Breakwater barrier island 'De Banjaard'

University: HZ University of Applied Sciences
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Vocabulary list

- **BESE:** Biodegradable mesh made out of cellulose/biopolymer and name of specific brand.
- **Sediment accretion:** accumulation of sediment over time along coastal regions by process of ocean current, movement of oceanic/continental plates and human activity (Buschsystems.com, 2016).
- **Wave attenuation:** Reflection of waves in other directions than the original and conversion of the wave energy to other forms is called wave attenuation (Iowa state university, sd).
- **ASG:** Abbreviation of Artificial Sea Grass.
- Epiphytes: Any plant that grows upon another plant or object for physical support (Britannica.com, sd).
- **Bio deposition:** Deposition of biogenic material on the bottom of a body of water, usually consistent of faeces or pseudo faeces (Globse.com, sd).
- **Vertical wave orbital velocities:** Passing waves create a circular current in the water which has an orbital like motion of the particles in the water (geo.libretexts.org, 2021).
- **Wave energy dissipation ratio (EDR):** Wave energy dissipation rate is the parameter to determine the amount of energy lost by forces in the turbulent flow of waves (petrowiki.spe.org, sd).
- **Disk harrowing:** Harrow that breaks up ploughed or rough land by means of disc arranged at angle with the line of draft (merriam-webster.com, sd).
- **Rhizomes:** Horizontal underground plant stems, capable of producing shoot and root systems of new plants (Britannica.com, sd).
- **Eco-tourism**: Tourism to nature area in a sustainable way without damaging the natural area but still sustain the well-being of the locals in the area (youmatter, 2020).
- **Power matrix**: A grid used to categorise the different stakeholders based on their interest and power influence (Improvement Service, n.d.).
- **Off-grid:** Not depending on or using public utilities like the supply of water and electricity (Cambridge Dictionary, n.d.).
- **Sea Gardening:** Growing and taking care of plants, mussels and oysters for consumption (Cambridge Dictionary, n.d.).

Abstract

As many other parts around the world, the Schouwen coast in Zeeland, Netherlands is being threatened by the effects of climate change. Hard structures that nowadays defend us from the sea are obsolete and will not withstand the sea level rise that is predicted. We need to think of other solutions. Therefore, we want to help Shared Concepts in building a plan for a dynamic breakwater system whose primary purpose is coastal protection. This dynamic breakwater system is called: ‘de Banjaard. This breakwater barrier island needs to be constructed, strengthened and utilized.

To strengthen the initial suppletion of sediment for “de Banjaard” bio builders are needed. Biodegradable bio builders will help the system by preserving ecological value that will be introduced to this breakwater barrier. For this design with biodegradable bio builders a multiple defense layer was chosen originally envisioned by Longhuan Zhu. The defense layers consist of suspended rope culture, submerged seagrass mats, emergent oyster reefs and a top layer of marram grass. These defense layers will protect the suppletion of sediment against erosion and also expand the initial suppletion by capturing additional sediment.

To succeed with this project, we must take into accounts the different opinions of the different stakeholders and find out what works for the most of them but also accommodate the needs from the minorities. There are some projects which have the same idea, goals or just looks like “de Banjaard”. These projects give us some insights on several possibilities for “de Banjaard”. Eco-tourism will be one of the main pillars to help with maintaining “de Banjaard” by creating income and raising awareness. With eco-tourism we want to provide the visitors with a unique and educational experience while not disturbing the nature.

By letting people make a reservation before visiting “de Banjaard”, you can easily limit the number of visitors and doing so have a small chance of disturbing the nature. The visitors can so experience an island where nature can take its course without (minimum) interference of men.

Introduction

Humanity is dealing with climate change and faster sea level rise as a result of growing CO2 levels. As a delta nation, the Netherlands must take action to adapt to these changes. On (limited) land, there is a limit to how high and how massive dikes and dams can get. Therefore, we have to look seawards. We believe that by harnessing the force of nature, we can not only address the issue but also benefit from it. Before the sea level rise reaches one meter, we have roughly 30 years, or one generation, remaining to conduct research and experiments.

Damming the Oosterschelde faced strong opposition in the 1960s. Do not give us the Oosterschelde dam, but then what? Was the title of a speech given at the time that accurately captured the sentiments of the populace and led to the development of the storm surge barrier (also known as "stormvloedkering") as we know it today. However, this magnificent feat of engineering was not built to withstand increases in sea level of more than one meter. So, the 1960s-era query "but then what?" has become more pertinent once more. A barrier island and subsequent breakwater landscape will emerge and evolve to the benefit of flora, animals, and people through a combination of one or more clever sand nourishments at or near the vicinity of the former island The Banjaard (Voordelta near Schouwen-Duiveland).

Our ultimate goal is to begin practical experiments in the Voordelta in 2025. Accordingly, the following inquiries must be answered in light of the WUR report "Breakwater barrier island "De Banjaard" dated 3 June 2022. Research into probable sources of sediment for the supply needed for the development of the barrier island is needed. The Schouwen coast's hydrodynamics and the barrier island's (introduced) ecosystem engineers should be able to work with the sediment's qualities. Not only the quality of the sediment is important, but also the quantity. Therefore, calculations and analysis to figure out how much sediment is needed. In addition to the Banjaard barrier island's physical (technical) and ecological characteristics, it is also necessary to look into the project's socioeconomic components. Within this initiative the bottom-up approach is used, as the support of the (local) community is essential to succeed. A stakeholder analysis, legal analysis and financial analysis are part of this (Shared concepts, sd).

Taken the above-mentioned things into account, the following research questions are addressed in this research project:

- What are the specifications of the initial sand nourishment, including their location(s), quantity(s), surface, and profile?
- Preferably, the nourishments should be performed with machinery on fossil fuels. Which sustainable options are available?
- What are the contributions of bio builders to protect, reinforce and expand the initial nourishment(s)?
- Given that this project is seen as the beginning of a process for the development of the area, what are the various functional uses of the breakwater landscape both now and in the future?

Before we move on to answering the above-mentioned research questions, the next chapter is about the research design of this research report. It will discuss the 3-phase strategy: construction, strengthening and utilization of the breakwater barrier island ‘de Banjaard’.

Hereafter, the next chapters in this research report are about the construction, strengthening and utilization of the breakwater barrier island ‘de Banjaard’. Specifications of the initial sand nourishment, including their location(s), quantity(s), and profile are discussed. Moreover, the contributions of bio builders to protect, reinforce and expand the barrier island as well as the multi-functional use both now and for in the future are addressed. The conclusion, discussion and appendices make up the end of this research report and will include a clear description of the answers to the research questions stated in the introduction.

Research design

To answer all the research question stated in the introduction, a 3-phased strategy is been thought out to realise the initiative of a breakwater island barrier "de Banjaard" and reach the ultimate goal of beginning practical experiments in the Voordelta in 2025. The 3-phase strategy that is been thought is about the construction of the breakwater barrier island, the strengthening of the breakwater barrier island and the utilization of the breakwater barrier island.

Construction phase

First of all, the breakwater barrier island will have to be constructed. To construct such a massive thing, research, analysis and calculations on the first two questions will give an insight into this.

- What are the specifications of the initial sand nourishment, including their location(s), quantity(s), surface, and profile?
- Preferably, the nourishments should be performed with machinery on fossil fuels. Which sustainable options are available?

Strengthening phase

After the construction of the breakwater barrier island, erosion in the form of waves, wind and storms will constantly try to break down the intertidal zones of the barrier island. To prevent high amount of erosion, research into research will be done during this phase on the next research question.

- What are the contributions of bio builders to protect, reinforce and expand the initial nourishment(s)?

Utilization phase

Finally, the third phase is about the utilization of the breakwater barrier island. Research on the last research question stated beneath will give insight in the possibilities to further develop such an area.

- Given that this project is seen as the beginning of a process for the development of the area, what are the various functional uses of the breakwater landscape both now and in the future?

Construction phase

To reach the ultimate goal of beginning practical experiments in the Voordelta in 2025, the breakwater barrier island will have to be constructed near the coast. To construct such a thing, analysis and calculations have to be carried out. The research questions addressed in this chapter are the following:

- What are the specifications of the initial sand nourishment, including their location(s), quantity(s), surface, and profile?
- Preferably, the nourishments should be performed with machinery on fossil fuels. Which sustainable options are available?

Theoretical framework

First, the specifications of the design of the breakwater barrier `de Banjaard` need to be determined to assess the possibilities for the island. To get started, surface area and volume of the suppletion need to be determined. This will be done by the help of a programme called Qgis. This programme is reliable and accurate enough to make these kinds of calculations. Furthermore, a design of the island will be drawn in a programme called AutoCAD. In this phase it is enough to draw the island in 2D. A top view and side profile should be sufficient enough to get a clearer picture.

Moreover, a calculation needs to be made with regards to amount of erosion that will occur at the site of the breakwater barrier island. This calculation will be done with help of the acquired knowledge of the morphology class of Hogeschool Rotterdam. It is also important to estimate the lifespan of the breakwater barrier. There is no inherent programme to make an estimation based on similar projects.

After all this is done a cost estimate is done based on a planning. Certain assumptions will be made in this chapter of the construction due to shortage of information on the costs.

Qgis

Using Qgis, we determined the Bathymetry of the North Sea at the location of the breakwater barrier. After loading this map, we plotted and clipped the breakwater barrier to the bathymetry. We were then able to calculate the volumes of the island. We also calculated the surface area using the Qgis map. We converted the drawing of the island in Qgis into an AutoCAD file so that the drawings matched the Qgis calculations.

Wooden piles

Wooden pile groins will be placed along the seaside to protect the most exposed part of the island. On the southwest side the wave energy will be the highest and the wind usually comes from the southwest. The wooden piles reduce the erosion in parallel direction and oysters and mussels are able to attach to the piles.

Rock protection

In the north and southern points of the island the area above average high water is protected with dumpingstone (300-1000kg). This is done to maintain the moon shaped form of the island, and to protect the inner side with the ecological implementations from the biggest waves and reduces the flowrate.

Surface & Volume

The total area of the Banjaard island is approximately 18 000 000 m², including the lower areas until -5m below NAP. To make an estimation of the required volume of sand and rock the area has been divided into higher and lower areas as shown on the image below. The yellow hatch is the higher area which has a height on the seaward side of +0m. NAP to +7,0m.

Table 1: specifications breakwater barrier island 'de Banjaard'

	Area (m²)	Height of material (m³)	Volume (m³)
Total area	17 983 001		
Higher area	2 062 785	2,5	7 200 000
Lower area	15 920 216	2,5	39 800 000
Dumping stones	137681	1,5	192 000 (499 000 ton)

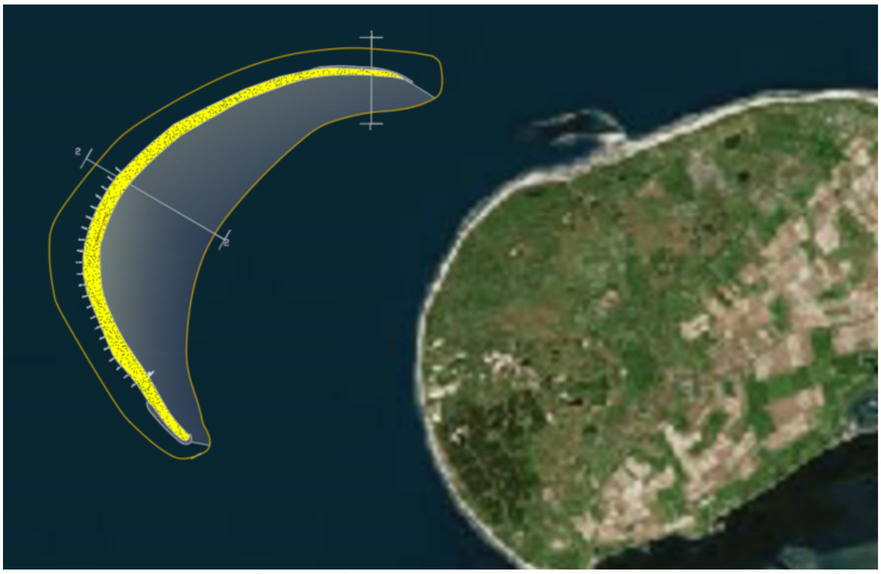


Figure 1: breakwater barrier island 'de Banjaard'

In total a volume of ± 45 million cubic metres of sand will be required for the sand suppletion. And roughly 499 000 ton of rock will be needed.

