The Mirror Project

Banjaard the Third

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1.0 Introduction

Since climate change and the sea level rise caused by it cause a growing threat to the Dutch coastlines and flood safety, experts are searching for new methods to protect the land and its inhabitants from the rising sea. In the past, this solution has mainly been sought inlands, by building dikes and reinforcing dunes. In this project, a solution will be discussed that will take place in the Voordelta.

The Banjaard is an existing sandbank located on the coast of Noord-Beveland, in the province of Zeeland. It lies in front of the Oosterscheldekering, the mechanical flood defense system that was built in response to the 1953 flood. This area and the existing sandbank will be the playing field for a project that involves creating an island in front of the coastline of Noord-Beveland that will be resilient to future changes in the sea level and other changes due to climate change, like more frequent and more fierce storms. Another goal of this project will be to provide a habitat for flora and fauna living in this part of the coast, which will in their place play a role in the resilience of the flood defense. In this way the biological and ecological aspects of the coastal zone will be improved, and a flood defense is designed that is resilient to future changes.

This project will be a continuation of the research done by students of Wageningen University (Menheere, et al., 2022) and will be based on the designs made and presented in their research.

1.1 Research questions

This research will mainly focus on the means needed for the execution phase of the project as stated in the research by the students of the Wageningen University. This involves the suppletion of the sediment needed for the construction of the island, the type of sediment used, the quantity of the sediment being used and the calculations, the involvement of the stakeholders, a legal analysis and a financial analysis. For this purpose, the following research questions have been stated:

- What kind of sediment needs to be used for the construction of the Banjaard island and in what quantities?
- Which stakeholders are involved and what are their interests?
- What are the most important legal aspects for the construction of the Banjaard island?
- What are the financial means needed for the construction of the Banjaard island?

2.0 Theoretical framework

2.0.1 Current situation

The Oosterscheldekering has protected the coastlines of the Oosterschelde since construction was finished in 1986. Despite the many advantages, the Oosterscheldekering also has some disadvantages for the surrounding ecosystems. This includes the sand depletion in the Oosterschelde, also referred to as the ‘’sand hunger’’. This phenomenon is caused by the fact that the Oosterscheldekering prevents the inlet of sand from the North Sea, resulting in the disappearance of sandbanks and salt marshes, which has a large impact on the biodiversity in the Oosterschelde (Deltares, 2018). The Oosterscheldekering also reduces the current in the Oosterschelde with 30%. Another disadvantage is the fact that the system has to be renewed sooner than expected due to climate change and sea level rise, as the storm surge barrier was designed for 40 cm of sea level rise, while we expect 100 cm of sea level rise at the end of the century. This can cause the closing frequency to increase, which can lead to the need for replacement (Deltares, 2018).

2.1.0 Project location

The location of the project is going to take place near the former Banjaard island [Voordelta near Schouwen- Duiveland], see figure 1.

The new Banjaard island will be a combination of sand nourishment and innovative Building with Nature techniques. The purpose of this island is to create a breakwater landscape. The island will be at 4 km away from the Schouwen coast, see figure 2. After analyzing the AutoCAD bathymetry contour lines file, see appendix A, it is discovered that the curve of the Schouwen coast has a radius of approximately 2892,83 m. For the design of the Banjaard island a radius of 2895 meters will be used. The shape of the island will be like a crest moon shape with a width of 200 meters.

Figure 1: Location of former The Banjaard island (old)

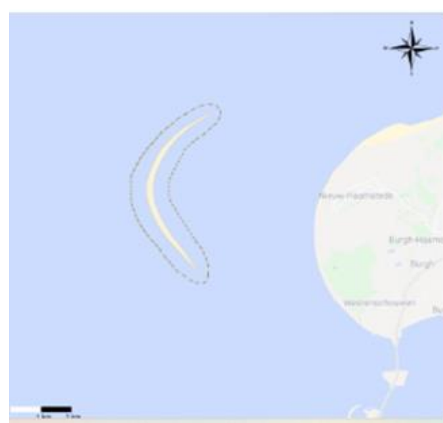


Figure 2:The new Banjaard island configuration, according to research report Breakwater barrier "De Banjaard"

2.2.0 Boundary conditions and requirements

The project is focused on a seaward solution to sea level rise, this is mainly because of a scarcity of land in the Netherlands. We have about 30 years or one generation to experiment and with this concept before sea level rise reaches a level that will be disastrous for the Netherlands. Wageningen University has done research and wrote a report for this project, their findings and suggestions need to be considered during this project. One of their suggestions is a break barrier island, this means that some dredging will be needed to supply enough sand for the island. Dredging involves permits that are necessary and sediment quality tests that have to be executed. All the regulations when it comes to dredging should be carefully considered. One of the main goals of this project is to start physical experiments in the Voordelta in 2025. The area of the project is in a Natura 2000 area which means it is a protected area with regulations that need to be followed.

