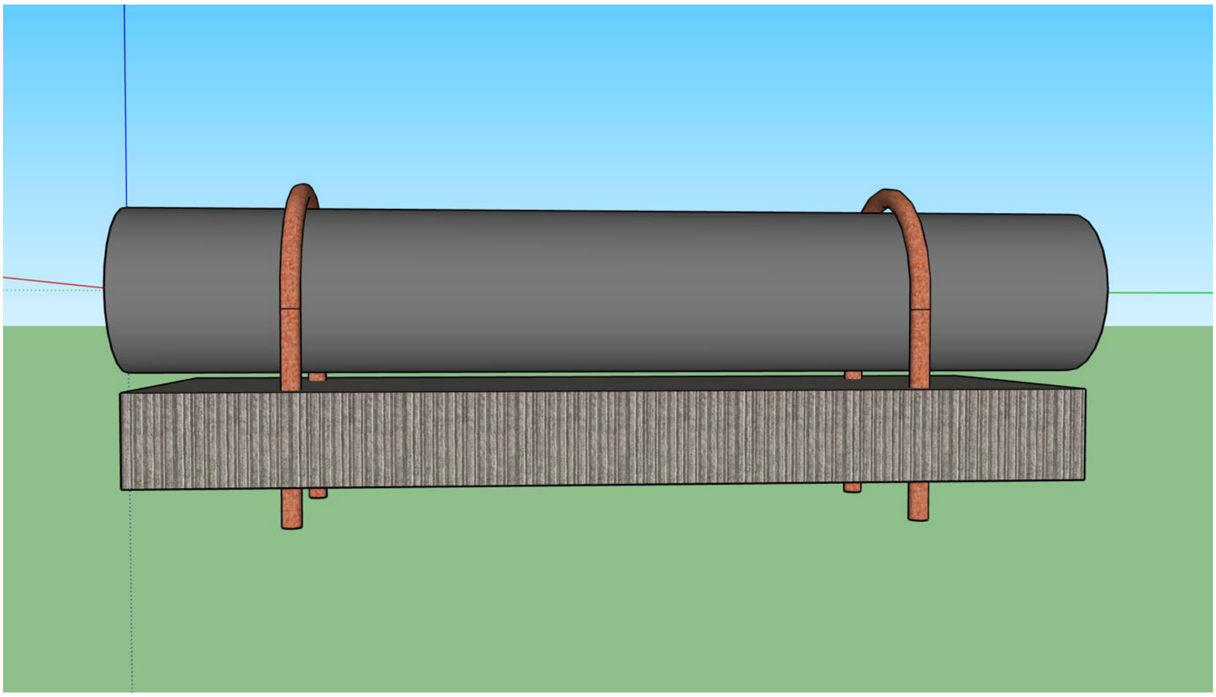
Step 3: bend rebar tight around PVC pipe. Make sure the PVC pipe can’t move inside the rebar



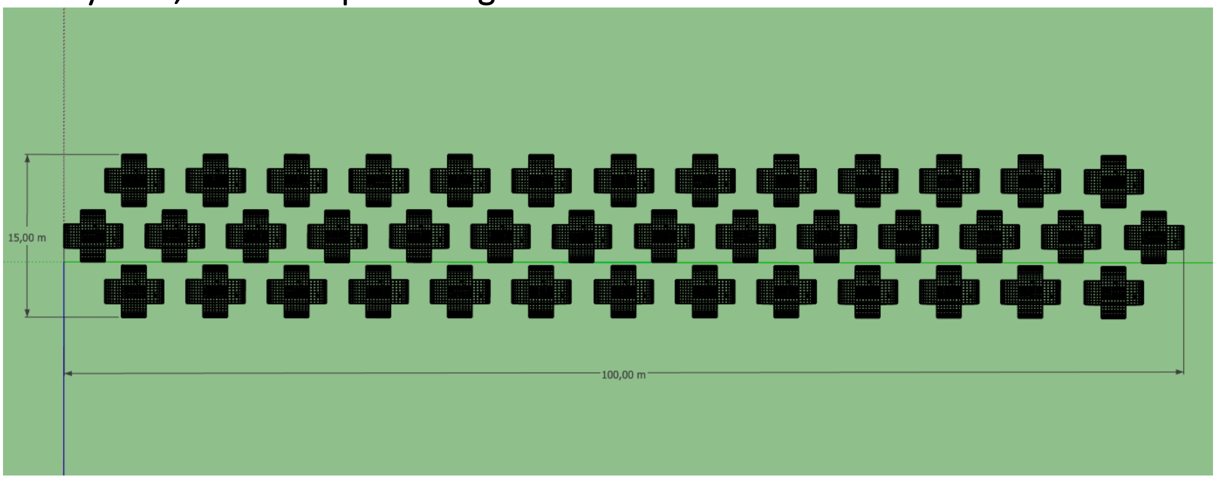


Step 4: fixate rebar in concrete block. Burry the concrete in the seabed, and it will act as an ground anchor.