Grain size

In the past measurements of grain sizes were made nearby the project location, in the figures below the location and the grain size analysis are shown. From the grain size analysis the most common grain size d50 can be derived. The size of the sand has a range between 0.1 mm and 0.9 mm. Any grainsize below d50 at the Banjaard will likely erode over time because the size is smaller than half of the sand particles that are present. Therefore the required sand needs a minumum grain size of d50. d50 has a diameter of approximately 0,22 mm.

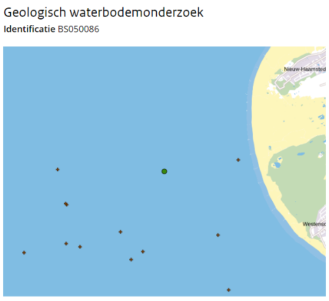


Figure 2: Geological bottom research

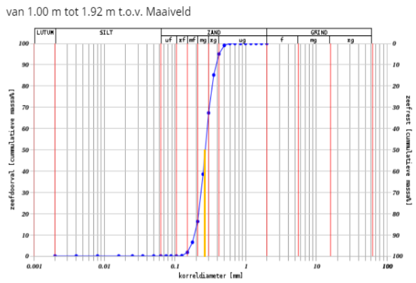


Figure 3: Grain size

Flow rates

It is important to find out the flow rates at the project location to determine how fast the suppleted soil will be transported along the coast. Rijkswaterstaat has a number of measuring locations near our project locations these have been used to calculate an average flow rate and flow direction. The locations are shown in the figure below.

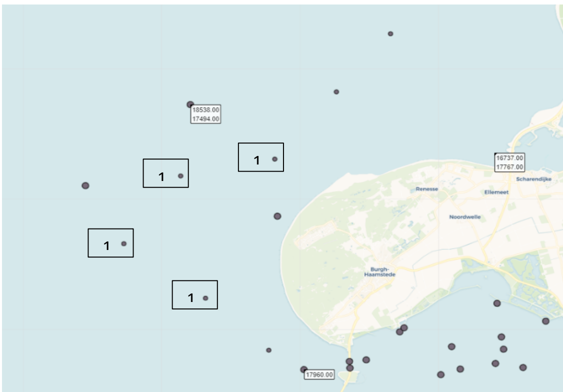


Figure 2: Average flow rate locations

Table 2: Flow specifications

MEETPUNT	GEM. STROOMSNELHEID (CM/S)	GEM. STROOMRICHTING (°)
11	33.455	33.764
12	43.768	25.621
13	36.714	28.167
14	33.774	27.626
GEMIDDELDE	36.928	28.795

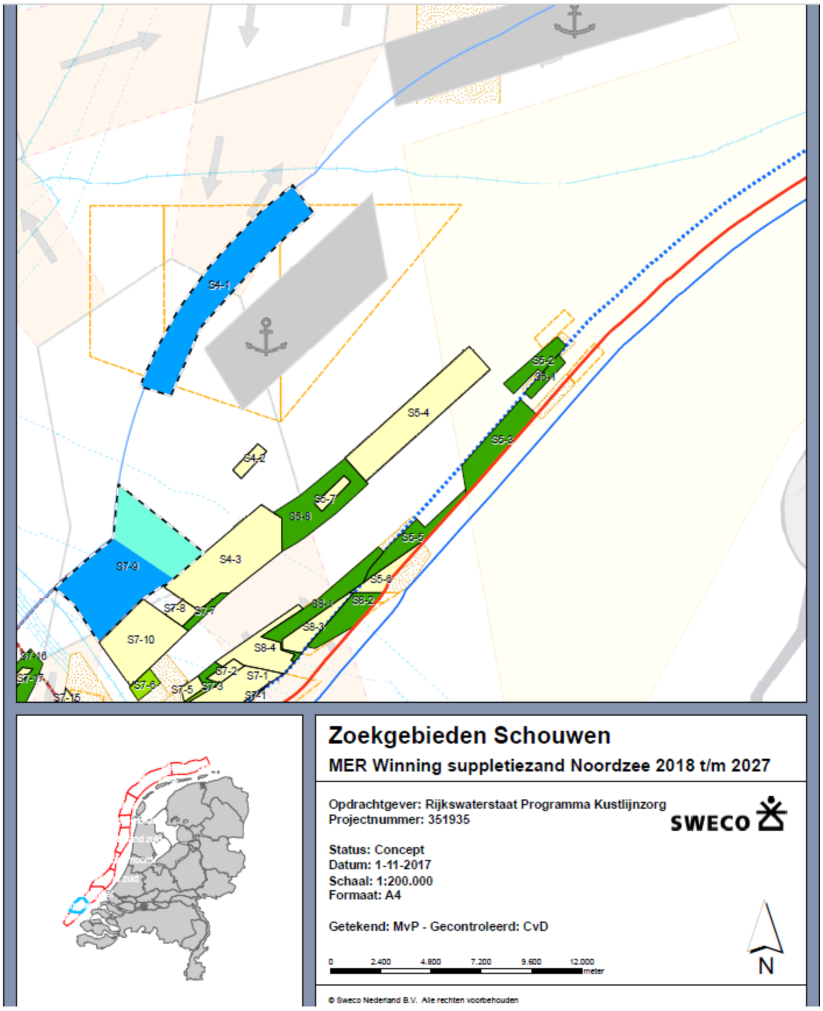
(Ondergrondgegevens, sd) (Zeeuwse wateren (modeluitvoer), sd)

Sand extraction locations

Possible sand extraction locations have been considered by Rijkswaterstaat. All obstacles are considered and are indicated on maps, see image below. the following criteria has been considered for possible locations:

- Ecologically (un)limited
- Wind parks
- 12-mile border
- NAP -20m-lijn
- Electrical- and telecom cables
- Aquaculture
- Anchoring areas
- Anchoring areas
- Shipping areas

Figure 5: Sand extraction locations Schouwen



Search area Schouwen seems the most suitable, because it is the closest to the Banjaard, so emissions due to sailing will be limited. In the area Schouwen the following areas near the shore are available for sand extraction; S5-2, S5-8, S5-3, S5-1, S5-5 S8-1 and S7-7, more seaward area S4-1 is available.

Table 1: Sand extraction area's

Search area	Area (million m²)	Win depth	Already extracted (million m³)	Calculation factor	Capacity (million m³)
S5-2	2,31	6	2,61	1,92	5,87
S5-8	7,08	6		3,51	12,11
S5-3	5,03	2		1,92	5,24
S5-1	1,13	2		1,92	0,77
S5-5	3,40	2	6,79	2,45	0,01
S8-1	4,55	6	8,07	2,45	7,84
S7-7	0,83	6	0,23	1,92	2,47
S4-1	18,52	6		1,92	57,88

An amount of 45 million m³ is required so the only nearby suitable location is area S4-1, because it has a sufficient capacity of 57,9 million m³. the sailing distance is roughly 20 km.

Lifetime (Erosion)

An important aspect in this research is the lifespan of the breakwater barrier. The lifespan of the island depends on several aspects.

Erosion

Various forms of erosion will occur and have an impact on the breakwater barrier, namely:

Table 2: Erosion types

Structural erosion	Degree of influence on the breakwater barrier
1. Varying wave climate	High
2. Curving of the coastline	Medium/high
3. Constructions along the coast	High
4. Sea level rise	High
5. Sand demand of tidal basins	High
6. Reduction of sediment supply	Medium
7. Incidental erosion	Low
8. Wind losses	Medium/low
9. Storm erosion	High

Varying wave climate

The wave climate is the average state of the waves in a certain place, calculated based on the height, the direction, the time period, etc. (Golfklimaat, sd)
High waves can be caused by the wind blowing in the direction of the waves or when the temperature difference between the air and water is large, such as in autumn and winter. Furthermore, showers with gusts of wind can also have a significant impact on wave hights. (Golven, sd)

Met opmaak: Standaard, Uitvullen

The breakwater barrier has the important function of attenuating the high waves in the area. Therefore, the island will have to absorb a lot of wave energy, with the result that erosion will be high and reinforcement is needed.

Constructions along the coast

France is the source of the sediment supply for the Dutch coast. The sediment is moved northward by the current. The silt, however, won't stay near the Dutch coast; instead, the current will primarily carry it elsewhere (mostly north). In general, it may be said that the sediment input and output will be roughly equal. This balance might be disturbed by any interference along the coast. The design of the pile heads serves as an illustration of this. Pile heads allow the silt to remain in place by slowing the coastal current. The flow of sediment will look for a new balance. On the coast to the south of the Banjaard, pile heads are also visible. These can therefore disrupt the sediment supply to a limited extent. Furthermore, other constructions can also be placed that stop the sediment supply.


Figure 6: Pile heads along the Dutch coast

Sea level rise

Sea level rise is one of the greatest climates issues the Netherlands is now dealing with. This is brought on by the sea's expansion, the melting of glaciers and minor ice caps, and the gradual retreat of Greenland's and Antarctica's huge ice caps. The KNMI claims that the quick erosion at the borders of the West Antarctic and Greenland ice sheets also contributes to the rise in sea level. (Zeespiegelstijging, sd)

Bending of the coastline

In the North Sea, longshore transport takes place along the coast from the south to the north. The construction of the breakwater barrier and possibly the breakwater, will interrupt the longshore transport along the coast. This results in sedimentation on the south side of the breakwater barrier and erosion on the north side. It is very important to protect the north side of the breakwater barrier from erosion, as this is the weakest link of the barrier. The protection can be applied, for example, by making that part of the barrier from a different type of material. Crushed rock is a possible solution. Because poured stone has a much higher critical soil shear stress.

Sand hunger

Because the Oosterscheldekering was built, the process of silting up canals has already begun. After such an intervention, the sea searches for a new equilibrium. This balance has not yet been reached. causing the gullies to be hungry for sand. Because the sediment does not receive enough energy to accumulate around the flats and mud flats, sand starvation prevents the flats and mud flats from growing. Nevertheless, erosion occurs, which makes the plates and mud flats disappear. Sea level rise makes this effect even stronger.

Reducing sediment deposit

By carrying out nourishments, artificial islands can be created to protect the coast. However, the sand from these nourishments will also have to be dredged. If this happens at a place upstream from the coast, the sediment supply to the coast will also subsequently decrease, resulting in erosion. It is therefore important that replenishment vessels dredge in the right place so that sediment transport is not jeopardized.

Incidental erosion

Incidental erosion can occur, for example when a ship becomes stuck along the coast and must be excavated. An example of this is the Evergreen that got stuck in the Suez Canal in 2021.

Wind losses

In addition to water, wind can also affect the coast. For example: storms can affect the coast heavily. The high wind speeds result into even larger waves and therefore more erosion.

Figure 7: Sand storm boulevard Vlissingen Februari 2nd 2022

Management and maintenance

Because most of the erosion takes place on the north side of the breakwater barrier, it is very important to maintain and inspect this section properly. This is also the weakest part of the breakwater barrier. Furthermore, sedimentation can occur on the south side of the breakwater barrier, resulting in growing. This will probably not cause any problems in the short term. Nevertheless, it is wise to inspect the nearby shipping channels because these can silt up. (Witteveen+Bos, 2011)

Determination lifetime

Overall

To determine the lifetime of the island, a model will have to be used that can simulate the influences on the island. Since we from the HZ have no capabilities and limited knowledge to use such a model, the life span of the island has to be determined in another way.
Using other artificial islands at sea in such conditions, we can draw up a comparison. In this way, we can estimate how long the island will remain intact and what maintenance needs to be done to extend its lifetime.

To determine the lifespan of the island, different types of erosion play a role. The different types of erosion have already been explained earlier in this report.

The Sand Motor

On the Dutch coast at the height of Kijkduin, a sand motor was constructed in 2011. This means that a hump of sand was raised against the coast with the help of ships. The northward current transports sediment from the sand motor up the Dutch coast. Partly, the sediment settles. This defends the Dutch coast via a natural way.
The sand motor constructed in 2011 has an estimated lifespan of 20 years. The lifespan is an estimate.

Researchers give five recommendations regarding the sand motor.
First of all, a vision must be drawn up for the future of the Sand Motor. This will ensure clear expectations among the various stakeholders.

Furthermore, the researchers recommend spreading the lessons learned from the Sand Motor, so that, among other things, the Dutch coast can be defended on a larger scale. This way cannot be applied everywhere. That is why at 'De Banjaard' the choice was made to place a breakwater barrier instead of a sand motor, because 'De Banjaard' is mainly meant to protect the nearby coast from sea level rise. The Sand Motor is more intended to counter erosion of the coast as a whole.