2.3.0 Site investigation

2.3.1.0 Bathymetry

The bathymetric of the project area was investigate using the software QGIS. The bathymetric file of the Zeeland elevation was provided in the second-year course of Civil engineering (Hz, 2020). This map has an elevation range of 1066 cm NAP to (-) 5072,4932 cm NAP, see figure 3.

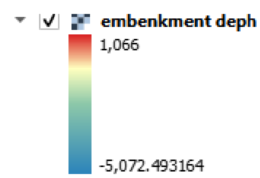
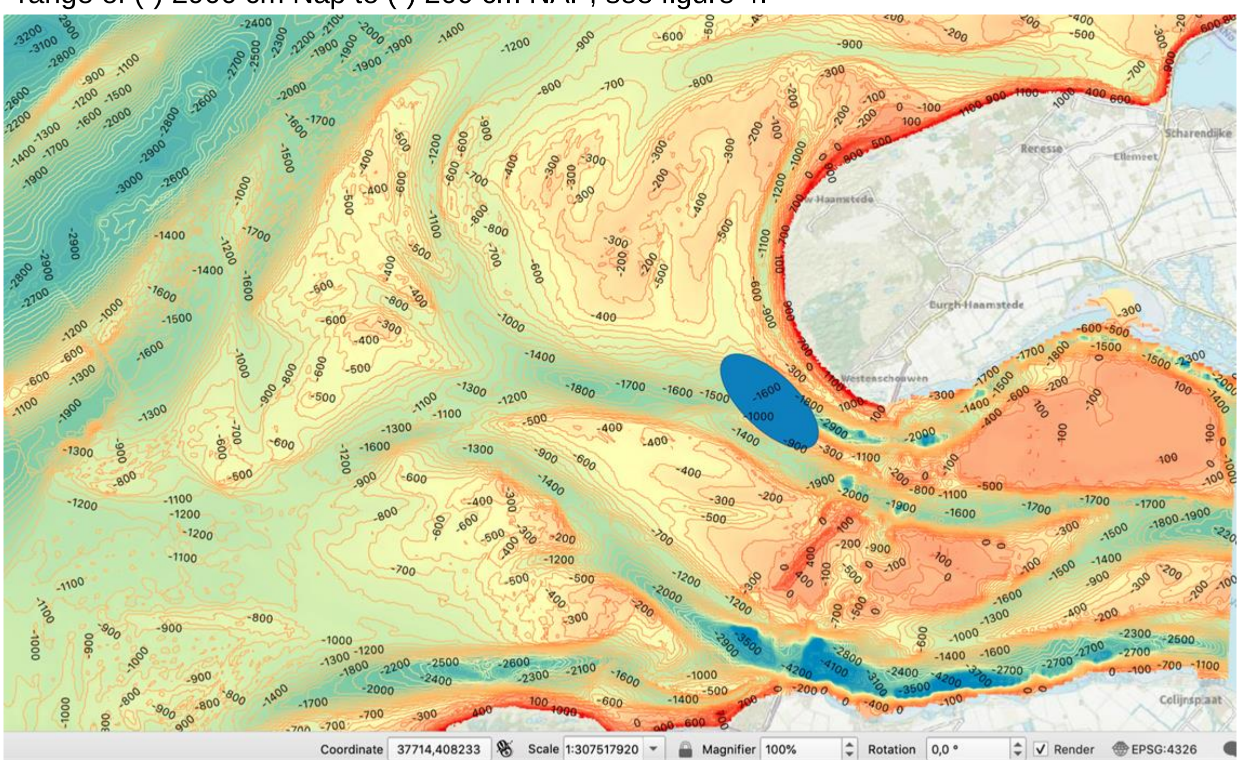


Figure 3: Elevation level in cm NAP

The location of where the new Banjaard island will be place has an elevation range of (-) 2900 cm Nap to (-) 200 cm NAP, see figure 4.