TCP-system, all cluster placed together



Placement of TCP-system at Tasikoki beach

Boundary Zuid: Starting point
Latitude: 1°23'25.65"N
Longitude: 125° 6'12.71"E

Botom TCP-structure of cluster 1 is to be built on this coordinate.

Boundary Noord: End point
Latitude: 1°23'27.16"N
Longitude: 125° 6'15.64"E

Botom TCP-structure of cluster 13 is to be built on this coordinate.

Location of power source

Red x marks the position of the power unit, cables of 100m will reach all structures or anodes

Power unit placed just behind the beach, where vegetation starts.

Power unit location (suggested)
1°23'28.33"N
125° 6'13.68"O

Connection power cable to TCP-structures and anodes

Step 1: Use rebar clamp to connect power cable to frame

Step 2: Insulate connection from water

- Clear silicone with rubber heat wrap
- Watertight epoxy with rubber heat wrap

Step 3: Connecting power cable to power supply

- Connect anode to positive output
- Connect TCP-structures to negative

So, 4 power cables will go to the negative output and 1 cable will go to the positive output.

Important: Connect power cables to TCP-structure before and anode before placing in the water!!!

Appendix P

Change in MHW in Asia

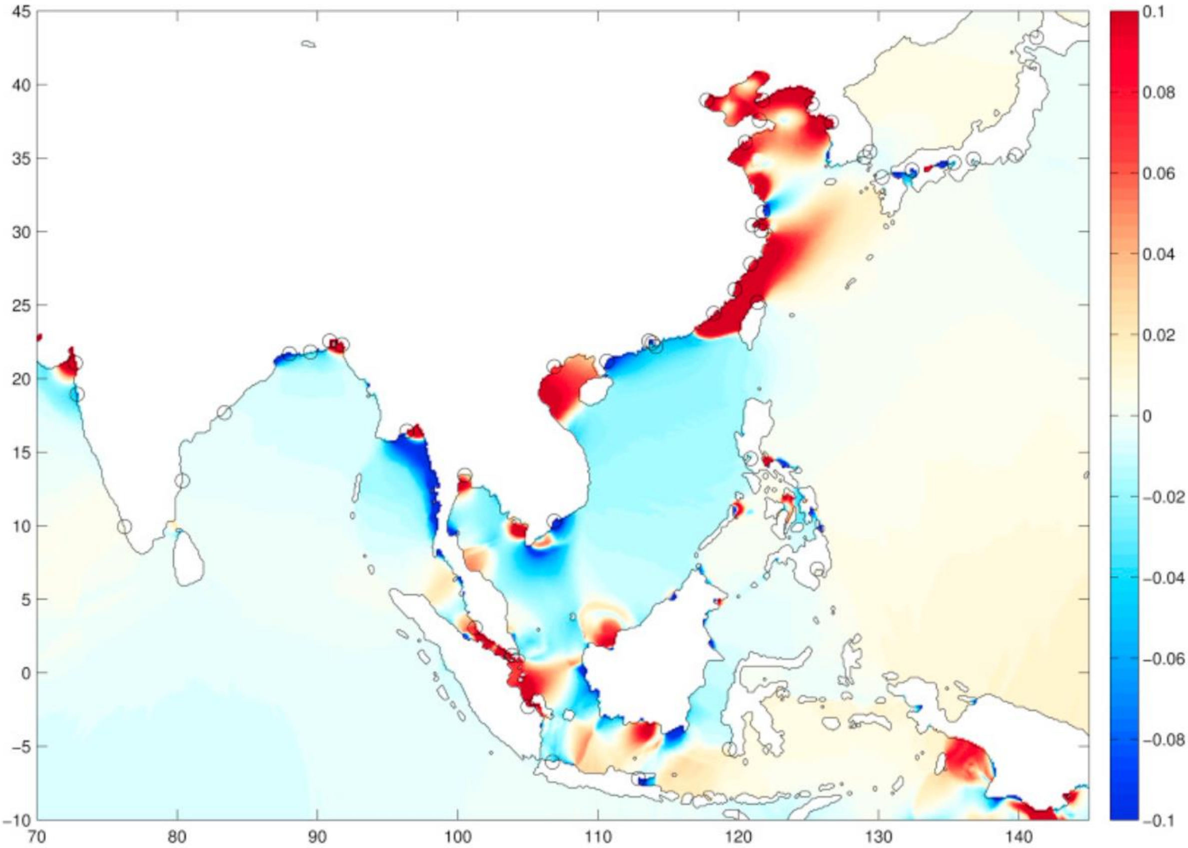


Figure 86 Asian change in MHW with 2 m of uniform SLR (Pickering, et al., 2017)