The third point is to evaluate the current monitoring programme(MEP). It is important to evaluate how the Sand Motor erodes after a number of years. Because in reality, this processcan be different from the models. Due to the many aspects involved in the erosion of

this island, it is very difficult to simulate a completely accurate model. Therefore, it is also not possible for us to make a good model for the erosion of the Banjaard.
Advice is also given to continue monitoring the Sand Motor. This mainly refers to the need-to-know things. So that the risks and important developments are identified, so that the sand motor and other such projects can be developed further.

Lastly, the researchers recommend that clear management agreements be laid down. Because the Sand Motor will keep changing and so will the management. Clear agreements prevent difficulties in the future.

The five advice mentioned above also apply to 'de Banjaard'. Most of this advice will only emerge at a later stage of the project. Still, it is good to mention these preconditions, when predicting the lifespan of 'de Banjaard'. (Gerdes, 2021)

Maasvlakte 2

To determine the lifetime of “de Banjaard, we look at the lifetime of the Sand Motor off the coast of Kijkduin. The Sand Motor is an island that is not protected. To give 'de Banjaard' a longer lifespan than the Sand Motor, it is necessary to protect 'de Banjaard from erosion. Therefore, it is necessary to analyse another type of coastal defence in the same conditions where coastal protection is applied. This is why we chose to look at the lifetime of Maasvlakte 2. Maasvlakte 2 is the Rotterdam port expansion project located west of the First Maasvlakte. Maasvlakte 2 is constructed in the sea. The protection of this port does exceed the protection of 'de Banjaard'.

The exposed location of Maasvlakte 2, at a water depth of 20 m, places high demands on the protection from the sea and the quality of the seawall (see Figure 2). For the construction of Maasvlakte 2, including the seawall, the use of sand is economically advantageous. Along the west and southwest coasts, a beach and dune protection will be constructed on sand and gravel maintained by periodic replenishment. In the north, a dike is constructed because this part of the coastline must withstand heavy wave attack and strong currents and space in the foreshore is limited due to the presence of the harbour entrance. This structure rests on heavy stone and concrete cubes. The dunes are constructed at a height of 11 metres. The design life of the harbour is 50 years. (Tweede Maasvlakte, sd)

Figuur 8: Maasvlakte 2

Schouwen

Finally, we consider the current coastline of Schouwen near 'de Banjaard'. This shows that in a period from 2010 to 2019, 4.2 million m³ was supplemented over a length of 17 kilometres. In the Delfland, only 2.6 million m³ was supplemented over a length of 21 kilometres in the same period. This means that conditions around Schouwen are more extreme than at Maasvlakte 2 and the Sand Motor. This has a negative effect on the lifespan of “de Banjaard”.

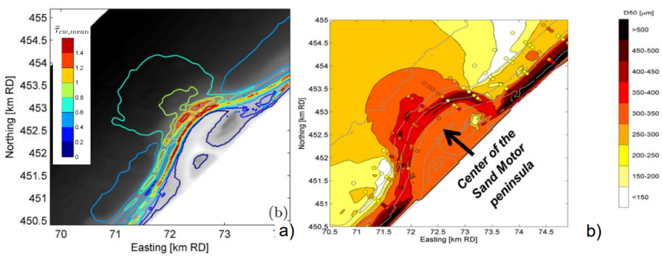
Conclusion

If “de Banjaard” will be constructed without protection, its lifespan is likely to be even significantly lower than the lifespan of the Sand Motor. However, the breakwater barrier will be protected by crushed rock at the ends. Furthermore, pile heads will be placed to slow down sediment transport. Various biobuilders will also be applied to extend the lifespan. The lifespan largely depends on the performance of the biobuilders. If they work well, the lifespan of the breakwater barrier can increase significantly. Furthermore, sea level rise plays a major role. For scientists, it is almost impossible to determine sea level rise over 50 to 100 years. Maintenance of the breakwater barrier is also an important aspect, because just like on the coast, the breakwater barrier needs to be maintained. Thus, replenishment will have to be applied when necessary. Furthermore, the requirements for a breakwater barrier are considerably lower than those for Maasvlakte 2, because consequences of flooding at a breakwater barrier are less than at a harbour.
Overall, we can conclude that 'the Banjaard is likely to last 40 to 70 years. This is only possible if the island is properly maintained.

Calculations shear stresses

the calculations are shown in appendix A.
The critical bottom shear stress at the site of 'De Banjaard' is 0.69. the bottom shear stress due to currents and waves is 4.87. This means erosion occurs.
If we compare this with the critical soil shear stress at the Zandmotoren site, we see that a critical soil shear stress of around 0.6-1.6 occurs there. This is much lower than 4.87. Nevertheless, this can be explained because the water depth at the location of the Sand Motor is much smaller than at 'de Banjaard'. In addition, the sand motor is located against the coast. This does not apply to the breakwater barrier.
(Natuur Veilig, sd)

Figure 9: Shear stresses de Zandmotor



Use of biofuels

In order to the reduce co2-emissions trailing suction hopper dredgers running on a hydrogen-, hybrid-, or lng-engine will be used. A choice will be made for the Banjaard project based on emissions, availability and efficiency.

A few hydrogen ships have been ordered by companies, however these ships are not for dredging. And have limited power. As dredging ships need a lot power for sailing, dredging and pumping this is currently not an option. Perhaps in the near future hydrogen-powered TSHD's are an suitable options when this technique is further-developed.

Diesel-electric engines have less then conventional dredgers, these vessels run on a combination of an electric motor and a diesel motor, due to this combination fuel is being used way more efficient.

Another option is lng-powered engines, there are currently 2 vessels under construction and 1 vessel is already in production. However lng (liquefied natural gas) is a fossil fuel, it has a reduction of 99% on sulfur oxides and small particles. The reduction on CO2-emissions is estimated at 80%.

For "de Banjaard" project lng-powered TSHD's will be used as they are the most suitable at the moment, and already two vessels are being built and one vessel already in production, these vessels have a barge capacity of 10500 m³. (Van Oord's LNG TSHD Vox Ariane busy on Elbe, sd) (Prioriteit KVNR: Realistische aanpak stikstofreductie zeevaart, sd) (Sustainable fuel strategy, sd)

Figure 10: Van Oord LNG ship

Drawings

Figure 11: 3 Top view breakwater barrier

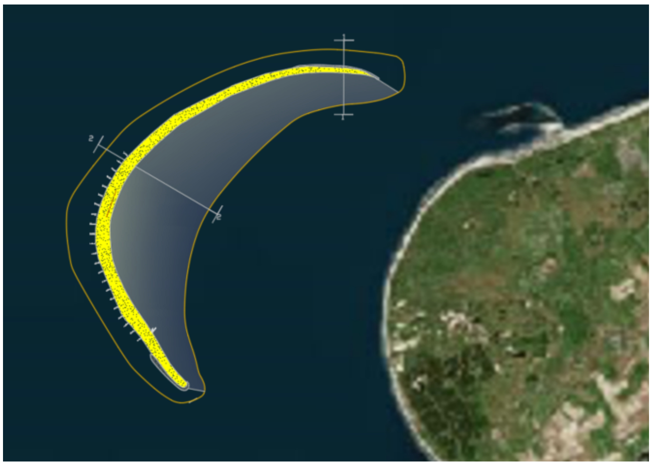


Figure 12: 4 Side view 1

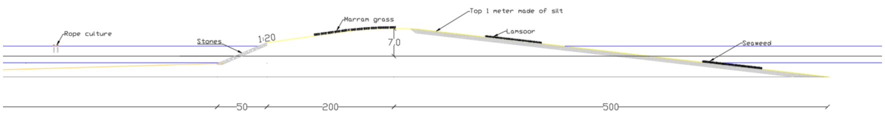


Figure 13: 5 Side view 2a

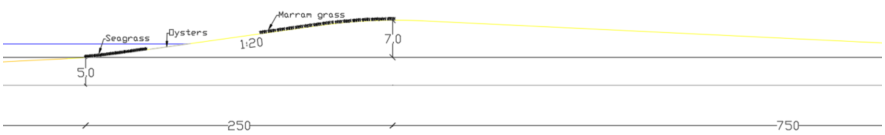
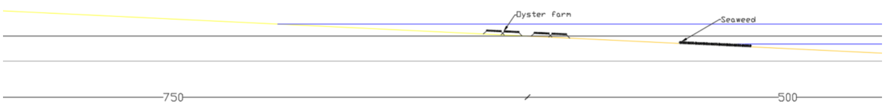


Figure 14:6 Side view 2b



Planning

To make a reasonable planning a cycletime of a trailing suction hopper dredger and a craneship has been constructed. The following assumptions have been made:

- Hopperbarge capacity of 10500 m³
- Max. sailing speed of 15 knts
- Max dredging depth of 42 m
- Tons stonework per week 7500 ton

Table 5: Hopper cycle times

Hoppercycletimes		
Hoppervolume (m³):	10500	Trailing suction *hopper dredgers*
loadfactor: 70%	7350	
Sailingdistance ca. 20 km	90	(minutes based on average sailingspeed of 15 km/h)
loadingtime	90	minutes
unloadingtime	90	minutes
Cycle	270	minutes
cycles per day	5,333333333	
cycles per day	5	round off to whole number
Average dayproduction	36750	
number of vessels	3	
total dayproduction	110250	
total workdays sand dumping	408	
Rockdumping		
Total tons stonework	499 000	
Tons per ship per week	7500	
Total ships	2	
total workweeks stonework	33	
total workdays stonework	233	

Execution method

In total the construction phase for only the sand suppletion would take 58 weeks. The average depth at the project location is ± 5m, so the hoppers will be able to rainbow the first loads, and when enough sand is disposed, a floating pipeline can be layed out. A pontoon will remain in the deeper water so that the hoppers can connect with the pipeline. On the other side of the pipeline a crane can move the pipeline and extend it with extra pipes. Bulldozers will move the sand from the pipeline to the required destination.

The suppletion will start on the north side and from there the work will continue in the southern direction. So that the machines can start levelling the island and the rock dumping on the north side can begin. At the same time the placing of the ecological applications can take place. The placing of the wooden pile groins can start after half of the island has been constructed since the pile groins are located at the southern part of the island.

The rock dumping will take 33 weeks, this can start after the north side of the island has been suppleted. The dumping will be done from 2 pontoons with cranes on it, and 2 vessels will continuously supply the rocks.

Costs

Preparation phase cost
The preparation cost are set at 10% this consists of the planning, mobilising ships, legislation, work preparation.
AKWR
AKWR stand for 'average costs', 'profit' and 'risk'. A contractor usually ads 3% on the total costs when making a contract.
Construction phase cost
These are the costs during the construction phase, this is also including failing costs which can play a big part in the overall cost, failing cost can be due to bad weather, so ships cannot sail or rising fuel/material prices. The failing costs are set at 10% of the construction costs. below an overview is given of the cost per type of material and equipment, prices per ton rock or cubic metres of sand include the costs of the ship, personnel and fuel.

Dredging 58 weeks in total:

- €2,75/m³
- crane €1300/day
- bulldozers €1300/day
- 1 shovel: €1100/day
- Pontoon: €2500/day

rocks 33 weeks in total:

- €15/ton
- Pontoon+crane+ personnel €310/hr
- Tugboat: €125/hour
- Hopperbarge: €10/hour

Wooden piles: 22 times 2*100m. 0,5 m h.o.h. 11 weeks in total:

- Pontoon+crane+ personnel €310/hour
- 2200 piles: €60/piece

Biobuilders and recreational houses:
Are estimated at €30.000.000, - in total, this will be further discussed in the following chapters.
(Baggeren en transporteren, kosten, sleephopperzuiger, sd)
(Faalkosten, sd)
(Paalhoofden, wachter van de kust, sd)

Table 6:7 Costs of breakwater barrier

Type of cost	Amount	Cost per day	Cost per week	total
Biobuilders and recreational houses				
Biobuilders				€ 15.000.000,0
Recreational houses				€ 15.000.000,0
Construction phase				
Dredging				
sand (€ 2,50/m³)	110250	€ 275.625,0	€ 1.929.375,0	€ 111.903.750,0
pontoon	1	€ 2.500,0	€ 17.500,0	€ 1.015.000,0
crane	1	€ 1.300,0	€ 9.100,0	€ 527.800,0
bulldozer	2	€ 2.600,0	€ 18.200,0	€ 1.055.600,0
shovel	1	€ 1.100,0	€ 7.700,0	€ 446.600,0
rockdumping				
rocks (€15,00/ton)	7500	€ 241.071,4	€ 112.500,0	€ 3.712.500,0
Pontoon+crane+personnel	2	€ 620,0	€ 4.340,0	€ 143.220,0
tugboat	2	€ 200,0	€ 1.400,0	€ 46.200,0
hopperbarge	2	€ 20,0	€ 140,0	€ 4.620,0
Woodenpile groins				
Wooden piles	2200	€ 3.428,6	€ 24.000,0	€ 168.000,0
Pontoon+crane+personnel	1	€ 310,0	€ 2.170,0	€ 23.870,0
Mooring Quay				
Pontoon+crane+personnel	1	€ 310,0	€ 2.170,0	€ 2.170,0
wooden quay	1	€ 10.000,0		€ 10.000,0
				€ 119.059.330,00
			failing costs(10%):	€ 11.905.933,00
			Preparation costs (10%):	€ 11.905.933,00
			AKWR (3%):	€ 3.571.779,90
			total:	€ 146.442.975,90

Strengthening phase

Now that the physical and technical aspects of the breakwater barrier island “de Banjaard” are analysed and calculated, the barrier island can be constructed. However, to keep the barrier island on its designated place and to withstand high amounts of erosion, strengthening the barrier island is of importance. Therefore, in this chapter there has been looked at the contributions of bio builders to protect, reinforce and expand the initial nourishment for the breakwater barrier island “de Banjaard”. The research question addressed in this chapter is the following:

- What are the contributions of bio builders to protect, reinforce and expand the initial nourishment(s)?