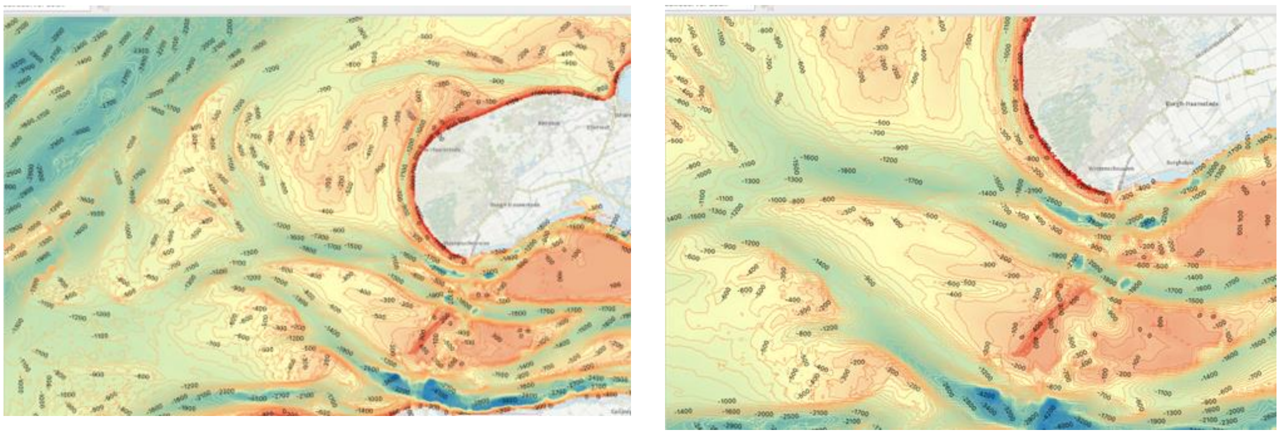


Figure 4: Elevations contour lines around the Schouwen coast

2.3.1.2 Soil investigation

To investigate the type of soil layers that are to be found in the project location, the software Dinoloket (Nederlandse Onderground, n.d.) is used. Dinoloket is a subsurface data free, geological survey of the Netherlands.

Several samples were taken along the project location and it was discovered that soil layers beneath consist of fine, medium and coarse sand layers, see figure 5. However, in some circumstances loam can be found, see figure 6.