Theoretical framework

Bio builders or bio engineers are defined as:
"Plants, animals, or other organisms that alter the physical properties of living or dead material in a way that adversely affects the availability of resources for other species".

The term "bio-engineers" comes from the original English term "ecosystem engineers," which actually more accurately describes what those species do: ecosystem engineers are organisms that change their environment through their presence or actions, either directly or indirectly. By doing this, they either alter, preserve, or create new habitat for both themselves and other living things. Take into account, for instance, how reef-forming shellfish, like oysters, can affect wave damping and sedimentation in addition to serving as a habitat for various other creatures.

There are two types of bio builders: autogenous and allogenic. Autogenous bio-builders contribute to the environment with their living or dead material, for example shells that become part of the sediment, corals or trees after the death of the organism. Allogeneic bio-builders are organisms that influence their environment through their physical presence or activity, but do so with existing material. For example, salt marsh plants have an allogeneic effect, because the plants influence waves and currents and thus promote sedimentation. Some bio builders are autogenous as well as allogenic, such as Pacific oyster reefs. As allogeneic bio-builders, oysters filter the water, making it clearer and (organic) material from the faeces is deposited on the bottom.

The management of water safety can benefit from bio builders in two ways. Due to their position on the forelands in front of the dike, they can first and foremost contribute to a physical flood defence. Second, bio builders can affect the rates of erosion and sedimentation as well as the accessibility of sediment, which in the long-term can have an impact on the morphology. Salt marshes can grow along with the rise in sea level. By catching moving sand in dunes, marram grass can establish the coastal zone for a considerable amount of time. These outcomes have a local but at the same time a systemic impact.

Biodegradable Bio-builder

Sandbank edges can be protected by using connected ecosystems, such as shellfish reefs and seagrass beds, which are able to stabilise and trap sediment, which in turn reduce hydrodynamic loads on the sandbank edges (Marin-Diaz, 2021). These bio-builder s influence their environment in such a way that they create their own ideal living conditions and help new species settle once a reef has been formed (v/d Heide, 2022). The optimal reef design is stable, easy to install, easy to locate, suitable for many species and cost efficient (De Rijke Noordzee).

Oyster reefs

Oyster reefs are frequently found at marsh edges. The vertical structure of the reef serves to attenuate wave energy and water velocity which results in reduced erosion as well as increased sediment deposit behind the oyster barrier (Chauvin, 2018). Moreover, they are believed to be an effective alternative to the normal and unsustainable coastal defence structures such as a rubble mound breakwater (Salatin, 2022). The potential to be a self-sustaining shoreline protection service makes them such a preferred alternative to the beforementioned traditional structures (Chauvin, 2018). Oyster reefs are able to reduce wave heights by 30-50% for water depths between 0,5-1,0 meters, 0-20% for water depths between 1,0-1,5 meters and <10% for water depths greater than 1,5 meter (Wilberg, 2019). Due to the wave dissipation reefs can successfully trap sediment at lower intertidal areas (Chowdhury, 2019).

Oyster reefs therefore could be ideal bio-builders since they have been built before in the province of Zeeland, see figure 15. Namely in the Eastern Scheldt estuary. An experiment run by Wageningen university has tested the formation of Japanese oysters (Crassostrea gigas) reefs by shells of Japanese oysters that are held in place by gauze.

Figure 13: Oyster reef constructed in the Eastern Scheldt estuary in the Netherlands (Roskamp, 2019)

Once an oyster finds hard substrate which in this case are the shells of the Japanese oyster itself, it becomes a robust reef that reduces erosion even while the gauze disintegrated after some time. (Roskamp, 2019).

The before mentioned experiment conducted by the Wageningen university is not the only experiment of oyster reefs in a biodegradable form. Another experiment with biodegradable oyster reef was finished in 2021. This experiment was conducted in the Wadden sea near a tidal flat called Griend, which is 2 to 6 cm in height and 10 to 30 meter in width (Marin-Diaz, 2021). See figure 16.

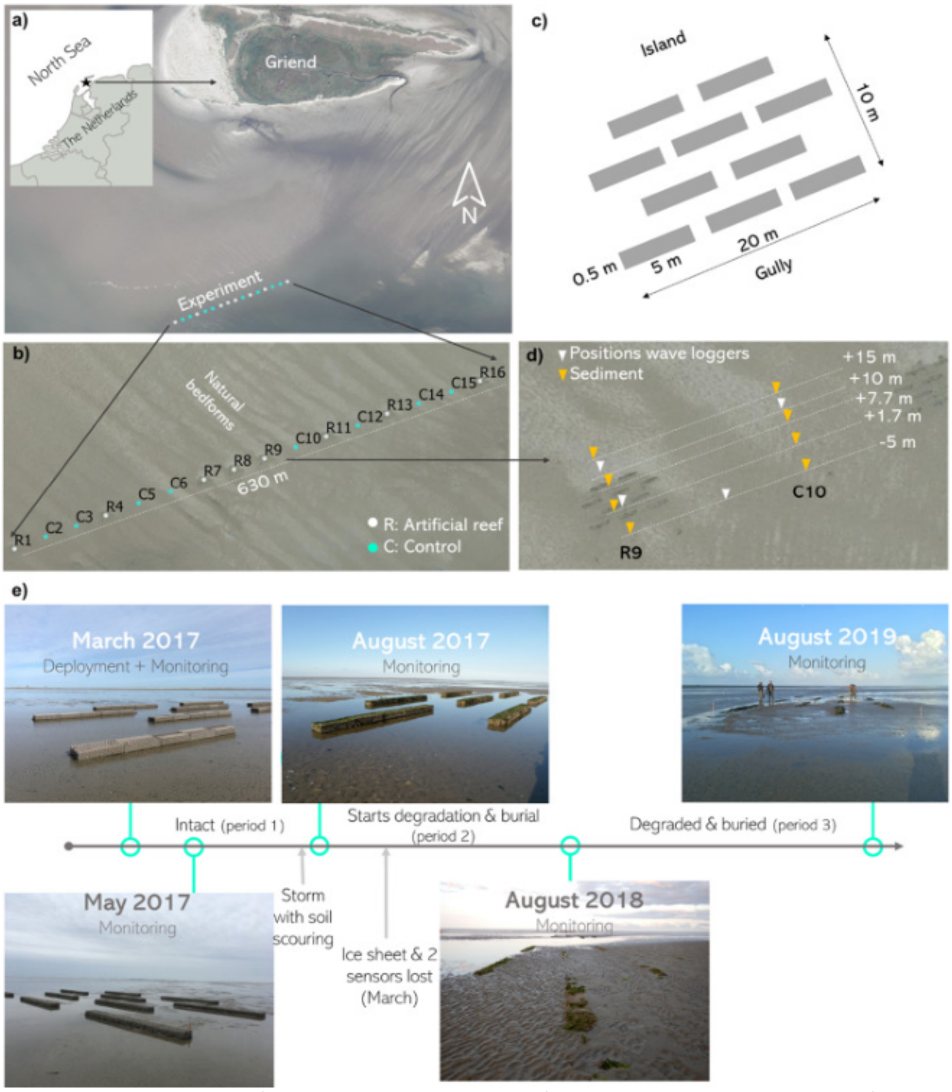


Figure 14: Methodology Griend tidal flat experiment in the Wadden sea. This figure shows the location, set-up, placement of sensors and timeline of events (Marin-Diaz, 2021).

For this experiment, BESE- biodegradable artificial reef structures were chosen. The main hypothesis was that an artificial biodegradable reef structure would promote sediment accretion, but that over the long-term morphological effects of these structures would depend on the integrity of the reef (Marin-Diaz, 2021). Therefore, three parameters were chosen to asses if this hypothesis was correct. The three parameters were as follows: attenuation of

	May 2017	August 2017	August 2018	August 2019
	(n = 16)	(n = 16)	(n = 16)	(n = 16)
Mean cumulative artificial reef height degradation (cm)	0.0 ± 2.4	0.0 ± 2.2	−12.6 ± 2.5	−14 ± 1.9
Remaining reef height (cm)	~20 (intact)	~20 (intact)	~8 (degraded)	~6 (degraded)

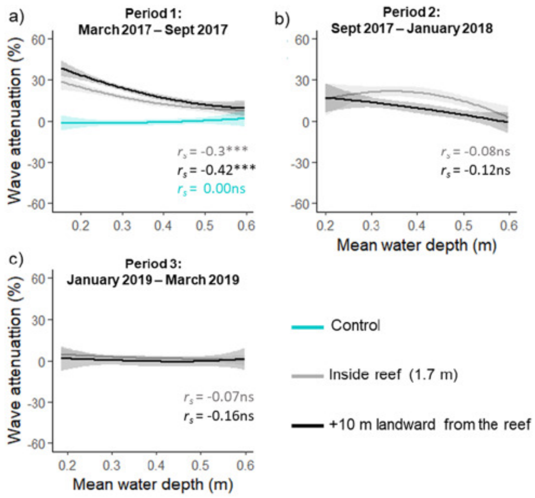


Figure 15: Wave attenuation of the biodegradable reef compared to the control which is a tidal flat (Marin-Diaz, 2021).

waves, the change of the tidal flat morphology and the effect on the surrounding sediment properties. The first result discussed is the wave attenuation coincided with reef height reduction over time. The biodegradable reef structure started with a height of 20 cm and lost a height of 12 cm in 2018 and 2 cm in 2019 which in total is 85% of the beginning of the height.

Including all the possible wind directions, wave attenuation of the biodegradable oyster reef was significantly higher when compared to the control with water levels below 0,5 metres. However, on the other hand, this was not the case for higher water levels (Marin-Diaz, 2021).

The second parameter researched, was the effect of the biodegradable reef on sediment dynamics. In this study, the installation of the biodegradable artificial reef in the tidal flat led to both erosion (up to 11cm) and accretion (up to 11 cm), as can be seen in figure 18 at the local scale which is approximately 10 metres land inwards (Marin-Diaz, 2021).

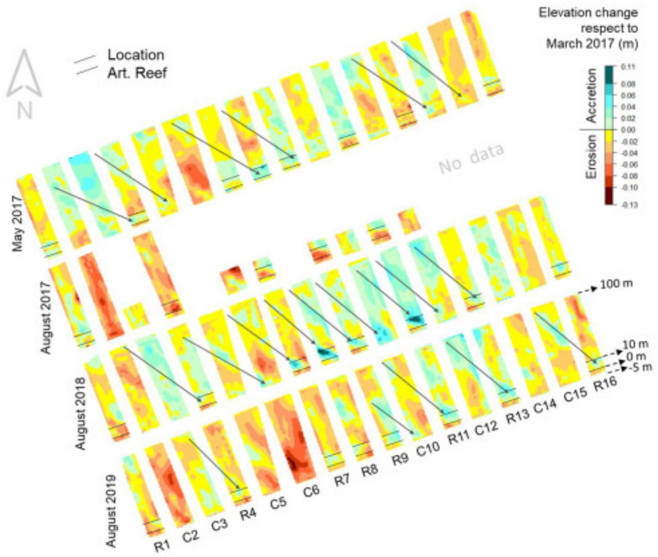


Figure 16: Elevation model of the biodegradable reef transect with elevation changes compared to the original situation in 2017 in meters (Marin-Diaz, 2021).

When looking back at figure 17, the 6 cm height biodegradable artificial reef did not have a significant effect on attenuation of waves but on the other hand, they most likely affected the sediment dynamics due to the attenuation of the flow velocities and thereby trapping sediment (Marin-Diaz, 2021). The last parameter researched was the change in sediment properties in the surrounding area. The results showed that the biodegradable reefs did not have a significant effect on sediment properties in the surrounding area when compared to the control tidal flat area.

The overall conclusion of this experiment was the following; the set-up was not resistant enough to persist long term, or to sustain a stable oyster reef which would overtake the effect of the reef by trapping sediment (Marin-Diaz, 2021). The research recommends to conduct this experiment on a larger scale due to a higher effect on tidal flat morphology and the use of a more resistant material.

Another trial with BESE and plastic was done in 2021 by C. K. Nitsch. The goal of this study was to determine if biodegradable BESE material is comparable for Oyster settlement when compared to traditional plastic material.

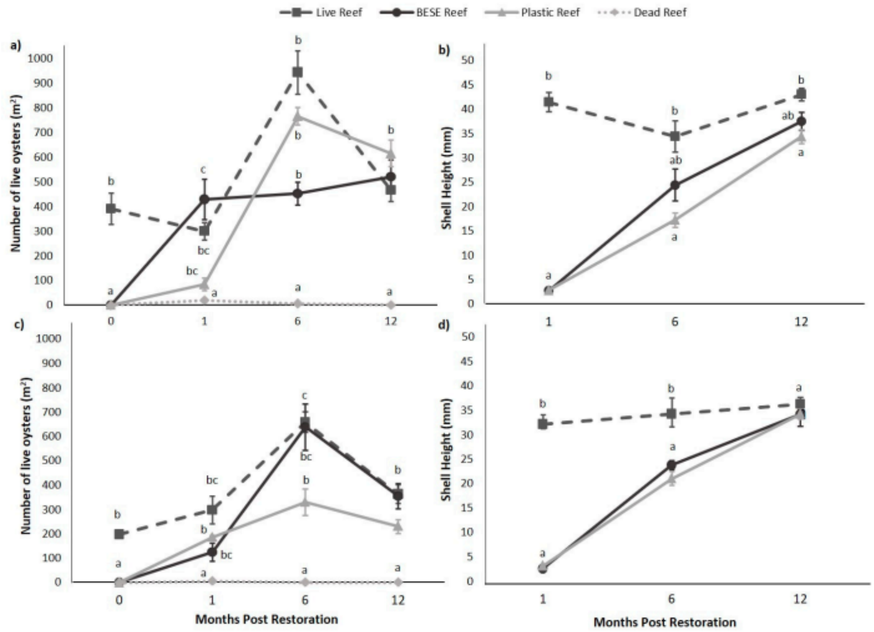


Figure 17: Oyster monitoring values for the experiment by C.K. Nitsch comparison live reef, BESE reef, plastic reef and dead reef. (Nitsch, 2021).

In field conditions, Oyster reef settlement was successful for both plastic and BESE. Furthermore, oyster densities did not differ significantly between plastic and BESE at any point in a period of 12 months (Nitsch, 2021).

BESE is not the only alternative in using biodegradable material. Other materials that are biodegradable are jute, cellulose and cotton. These materials can also be used for the construction of artificial oyster reefs. An experiment finished in July 2022 used recycled oyster shells in mesh bags from four different materials (plastic, cellulose, jute and cotton). The reason to use recycled oyster shells is that it offers a hard substrate which Oyster settlers seem to prefer rather than a soft substrate. The results in figure 6 show that the biodegradable mesh which turned into loose shells had larger size oysters (46 mm) when compared to the plastic mesh bags (40 mm) (Comba, 2022). A cost comparison was set up for all four materials as can be seen in table 1. Table 1 shows that the total cost for plastic bags is the lowest when compared to the other three biodegradable materials. However, table 1 shows that plastic has a high estimated environmental cost which on a large-scale project could be even higher.

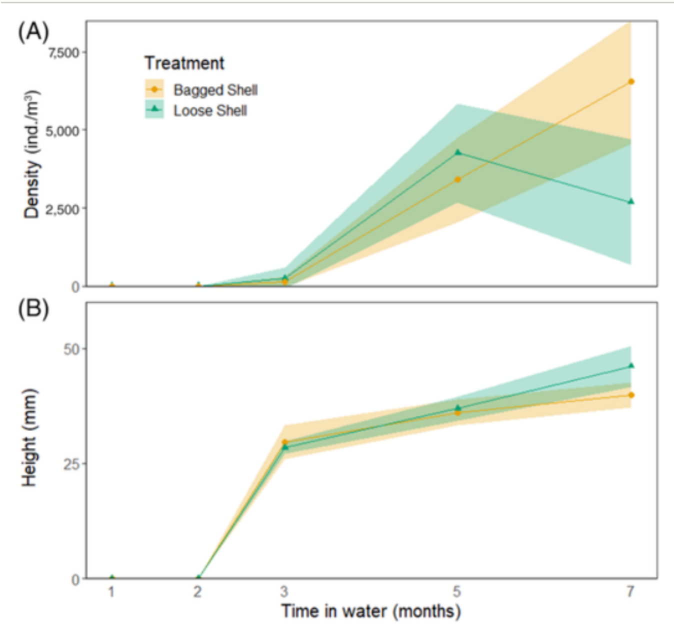


Figure 8: (A) Mean density of bagged plastic mesh oysters and biodegradable bags/ loose shells and (B) height of the shell in both situations (Comba, 2022).

Table 7: Cost comparison of four materials used in mesh oyster bags (Comba, 2022).

	Material Cost	Shipping Cost	Time (hours)	Labor Cost	Environmental Cost	Total Cost
Cellulose	$4,400	$660	11.9	$339	$0	$5,411
Jute	$2,200	$550	22.2	$633	$0	$3,405
Cotton	$1,500	$520	14.9	$426	$0	$2,460
Plastic	$127	$188	25.1	$717	$139–$1,391	$1,196–$2,448

The research done by C.K. Nitsch looked into the BESE properties when compared to traditional used plastics for constructing artificial oyster reefs. Results show that BESE is as successful as traditional plastic based artificial reefs without requiring the use of plastics (Nitsch, 2021). However, the research done by Comba seems to suggest some hurdles to overcome in the form of the speed of disintegration which in their research was less than two months. The cellulose bags are made in the Netherlands and are specifically tailored to Baltic Sea conditions (Comba, 2022). A reason that the disintegration was higher than expected is that the cellulose bag was made for Baltic conditions and not for condition in the Mexican gulf where the experiment was carried out. The BESE biodegradable artificial reefs lost 7-12% of mass over a 12-month period and was placed at the Atlantic coast of America (Nitsch, 2021). Reasoning and results seem to suggest that the rate of disintegration is not a hurdle under the conditions of the Banjaard.

Seagrass

Seagrasses are named so because of their long green grass like leaves. Seagrasses are found in shallow salty/brackish waters in all parts of the world (Reynolds, sd). From a physical point of view as eco-engineers seagrasses are able to reduce current flow, dissipating wave energy and stabilize sediment (Ondiviela, 2013). Seagrass meadows are important for sediment trapping and sediment stabilisation (McKenzie, 2007). The way seagrass dissipates wave energy is by deflecting the flow above the canopy to the sides of the bed, which leads to a reduced flow speed through the seagrass bed (Beena, 2016).

Artificial structures promote a positive feedback loop of natural seagrass by preventing transplants being dislodged by waves, currents and foraging fauna (Carus, 2021). One type of these artificial structures are the ASG seagrass mats which are made of several leaves built into a mat. Usually, the artificial seagrass is made using polypropylene rope, old nets, stones and floats and is set in the sand-muddy shallow subtidal zone at a depth of 0,5-1,5 meters (Gonzales, 1994).

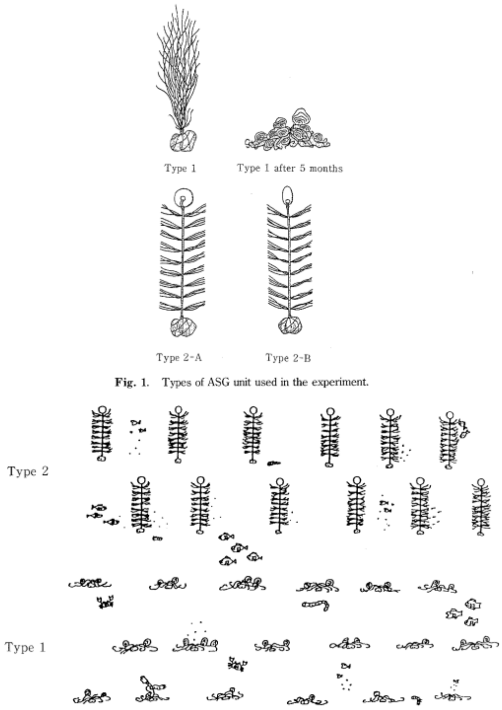


Figure 9: ASG beds after five months. Showing type 1 (settled on the ground) and type 2 (still at vertical positioning (Gonzales, 1994).

ASG of different lengths are highly flexible at a length of 1 meter parallel to the flow and can potentially help seagrass restore under high flow/turbidity conditions (Carus, 2021). Type 1 that can be seen in figure 7 had more seagrass epiphytes than type 2A and 2-B, however the epiphytes remained in a vertical position (Gonzales, 1994). Moving away from plastic there is pure cellulosic fibres, cotton, linen fabric and compostable plastic (Carus, 2021).

Rope culture

Large aquaculture systems may have the potential to dampen wave energy to protect coastal zones (Longhuan Z. , 2021). One of these aquaculture systems is rope culture for sugar kelp or for mussels. The aquaculture industry uses suspended rope culturing in the form of long line structures of ropes supported by floats (Stevens, 2007). This aquaculture system will interact with the hydrodynamics of the area causing water flow distortion, current attenuation, wake formation, distorting water column stratification, effect on nutrients supply, altering material dispersal, bio deposition, resuspension and an effect on carrying capacity of the system (Cabre, 2021).

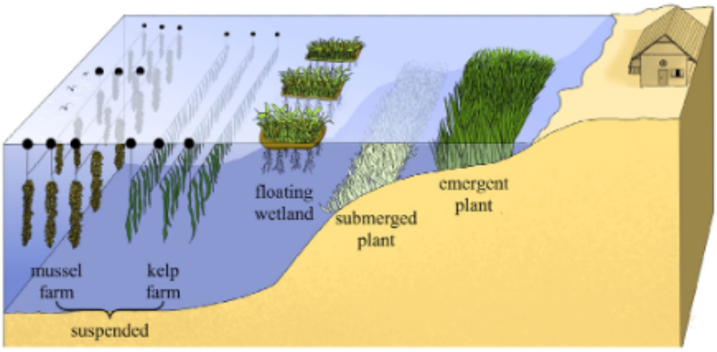


Figure 10: Coastal defence concept consisting of suspended rope culture, floating wetlands, submerged plants and emergent plants (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020)

Near surface cultivated rope kelp may damp more wave energy than bottom culture kelp since the wave motion decreases near the bottom (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020). This is most likely due to the blade dynamics of kelp which create an asymmetric motion in the water by vertical wave orbital velocities (Longhuan Z. , 2021). Mussel rope cultures seem to show the same properties as kelp rope cultures. Long line mussel farms move and flex to accommodate wave energy that induces drag in the water flow velocities, which have the potential to enhance mixing horizontal and vertical and this benefit is not seen in bottom culture which generates turbulence (Cabre, 2021). These are not the only benefits these culture systems have. Kelp for instance can absorb carbon to mitigate climate change and reduce nutrients to improve water quality which results in an increase in the growth rate of marine species in the surrounding area (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020).

Long-line mussels show an increase in the biomass and pelagic organisms between and around the rope cultures using them as shelter, refuge and nursery (Cabre, 2021).

Kelp

An experiment was done in Maine, USA with Sugar kelp (Saccharina latissimi) in Saco Bay in august 2020. The aim of the experiment was to see the wave attenuation characteristics of suspended sugar kelp farms. The results from this experiment show that 20 longlines with 1-meter-long blades and 100 blades per meter have a potential to dampen wave energy up to 33,7% (Longhuan Z. , 2021).