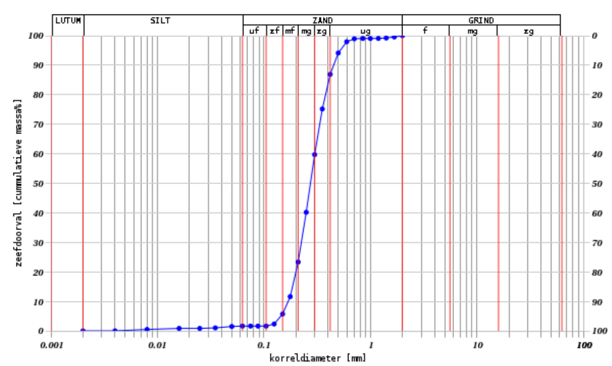


Figure 5: Soil layers and grain size distribution

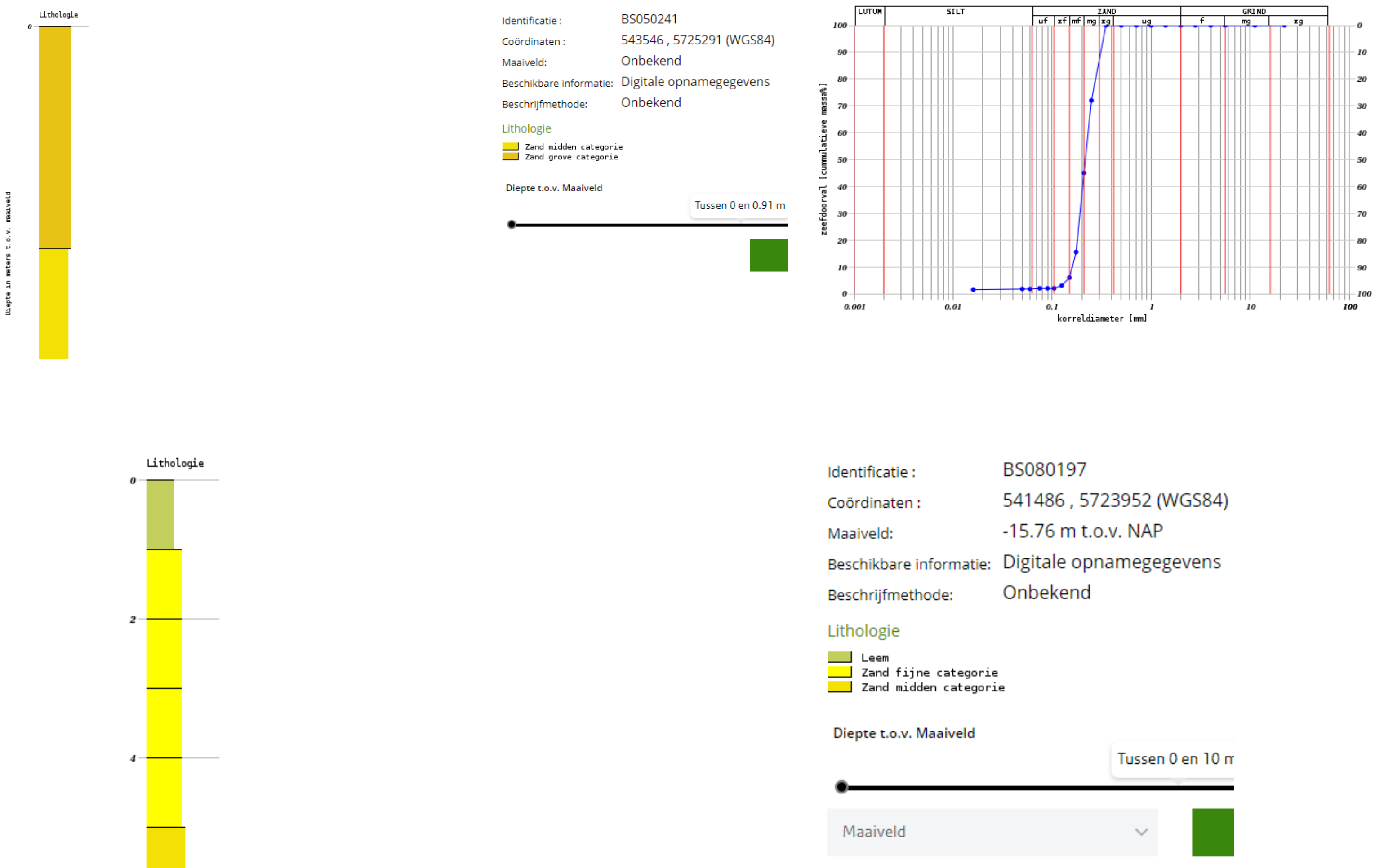


Figure 6: Special circumstances soil layers distribution with loam

2.3.1.2.1 Soil properties per layer

Granular soils, sand are non-cohesive soils and have no shear strength. Sand is permeable and their grains stick together due to negative pore pressure. Strength, bearing capacity and slope stability all derived from internal friction ϕ (Phi) and has a range from 30° to 45°. ϕ increases due to grading, packing density and grain angularity.

Coarse grained soils are more permeable to water and, unless saturated, may have very little water in their voids when well consolidated and confined they form a foundation stable as a rock.

Loam, clay and silts are cohesive soils and have shear strength. Cohesion results from the mutual attraction, which exists between fine particles and tends to hold them together in a solid mass without the application of external forces. Loam is impermeable and consists of very fine microscopic particles which hold water to increase their volume, and release moisture to decrease their volume. This will cause settlement and precaution needs to be taken in the design of footings to resist or avoid the forces caused by shrinking and swelling.

2.3.2.0 Hydrodynamics conditions and Meteorological data

The hydrodynamics of the North Sea is dominated by tidal-driven forces such as semidiurnal lunar tide, M2 and semi-diurnal solar tide, S2; wind-driven forces, and seasonal density-driven circulation. Furthermore, the change of climate can also have a long-term effect on the hydrodynamics of the North Sea.

2.3.2.1 Wave and Current

The unique between the tidal system of the sea can be cause from the different between the depth of the seabed, the velocity of the waterflow and the shape of the seabed. Furthermore, the weather conditions can also influence the tidal system. For instance, influencing the amount of time the cycle high to low tide may occur in a place (PlaneetZee, 2020). See figure 8.

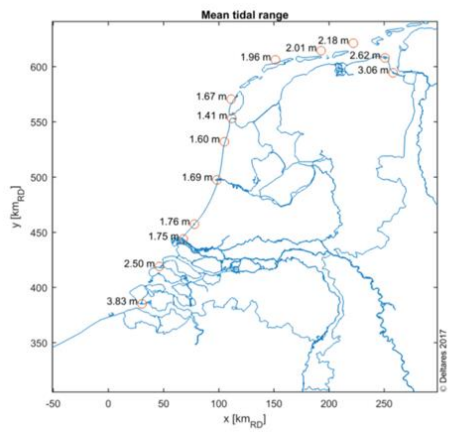


Figure 7: Nederland mean tidal range in m

Figure 8: Tidal wave in the North Atlantic Ocean and the North Sea

According to the lower Dutch foreshore (Deltares, 2017) the mean tidal range of the Netherlands decreases from Vlissingen to Den Helder but increases in the eastern direction, see figure 7. To investigate the mean tidal range of Schouwen coast the method of interpolation was used. Using the information of the tidal range of Vlissingen and Grevelingen an estimation was found. A scheme was created between the two places and an estimation was discovered.

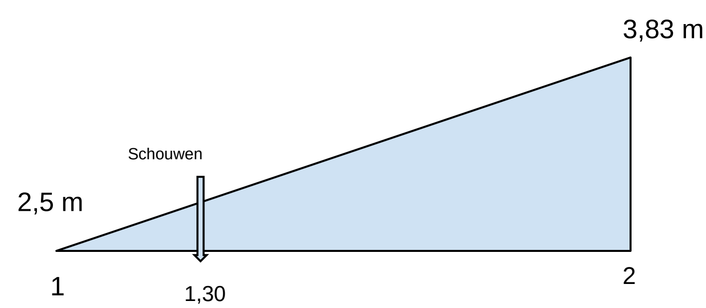


Figure 9: Calculation scheme

The equation was used:

- $$\frac{1-1.30}{1.30-2}=\frac{2.5-x}{x-3.83}$$

* Where x represents the tidal range of Schouwen.

Solution:

$$(-0.7) * (2.5 - x) = (-0.3) * (x - 3.83)$$

$$-1.75 + 0.7 * x = -0.3 * x + 1.149$$

$$x = 2.899\,m$$

Thus, the mean tidal range of Schouwen is around 2.899 meters. The tidal range controls the vertical distances in which waves and currents are effective in shaping shorelines. Moreover, in union with the slope of a shoreline tidal range can also determine the extent of intertidal zone which is the area between low and high tide.

The current of the North Sea is directed along the shore. However, due to the Coriolis force the current deflected to the northern hemisphere. Since the Oosterschelde is an ebb-tidal area the current tends to bend offshore.

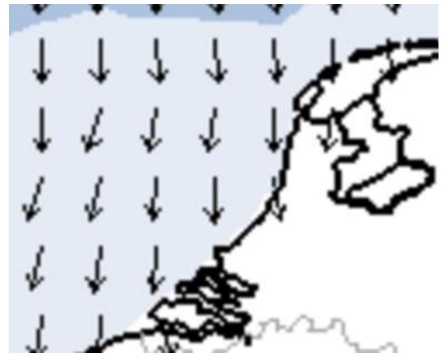


Figure 10: Wind wave direction

Meteoblue is used to determine wave wind direction. It is a source that provides marine weather data of a period of days and thus it is not completely reliable. The current velocity has a range from 0- 0.36 km/h, the significant wave height, the swell height, and the wind wave height, see figure 10, has the same height range of 0 - 0.3 m. The wind wave period is from 0 - 2 seconds and the swell period lasts between 6 to 8 seconds (PassageWeather, 2006-2023).

2.3.2.2 Sediment transport and Turbidity

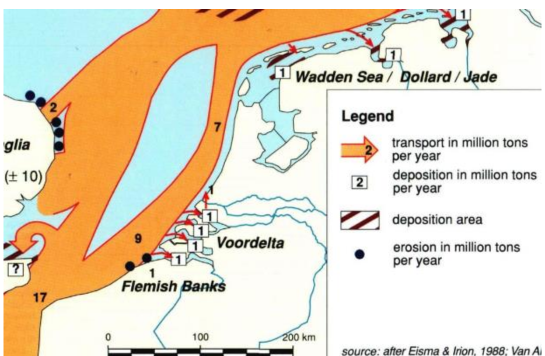


Figure 11: Sediment Transport

The sediment transport of the North Sea with a grain size of 63 micrometers can be determined by multiplying the concentration by the volume of water movement. The sediment of the North Sea is brought by the Atlantic waters, rivers and erosion of the clay banks or coast. Along the Netherlands coast 10 million tons of sediment is being transport with a zone of 20 km wide, see figure 11 (Icona, 1992).

The suspended matter of the North Sea consists of organics and of non-organic material such as clay. But it can also be brought in as precipitation from the atmosphere. In the Voordelta area the suspended matter concentration is from 10 to 50 mg/l. Since the North Sea around Schouwen is shallow the sediment is stirred up by the waves and current and it is held in suspension, see figure 12.