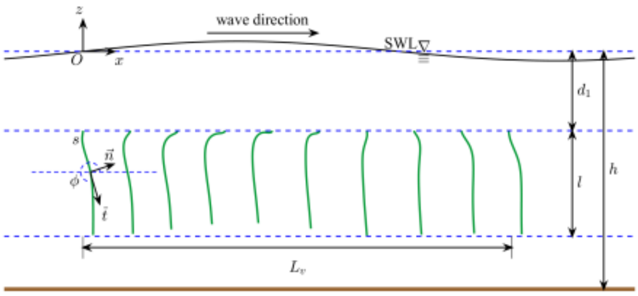


Figure 11: Sketch up of the experimental set-up Saco bay, Maine, USA (Longhuan Z. , 2021).

This reduction in wave energy could be increased to 50% when a larger farm is emplaced with an amount of 250 longlines (Longhuan Z. , Green Alternatives to wave attenuation in a changing climate., 2019). This can be seen in figure 10. 33,7% attenuation of wave energy can be seen in the blue line (125 longlines) and 50% attenuation of wave energy can be seen in the red line (250 longlines).

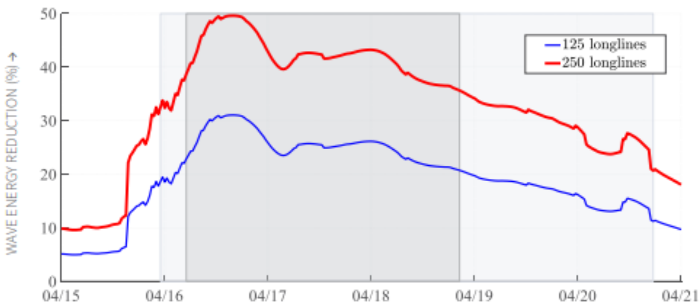


Figure 12: Wave energy reduction by model kelp aquaculture farm in Saco Bay, Maine. The light and dark shade indicate the significant wave height higher than 1m and 2m (Longhuan Z. , Green Alternatives to wave attenuation in a changing climate., 2019).

Wave attenuation of kelp beds on the seafloor have been recorded at 10% of waves approaching the shore (Morris, 2020). This might be due to the fact that the stipe-blade bundle increased drag while the flow velocity decreases (Lei, 2021). This theory is not been tested in field but in 2D models however, this theory is correct. This would mean that rope cultured kelp might be an effective tool to decrease wave energy. Wave dampening by kelp aquaculture farms is also less affected by water level changes such as tides, surge and sea level rise, which makes them a resilient shoreline protection measurement in a climate changing environment (Longhuan Z. , Green Alternatives to wave attenuation in a changing climate., 2019).

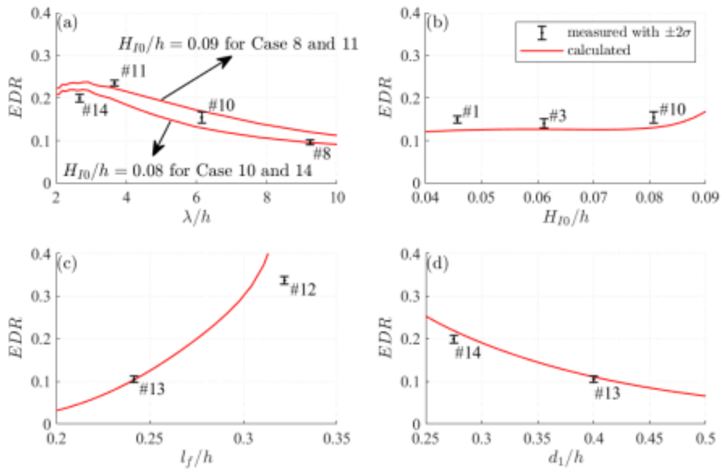


Figure 13: Measured and calculated wave energy dissipation ratio (EDR) for suspended model kelp culture (Longhuan Z. , 2021).

As the water depth decreases the rope culture takes up more of the water column so that the EDR increases, as can be seen in figure 11 c, which is because of the rope culture moving upward can lead to improved wave attenuation characteristics. This can be seen in figure 11 d (Longhuan Z. , 2021).

Kelp rope culture can dissipate more wave energy than suspended mussel rope culture, however wave attenuation of the kelp is influenced by changes in the water level. A decrease is seen during high tides, storm surges or storm tides (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020). This may indicate that Kelp rope cultures would function less efficient during extreme events like storm surges or tides because erosion still takes place during such an event. Another drawback of Kelp rope culture is that it is dependent on water depth due to light and nutrients (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020).

Mussels

Saco bay, Maine housed another experiment in the form of wave attenuation by rope cultured mussels. Figure 26 shows that the wave energy dissipation ratio (EDR) increases with significant wave height, however the EDR decreases with water level resulting in wave attenuation with the same period of the tidal cycle (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020). Mussels are even more resilient then SAV (Kelp farms) since they can move easier up and down with the buoys. The larger and denser the mussel farm is the more pronounced the wave attenuation is with an EDR up to 32%, which is a bit more than a similar size SAV (Kelp farm) at 26% EDR (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020). However, this can be increased for the SAV (Kelp farm) by increasing the density of the blades which will result in the before mentioned EDR of 50%.

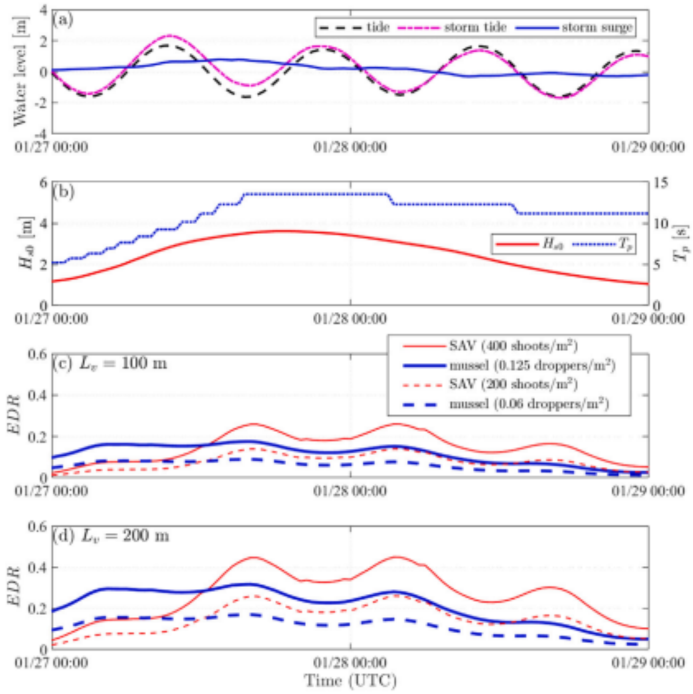


Figure 14: Wave attenuation/ EDR of mussel rope culture recorded in January 2015 Saco Bay, Maine (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020).

Hydrodynamic studies have shown that offshore mussel rope culture reduce water flow velocities both near the bed and within the canopy, while the highest velocities are found around the farm and beneath the farm between the bed and the suspended canopy of the rope culture (Cabre, 2021).

If the rope culture upstream is aligned with the flow, only a fraction of the water goes through which is slowed down by great velocities, however if the rope culture is placed perpendicular to the current the water flow modification is more wide spread (Cabre, 2021). The first option might be problematic since the downstream mussel rope cultures get a lot of supply for food but this is used up the further upstream the flow goes. The rope cultures therefore perform the best when they are placed at a 45^0 angle to the flow and larger rope cultures at an angle between 50^0 to 90^0 to the current (Cabre, 2021).

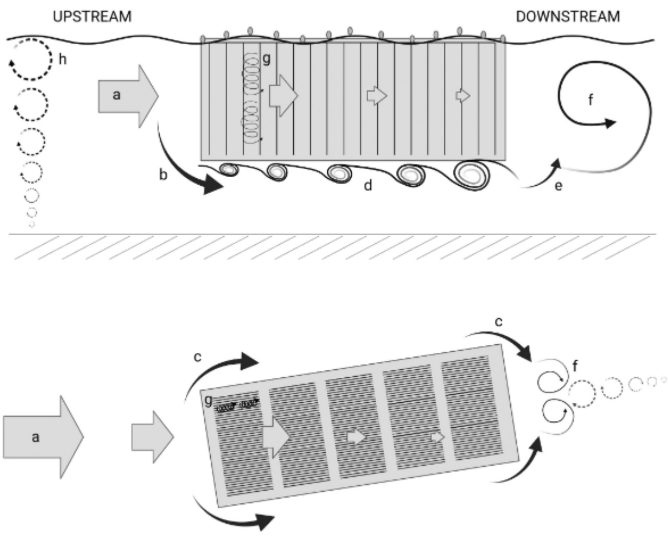


Figure 15: An offshore longline mussel farm and the hydrodynamic processes it forms as seen from the side and top (Cabre, 2021).

When compared to the Kelp rope culture, mussel rope culture has no depth restriction, which means in theory mussel rope culture can be designed to achieve an optimal wave attenuation (Longhuan Z. , Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies., 2020). If the mussel rope culture can be well enough designed that the incident wave height is as low as the normally average wave height, the mussel rope culture can mitigate erosion. This can be designed with a formula found in the report by Zhu Longhuan seen in figure 28.

$$L_v > \frac{1}{\beta\left(\omega_c\right)} \ln \frac{H_{s0}}{H_{sT}},$$

Figure 16: A formula to design mussel rope culture to optimally achieve wave attenuation.

Biodegradable lines are made out of jute or coconut fibre and cost 1000 Indonesian roepiah per metre which is 0,00060 euro (Rejeki, 2020). Spat of mussels and blades of Sugar Kelp are readily available since the two species are cultured in the Eastern Scheldt. Costs of placement of buoys is unclear however the costs of spat and Sugar kelp should fall to the owners of the suspended rope cultures.

Eco-concrete

Eco-concrete is different to traditional concrete in the way that traditional concrete is smooth and that eco-concrete is rough, has different textures and shapes. Eco-concrete will stimulate growth and biodiversity in exposed environments (Ecoshape, sd). This nature-based design of the units mimics favourable habitat conditions for native target species (Econcrete, 2021). The surface of the blocks, the spaces between and inside them create a habitat for multiple marine flora and fauna like algae, crabs, shellfish and birds (Ecoshape, sd). The sedentary species that make the eco-concrete their home can even help strengthen the concrete with a layer of calcite armor from barnacle or clam shells, while carbon storing grows their skeleton (Econcrete, 2021).

Eco slabs usually have a size of 75 cm x 50 cm. They are attached both horizontally and vertically to the concrete blocks and the geometrical shapes vertically placed slabs are different to horizontally placed slabs (Ecoshape, sd). Table 2 shows that six different shapes and textures are available for the eco-slabs. The eco-slabs were placed on 15 large X-blocks s(2m by 2m) as shown in figure 29.

Table 8: A list of the six textures/shapes for both the horizontal and vertical slabs (Ecoshape, sd).

	vertical slabs		horizontal slabs
1	vertical grooves	1	fine and smooth surface structure
2	small holes	2	cup (45% of surface)
3	fine surface structure	3	horizontal grooves
4	horizontal grooves	4	smooth surface structure
5	medium-fine surface structure	5	small holes
6	smooth surface structure	6	vertical grooves

Figure 17: X-blocks used in Ijmuiden for placement of eco-slabs (Ecoshape, sd).

The eco-slabs will have a rough defensive layer of marine life in the form of oysters and tubeworms which help to dissipate wave energy, buffer hydrodynamic forces and add stabilizing weight (Econcrete, 2021). This can be particularly designed by controlling the settlement since mussel prefer grooves and periwinkles settle in holes (Ecoshape, sd).

The costs for the production of the eco-slabs are €60 per slab. The complete constructional costs are estimated at €6000 for 10 eco-slabs (Ecoshape, sd). The x-blocks for the foundation are estimated at a cost of in total €14.732. This is calculated by adding up the trunk and head costs in table 9. With the added cost the eco-slabs provide a benefit in the form of mitigation penalties which were reduced by 80%, in this case €15 million (Econcrete, 2021). As a last note the estimated additional costs of eco-slabs are expected to be about 2 to 3 % of the costs of normal blocks (Ecoshape, sd).

Table 9: Total costs of the x-blocks can be derived by adding up total cost trunk and total cost head (Wagner, 2004).

	Accropode	Xbloc	Cube3800
Total cost trunk [euro]	7,250	6,350	20,851
Total cost head [euro]	10,094	8,382	24,492

Marram grass

Dunes emerge through interaction between sand, wind and vegetation (Tangelder, 2013). Vegetation plays a vital role in this interaction by slowing down the wind to such a degree near the vegetation that sand can settle on the spot. Marram grass is one of these plants and its fibrous, matted roots bind sand down, which promotes colonisation of other plants in the surrounding area (The Wildlife Trusts, sd). Continuous supply of sand and an onshore beach wind direction is of vital importance for Marram grass survival (Tangelder, 2013).