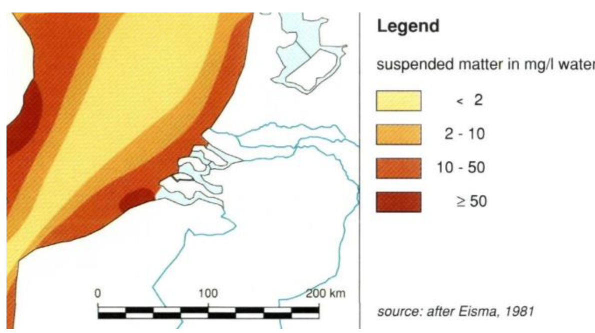
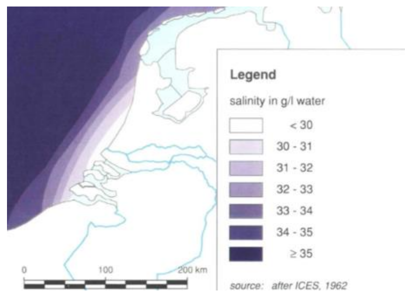


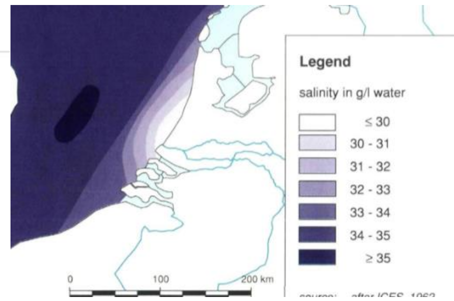
Figure 12: Suspended matter in mg/L

Placing an island near the mouth of the Schouwen coast will narrow the cross-sectional mouth inlet which will cause an increasement in the flow velocity and the residual currents. As result there will be more sediment transport and suspension. In ebb-delta areas the placement of an island will increase sediment deposition in the basin. On the other hand, in a tidal basin the island tends to cause more erosion with higher tidal currents and more sediment transport (Wei, 2022).

2.3.2.3 Salinity

The average salinity of the North Sea variates depending on the climate conditions and the seasons. During winter, according to the North Sea Atlas,1992 the salinity range around Schouwen is from 31-33 g/l (Icona, 1992).





2.3.3.4 Sand Quantity

Using the Surface Raster calculator of QGIS it was able to determine the amount of sand that is required to build the island. The base level of the surface was -2900 cm NAP and the calculator calculated the volume and area above the base level, see figure 13 . The volume required to build the island is 4914306.99 m^3.

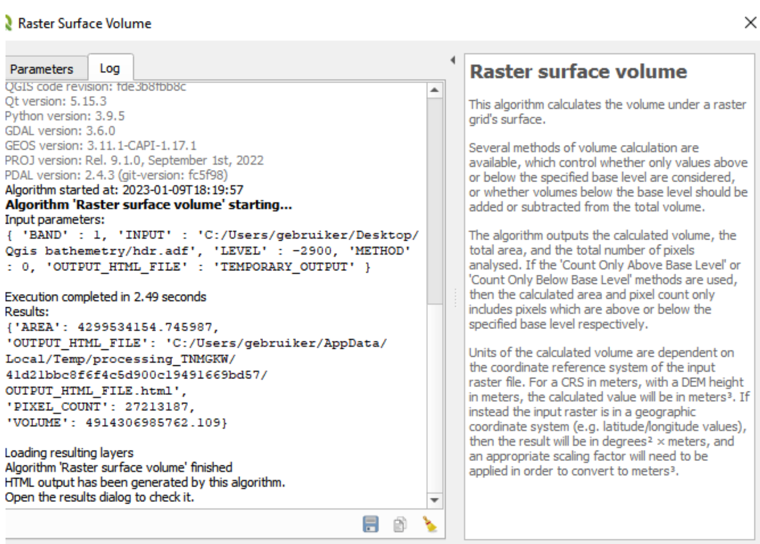


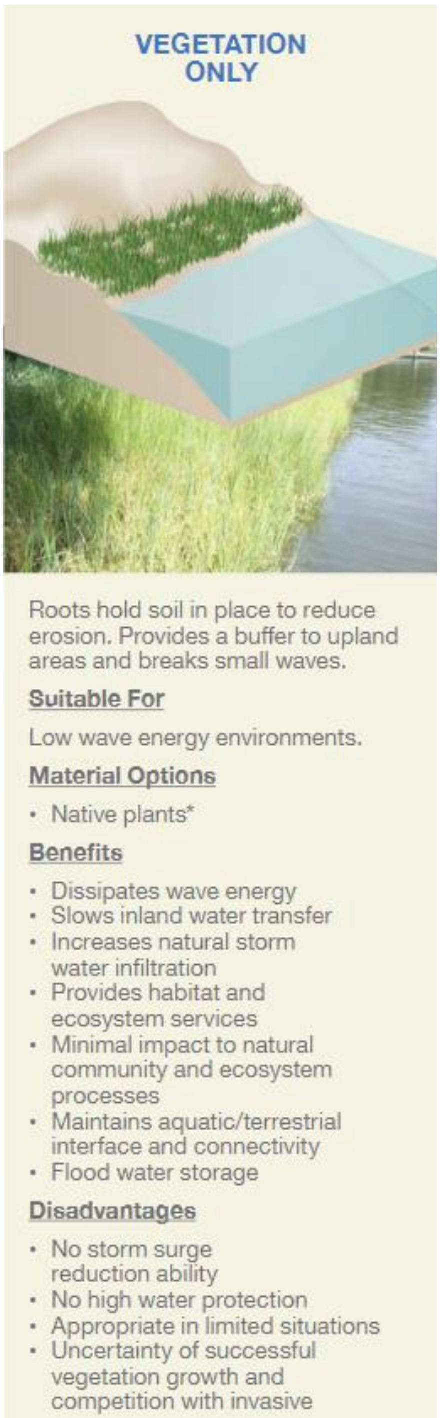
Figure 13: Raster calculation of volume results

2.4.0 Alternatives

2.4.1 Shoreline alternatives

From the different resilient shorelines laid out by SAGE (SAGE, 2015) greener techniques were applied to the Banjaard location and compared.

2.4.1.1 Vegetations only shoreline



A vegetation only- shoreline is designed to be a buffer for the coast and protecting it by breaking small waves. It is composed of sediment with various types of vegetation, like seagrass and Salicornia. This way, it breaks the waves landing on the shore, thus protecting the coastline. This type of shoreline is only designed for low wave energy environments and does not provide protection in case of a storm. It does, however, provide a good environment for different types of vegetation to settle, and therefore attract various types of animals. This also causes more sediment to settle in this area, which makes it better capable of protecting the coast. This type of shoreline is also very dynamic, which makes it capable of changing together with the sea level rise. With these points taken in consideration, the following advantages and disadvantages for this type of shoreline can be given:

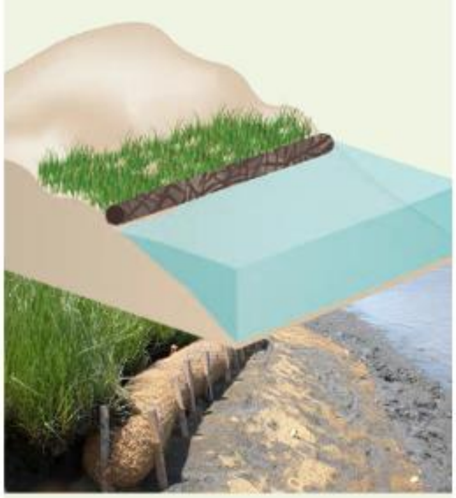
Advantages:

- Increases biodiversity
- Creates a habitat for different types of animals and vegetation
- Changes with sea level rise
- Protects coasts from sea level rise
- Low construction costs
- Creates opportunities for tourism
- Creates options for saline agriculture

Disadvantages:

- Does not protect coast in case of storm
- High maintenance
- Relatively more dredging needed than other solutions

EDGING



Structure to hold the toe of existing or vegetated slope in place. Protects against shoreline erosion.

Suitable For

Most areas except high wave energy environments.

Vegetation* Base with Material Options

(low wave only, temporary)
- "Snow" fencing
- Erosion control blankets
- Geotextile tubes
- Living reef (oyster/mussel)
- Rock gabion baskets

Benefits

- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

Disadvantages

- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

2.4.1.2 Edging shoreline

This mainly involves adding a protective barrier spanning the mean tidal zone of a coast to prevent erosion. This can be solid materials like rock and concrete, but also materials like reeds or bamboo.