Figure 18: Dune development at the Sand Motor (Ecoshape.org, sd)

Marram grass (Ammophila arenaria) is a coastal grass species that combines two unique advantages for dune building. These two unique advantages include a very high tolerance to burial by wind-blown sand and more vigorous growth due to a positive feedback loop created by burial by wind-blown sand (Nolet, 2018). To establish Marram grass, two methods are developed which are sowing the seeds and disk harrowing of rhizomes (Putten, 1989). When planting this Marram grass note should be taken that the plant is tolerant to salt spray but not to full immersion (Risc-Kit, sd). Field experiments done by Wageningen University show that high sowing rates in combination with high planting densities resulted in a high number of seedlings. Moreover, application of NPK fertilizer increased the number after one growing season (Putten, 1989). The sand motor has dunes nearby which have had empirical research done on them on the optimal burial rate of marram grass. The results show that the optimal burial rate is around 0.31 meters of sand per growing season and a maximum burial tolerance between 0.78 meters and 0.96 meters of sand (Ecoshape.org, sd).

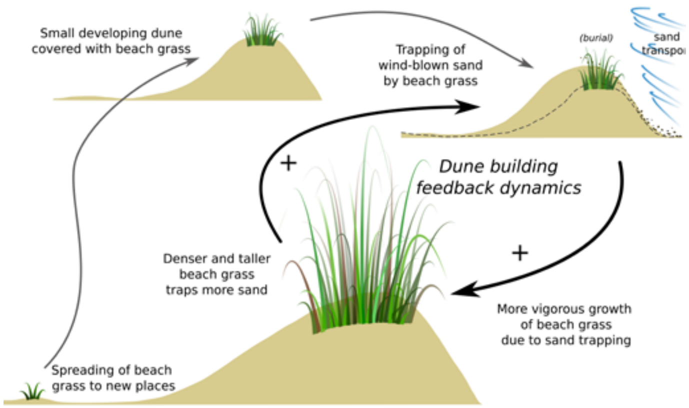


Figure 19: Overview of Marram grass positive feedback dynamics (Ecoshape.org, sd.

Marram grass is already available in the Netherlands since it is in use in coastal defence. Individually the plants commercially range from €1,95 to €2,69 on gardening websites. For the Banjaard it is probably best to avoid buying seeds and better to use grown Marram grass. This is due to the harsh conditions on site and to get the highest survival rate it is therefore better to buy grown Marram grass of 30-60 centimetres. Plants of these sizes range from €8,96 to €11,95 on the same gardening websites. The ideal density is 9 Marram grass plants per square meter (Directplant, sd). Labour costs were estimated at € 22619.60 per/ kilometre but this work can also be done by a volunteer group which negates these costs entirely (Risc-Kit, sd).

Design

For the design of the bio builders placed on and around the breakwater island 'de Banjaard', figure 8 seems to be ideally suited. Kelp and mussel rope cultures form the first defence layer in the form of suspended bio-builders of the barrier island. This system will interact with the hydrodynamics of the area causing water flow distortion, current attenuation, wake formation, distorting water column stratification, effect on the supply of nutrients, altering material dispersal, bio deposition, resuspension and an effect on carrying capacity of the system. The next defence layer are the submerged plants which in this design takes the form of artificial seagrass beds. Seagrass meadows are important for sediment trapping, sediment stabilisation and they dissipate wave energy which leads to a reduced flow speed through the seagrass bed. Emergent plants in the design of figure 22 will be replaced by Oyster reefs. This will form an additional in conjunction with the seagrass beds since Oyster reefs can fall dry for short periods of time where seagrass meadows cannot. The oyster reef will serve to attenuate wave energy and water velocity even further which results in a reduced erosion as well as increased sediment deposit behind the oyster barrier.

Two additional layers will be introduced in the form of eco-concrete and Marram grass. Eco-concrete is optional and can be placed on the edges of the Banjaard in conjunction with Oysters to reduce the highest waves and strongest currents on these sides of the island. This in turn will reduce erosion on these edges to a high degree. Eco-concrete will be in the same layer as the emergent plants as figure 8 just as the Oysters are. The last defence layer will be placed where the structures and dikes are located in figure 8. This defence layer consists of Marram grass which will catch and trap sand which in turn will create and further develop dunes on the breakwater island Banjaard.

Utilization phase

The research question addressed in this chapter is the following:

- Given that this project is seen as the beginning of a process for the development of the area, what are the various functional uses of the breakwater landscape both now and in the future?

Theoretical framework

To make “de Banjaard” viable and successful, the people need to know what the opportunities are after realizing this project.

“De Banjaard” is not just a project where you pour money into it to realize it and after completion you let nature and time takes its course. To maintain and improve “de Banjaard” it is necessarily to also generate income to keep funding the project and get more support from people and different organizations. Doing so, the project can sustain itself a little bit.

To generate income and not damage or disturb the nature on “de Banjaard”, we will look into the possibilities of eco-tourism for “de Banjaard. What kinds of activities and possibilities are there and how it will connect with “de Banjaard itself.

Banjaard

The “Zandmotor” is being use as the supplement sand to the coast of the Hague, to gain knowledge about innovative sand suppletion and boost the nature and art of the Delflandsekust. This idea looks pretty much the same to the idea of “de Banjaard” but it is further away from the coast.

The zandmotor adds extra recreational activities to the Delflandsekust. Walkers, runners, kite surfers and bathers are the ones who visit the Zandmotor the most. They appreciate the Zandmotor more than other beaches near the area. It was surprising that there was also unforeseen use of the Zandmotor for art and culture, by archaeologists and palaeontologists. This happened spontaneously and it has been learned that the absence of direction did not prevent this or even increased the chance of occurrence. The landscape of the Zandmotor looks very naturally, in particularly because “helmgras” caused the creation of dunes. The number of benthic animals has increased and the biodiversity of it has also increased which led to more birds visiting and foraging the area for food.

The Zandmotor has led to a naturally increased of dunes. We have learned that a project like this led to an increase of dune creation, and it is good for the coastal protection, but the design of the project plays an important part of it.

Figure 20, An impression of "de Marker Wadden" (Natuur Veilig, sd)

Due to the Zandmotor there has been many research programs were set up. This led to a deepening of the knowledge system of large-scale land suppletion, innovative measurement technics and widely applicable calculation models. The knowledge gained from this has already been used for other projects (Huisman, et al., 2021).

"De Banjaard" is a similar project compared to the "Zandmotor" but "de Banjaard" will have a larger impact on a larger area. That's why we expect that some of the effects of the "Zandmotor" also applies to "de Banjaard". We will also look into "de Marker wadden" to see what the opportunities of an artificial island are.

Stakeholders

For "de Banjaard" project contact with the stakeholders is very important. The project is still in the developing phase and the support from the stakeholders are needed to realise "de Banjaard" project. Rijkswaterstaat, the Province of Zeeland and several municipalities are some of the stakeholders with the most power, they are also the ones who will provides most if not all the budgets. Other parties with a high interest in the project are environmental organizations, beach club and vacation park owners. They may not have any power to make the decision for "de Banjaard" project, but the project has a direct impact for them. As far as we can see, the place where we want to place "de Banjaard", is not that often used by ships and if "de Banjaard" is in place, there won't be any inconvenience to any shipping route, and it may even provide a safe haven for smaller ship vessels.

The opinions of the local residents should also be included to make this project a success. They should be informed about the functions of "de Banjaard" and why it needs to be there. Tourists in that area are also stakeholders, they may not have any decisions power for the project, but they can keep the project "alive" by visiting the area and boosting the local economy.

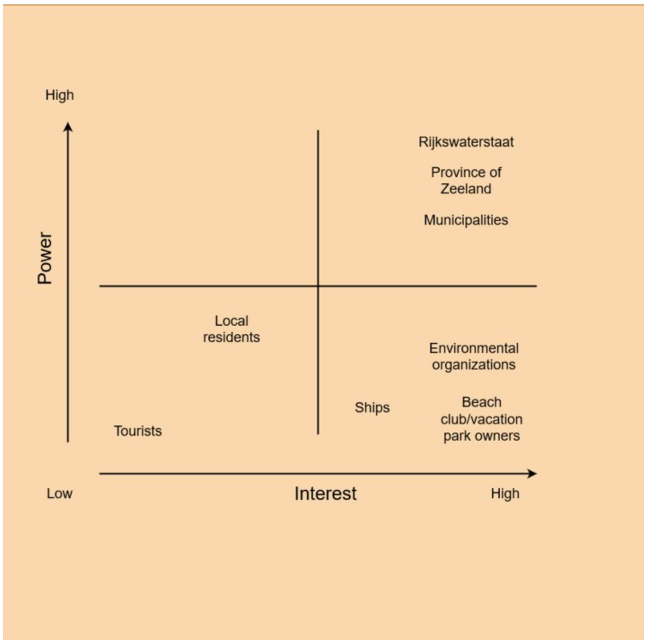


Figure 33, Power matrix

Promoting the project

To generate support and keep the project viable after implementing it we recommend several options to be implemented. These options are to be used to generate income to maintain and improve the Island, not to make profit off it.

Eco-tourism

Figure 34, Hiking trail (Natuurmonumenten, n.d.)

We recommend opening "de Banjaard" to eco-tourism. A small-scale tourism where visitors travel to natural areas without inflicting damages to them. As "de Banjaard" is an island, it can only be visited by boat. This is useful for limiting the number of visitors per day, so it won't get too crowded and disturb the local nature. For this purpose, the ferry doesn't have to be big and ferry a lot of people every time. For this purpose, the use of an electric ferry or one powered by hydrogen is optimal. Unlike a ferry powered by hydrogen, which currently there is only one in the world right now, it is also too big to be used for "de Banjaard" for our purpose (h2platform, 2021). And if the choice falls on using a hydrogen powered ferry, where will the hydrogen be produced and stored?

Figure 35, Sandøy ship (Bruinekool, 2021)

But if we choose an electric ferry, there is more choices and they come in smaller sizes. The Sandøy is built by Holland Shipyards Group and is going to be used to connect Brevik with the islands Sandøya and Bjørkøya in Norway (Bruinekool, 2021).

To visit “de Banjaard” we recommend working with a reservation system, doing so you have control on how many people can visit the island at a time and the money that gets collected can be used to the preservation of nature on the island. The prices should be reasonable, and the preservation of nature should be the top priority.

Figure 36, Birdwatching tower (Hond, n.d.)

“De Banjaard” should only have hiking trails which should be accessible for people in a wheelchair. Those trails should not cover the entire island but part of it to not disturb the local fauna. Along the trail there is room to place some observation post to observe the local area and great for bird watching.

The ferry should not be the only option to reach the island, people with their own boat should be able to dock at the harbour not only to visit the island but also to seek shelter from storms. For this we can ask the boatowners to pay contribution to be able to dock at “de Banjaard”. For this there also can be an option for the boatowners to compensate their c02 emissions.

There should be several facilities on the island, for management, supervision, receiving visitors and research. The total size of this settlement should be limited as much as possible to not intrude and obstruct the primary use of “de Banjaard”. It would be nice if the buildings are made from sustainable materials and be self-sufficient. Generating energy with solar panels and maybe a small windmill next to the harbour so that you do not only rely on solar energy. Water should be recycled as much as possible. “De Banjaard” should thrive to be the second off-grid island in the Netherland (Natuurmonumenten, n.d.).

Because this is a unique project and vital to the coast protection of the Netherlands, it offers a unique experience for education. This can be school field trip, educating the next generation about the impact of climate change and how we can combat that without building more dykes and Delta works. These kinds of field trips should also be made available for other groups.

“De Banjaard” offers researchers the opportunity to follow the process of creating an artificial island and see how the nature reacts on it. This knowledge can be used to further improve “de Banjaard” or be used for another similar project.

Besides we see an opportunity to use “de Banjaard” for “sea gardening”. “Sea gardening” is just like a vegetable garden but then at sea and instead of vegetables, they will grow mussels, oysters and sea kelp. The purpose of this is to have a community who takes care of this sea garden, and they are the ones who also will be using the harvest. For this we can work with a subscription-based system, where the funds go to maintenance of “de Banjaard”, repairs of the equipment’s and emergency funds. Doing so we wants the local community to also be attracted to the project.

*Figure 37, Mussels and sea kelp can be grown on a rope, and it is easily harvested***Ongeldige bron opgegeven.**

With “sea gardening” we provide the local community with local grown and harvested food; a smaller ecological footprint and they will provide “de Banjaard” with some wave protection as mention before. After eating the oysters and mussels, their shells can be collected and be used as a bio builder. Doing so, the production and consumption from the “sea garden” can be circular.

The Western Scheldt is a popular breeding ground for birds and seals and migrating birds use this area a lot to rest and foraging food before continuing their journey (Middelburgse&Veerse Bode, 2022). We believe that “de Banjaard” would be a perfect location for this. There is enough sand, food and no natural predators. But to do this we advise that “de Banjaard” would be closed for public during breeding season and that not all the island's area are made accessible to the general public.

Figure 38, A tiny house that visitors can rent out to spend the night on the island

To provide the visitors with a unique experience we can build some "nature houses" where visitors can stay the night at the Island. A night at "de Banjaard" where there is no light pollution, no traffic noises only the sound of nature.

Discussion

The grain size at the location of the breakwater barrier was taken from measurements made in 1997. Furthermore, these are random samples, so the actual grain size may differ because the seabed is not the same everywhere.
The flow rate decreases after construction of the island, as the water depth decreases. This will reduce the critical bottom shear stress and erosion also as a result.
The extraction locations are from a 2017 report. In the past five years, there may well have been a change there. This may affect the cost of sand and transport price.
The lifetime of the island is difficult to determine because we do not have access to the right programmes. As a result, the estimate is very rough. It is also difficult to predict how much the sea level will rise in the coming years. In addition, the projects compared are quite different from the breakwater barrier.

The shear stress calculations are quite precise. Yet there are also possible anomalies in this. The current measurements will partly change with the construction of the breakwater barrier. Furthermore, it is possible that the actual data deviate from the measurements because the measurements were sometimes taken near the breakwater barrier and may deviate because of this.

The planning for such a large project is difficult to establish because it has not yet been contracted out. However, a rough schedule has been established. Because this is a large project, certain parts can be more efficient, this has not always been taken into account, due to lack of knowledge. Furthermore, the currently scheduled weeks are all used to work. In reality, days off will also play an important role, which could make the schedule longer.
Prices are partly based on guidelines from sites and the knowledge of professionals. These may differ in reality as the sources are not very reliable. Furthermore, the quantity of parts also plays a major role. Furthermore, biobuilders and recreation are both seen as items. These items are not well substantiated and need follow-up research.
It is possible to conduct a follow-up study of 'the Banjaard'.
Some components that could be investigated have been drawn up below:

- Working out an optimisation of the island as option two. Here it is important to keep the main and secondary goals in focus.
- A modulation of the island in the environment to determine the life span and be able to strengthen the island where necessary.
- Conduct trials of biobuilders to see how they function in the relevant conditions.
- Investigate and work out more recreational opportunities.
- A precise cost estimate of the biobuilders;
- A precise cost estimate of recreation;
- A 3D model of the island
- Investigate the advantages and disadvantages in implementing the project with all-green energy.

To strengthen the initial suppletion of sediment for “de Banjaard” bio builders are needed. Biodegradable bio builders will help the system by preserving ecological value that will be introduced to this breakwater barrier. For this design with biodegradable bio builders a multiple defence layer was chosen originally envisioned by Longhuan Zhu. The defence layers consist of suspended rope culture, submerged seagrass mats, emergent oyster reefs and a top layer of marram grass. These defence layers will protect the suppletion of sediment against erosion and also expand the initial suppletion by capturing additional sediment.

Conclusion

What are the specifications of the initial sand nourishment, including their location(s), quantity(s), surface, and profile?

The area of the breakwater barrier is 17 983 001 m². The total volume of sand to be supplemented is 192,000 m³. Its specific location and profiles can be found on the drawings. A total of 58 weeks of sand will be applied and 33 weeks of stones will be placed. The pile heads will be placed in 11 weeks. The total cost of the project is €146,442,975. The lifespan of the breakwater will be around 40 to 70 years, assuming 'de Banjaard' is properly maintained.

Preferably, the nourishments should be performed with machinery on fossil fuels. Which sustainable options are available?

For “de Banjaard” project lng-powered TSHD’s will be used as they are the most suitable at the moment, and already two vessels are being built and one vessel already in production, these vessels have a barge capacity of 10500 m³.

The research question stated in the strengthening phase is as follows **“What are the contributions of bio builders to protect, reinforce and expand the initial nourishment(s)?”.**

Bio builders can contribute to protect and reinforce in the form of flow distortion, current attenuation, wake formation and dissipating wave energy. Expansion will happen above water as well as in the water column in this case. Expansion above water happens by entrapment by vegetation by slowing down the wind so sand can settle. In the water column this can be done by reducing the flow over a bed of oysters/seagrass so sand can settle and also attenuation of wave energy, which results in reduced erosion of the settled sand.

The answers to the research question addressed in this chapter, **given that this project is seen as the beginning of a process for the development of the area, what are the various functional uses of the breakwater landscape both now and in the future?**

There are a lot of possibilities for eco-tourism for “de Banjaard”. Choosing eco-tourism for “de Banjaard” is a good choice to make the project more viable and sustainable without damaging the primary purpose of the project.

Appendix A: Bed shear stress calculations

Soil shear stress due to waves			
Quantity	Symbol	Unit	Formula
Soil shear stress due to waves	$\tau_{w,\max}$	N/m²	$\tau_{w,\max} = \frac{1}{2} \cdot \rho . f_w \cdot U^2 m$
Density	ρ	Kg/m³	
	f_w		$f_w = e\hat{} \left(5{,}5 \cdot \left(\frac{k_s}{A}\right)^{0{,}2} - 6{,}3\right)$
Soil roughness	ks	M	$ks = 100 \times 0{,}00022$
Area	A	M²	$A = \frac{1}{2} \cdot H \cdot \frac{1}{\sinh(kh)}$
Wave height	H	m	
Wavenumber	k	m^-1	$k = \frac{2\pi}{L}$
Wavelength	L	m	
Water depth	h	m	
Wavelength deep water	L_0	M	$L_0 = 1{,}56T^2$
Wave period	T	S	
maximum horizontal velocity of a water particle just above the bottom	Um	m/s	$Um = A * \omega$
angular frequency	ω	Degree	

$$\tau_{w,\max} = \frac{1}{2} \cdot \rho . f_w \cdot U^2 m$$

$$f_w = e\wedge \left(5,5 \cdot \left(\frac{k_s}{A}\right)^{0,2} - 6,3\right)$$

$$ks = 100 \times 0,00022$$

$$ks = 0,022m$$

$$A = \frac{1}{2} \cdot H \cdot \frac{1}{\sinh(kh)}$$

$$L_0 = 1,56T^2$$

$$1,56 * 12,3^2 = 43,8 \text{ m}$$

$$h/L_0 = 3/43,8$$

$$= 0,068$$

$$tabel \rightarrow h/L = 0,112$$

$$L = 26,8m$$

$$k = \frac{2\pi}{L}$$

$$\frac{2\pi}{26,8}$$

$$= 0,23m^{-1}$$

$$\omega = \frac{2\pi}{T}$$

$$\frac{2\pi}{5,3} = 1,18s^{-1}$$

$$A = \frac{1}{2} \cdot 0,98 \cdot \frac{1}{\sinh(0,23 \cdot 3)} = 0,66$$

$$f_w = \exp(5,5 \cdot (0,022/0,66)^{0,2} - 6,3) = 0,029$$

$$\tau_w, max = \frac{1}{2} . \rho \cdot fw \cdot U_m^2$$

$$Um = A * \omega = 0,66 * 1,18 = 0,78$$

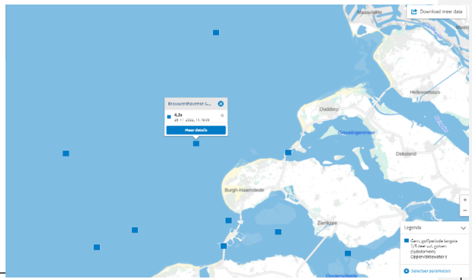
$$\frac{1}{2} * 1025 \cdot 0,029 \cdot 0,78^2 = 9,0 \frac{n}{m^2}$$

See excel data for calculation
From :
https://waterinfo.rws.nl/#!/kaart/golfhoogte/

Hs is the average of 1/3 of the highest waves.
Tp is the period with the highest wave energy.
Average water height is 3m.
Average flow rate: 0,37 m/s

Ks= 100*D50 roughness of the bottom
U_m= max. horizontal speed of a water particle right above the bottom

	Symbol	Value	Unit
Average significant wave height		98,1	cm
Corresponding wave periods		5,3	s



Soil shear stress due to current			
Quantity	Symbol	Unit	Formula
Chezy	C		$C = 18 \cdot \log\left(12 \cdot \frac{h}{ks}\right)$
Waterdepth	h	M	
Soil roughness	ks	M	$ks = 100 \times 0{,}00022$
Critical velocity	u_*	m/s	
Tau current (current)	τ_c	N/m²	$\tau_c = \rho_w \cdot u_*^2$
Water density	ρ_w	Kg/m³	

τ_c

$$C = 18 \cdot \log\left(12 \cdot \frac{h}{ks}\right)$$

$$18 \times \log\left(12 \cdot \frac{3}{0{,}022}\right) = 57{,}8\, m_s^{\frac{1}{2}}$$

$$u_* = \frac{U}{C} \cdot \sqrt{g}$$

$$\frac{0{,}37}{57{,}8} \cdot \sqrt{9{,}81} = 0{,}02\frac{m}{s}$$

$$\tau_c = \rho_w \cdot u_*^2$$

$$1025 * 0{,}02^2 = 0{,}41\frac{n}{m^2}$$

$$\tau_{wc} = \frac{1}{2} * \tau_{w,max} + \tau_c$$

$$\tau_{wc} = \frac{1}{2} * 9 + 0{,}37 = 4{,}87\, N/m^2$$

Critical soil stress			
Quantity	Symbol	Unit	Formula
Critical soil stress	τ_{cr}		$\tau_{cr} = p \cdot ucr^2$
Critical shield parameter	D_*		$D_* = \sqrt[3]{\frac{\Delta \cdot g}{v^2}}.D$
Delta	Δ		$\Delta = \frac{\rho_s - \rho_w}{\rho_w}$
velocity	v^2	m/s	
Grain size	D	m	
Critical velocity	u_{*cr}	m/s	$u_{*cr} = \sqrt{\frac{\theta cr \cdot \Delta \cdot g \cdot D}{\tau_{cr}}}$

$$D_* = \sqrt[3]{\frac{\Delta \cdot g}{v^2}}.D$$

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w}$$

$$\frac{2650 - 1025}{1025} = 1{,}59$$

$$D_* = \sqrt[3]{\frac{1{,}59 \cdot 9{,}81}{10^{-6}}}.0{,}00022 = 1{,}18$$

$$1 < D^* \leq 4$$

$$\theta_{cr} = 0{,}24/1{,}18 = 0{,}20$$

$$u_{*cr} = \sqrt{\theta cr \cdot \Delta \cdot g \cdot D}$$

$$\sqrt{0{,}2 \cdot 1{,}59 \cdot 9{,}8 \cdot 0{,}00022} = 0{,}026\frac{n}{m^2}$$

$$\tau_{cr} = p \cdot ucr^2 = 1025 \cdot 0{,}026^2 = 0{,}69 \times \frac{n}{m^2}$$

$$\tau_{cr} < \tau_{wc} \rightarrow 0{,}69 < 4{,}87$$

Appendix B: Drawings

See Attachment

Appendix C: Planning and calculations

Area and voumes (from Qgis and Autocad)

					dumbstone			
	Area above and below waterlevel	Above waterlevel	Below waterlevel	Total (m³)	North	South	Total	Total (Tons)
Surface (m²)	17983001	2062785	15920216		54507	73345	127852	
Average height from NAP. (m)		2,5	2,5		1,5	1,5		
Volume		5156962,5	39800540	44957502,5	81761	110017,5	191778	498623

Used heights

	Lower area	Higher area
width (m)	1000	500
highest point from NAP (m)	0	7
lowest point from NAP (m)	5	2,4
average filling up height (m)	2,5	2,3

Workpreparation	**environment**
planning ships	report starting work and update
Kick-off	
Setting up construction site	**Veiligheid**
Patterns	Kick-off
	Werkplekinspectie
Documents	Toolbox
Bepaalde opleverdata documenten	Audits
Construction phase	**Aanwezigheid**
Surveying	Verlof
Mobilising required ships	
dumping sand	**Onderaanneming**
unloading rock	possible subcontractors
transport of machines and equipment	apply ecological applications
	Placing breakwater groins (wooden piles)
	Constructing mooring quay

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