Advantages:

- Does not alter the landscape as much as a sill or breakwater and is cheaper and easier to construct
- Can be constructed to be easy to remove or if made from plant material simple left there if no longer necessary
- Can be used as a habitat for certain coastal species

Disadvantages:

- Less effective during storms and big waves that exceed the mean tidal zone
- Prevents natural erosion and sedimentation
- Non-native material can litter the area

2.4.1.3 Breakwater shoreline

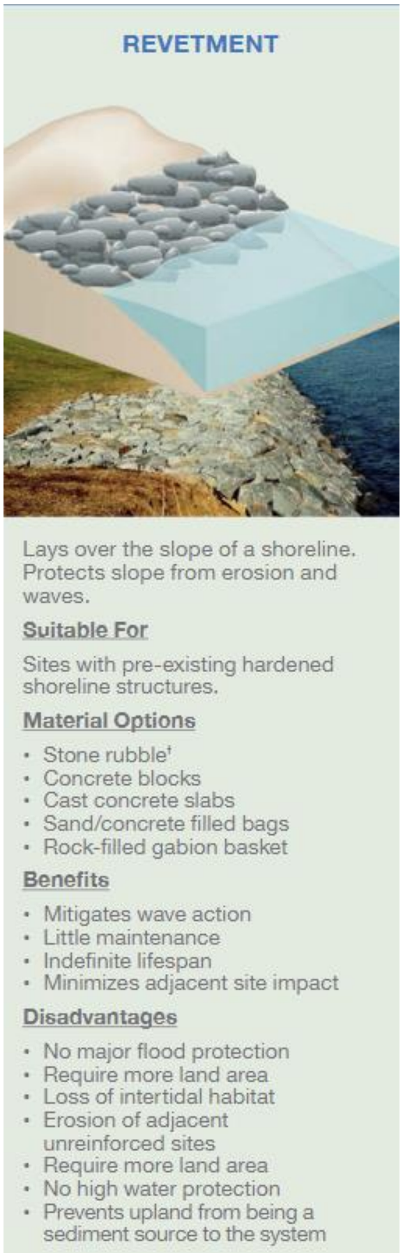
A breakwater shoreline is designed with an offshore structure to break waves and encourage sedimentation.

The advantages of a breakwater shoreline are:

- The structure can be designed in a way that it can act as a reef
- Breakwater shoreline has been in use for a while and therefore there is a lot of experience and examples that can be used to learn from.
- Various options for the design

The disadvantages of a breakwater shoreline are:

- Can be expensive in deeper water, this is because it will require more construction which will drive up the costs.
- There is little to no high-water protection and storm protection



2.4.1.4 Revetment shoreline

Revetment are sloping structures that can be built on embankment or shorelines. A revetment absorbs and dissipates wave energy to reduce coastal erosion and is typically built on exposed and moderately exposed sedimentary coastline. Revetments can be built of concrete, stone, asphalt or wood and the height is designed to stop waves overtopping. Revetments can be impermeable or permeable, an impermeable revetment is a continuous slopping defense made of stone or concrete that acts as a barrier against high tide and storm surges. On the other hand, a permeable revetment can reduce the erosive power of waves by dissipating their energy as they reach the shore. However, it does not address sediment deficits which are the root of erosion. Sediment deficits are defined as the difference between the mass or volume of accumulating sediment and the mass or volume needed to fill the accommodation created by relative sea level rise. In contrast, revetments can be combined with other protection measures such as breakwater, groins, dikes, and beach nourishment to tackle sediment deficit.

Environmental Benefits

- Limits interference with longshore sediment processes and can maintain coastal stability while still allowing some natural coastal processes to occur.
- Combines with soft engineering approaches such as beach nourishment to maintain the natural coastal appearance.

Advantages:

- Large rock revetment will typically have a longer life than those constructed of gabions and are also likely to have lower maintenance requirements.
- The structures simple to construct and do not cause major interference with longshore sediment transport.
- They are strong structures that can be used for long-term coastal stabilization.

Disadvantages:

- Effective at dissipating wave energy and reduce erosion, however it does not address sediment loss
- May conflict with natural coastal dynamics and erosion acceleration to unprotected coastline due to being a static structure.
- They can be difficult to build due to construction costs, material availability, and lack of data for the initial design.

2.4.2 Sediment source alternatives

2.4.2.1 North Sea

In the North Sea, 27 to 35 m^3 sediment is dredged every year (Noordzeeloket, sd.). This is mostly used for coastal protection and heightening of the beaches. This sediment mostly consists of sand. Since the North Sea is protected by the Natura 2000 regulations, dredging can only take place in certain areas, as the dredging has a negative impact on the benthic life. Additionally, dredging in the North Sea is expensive, mainly because of the longer transport route.

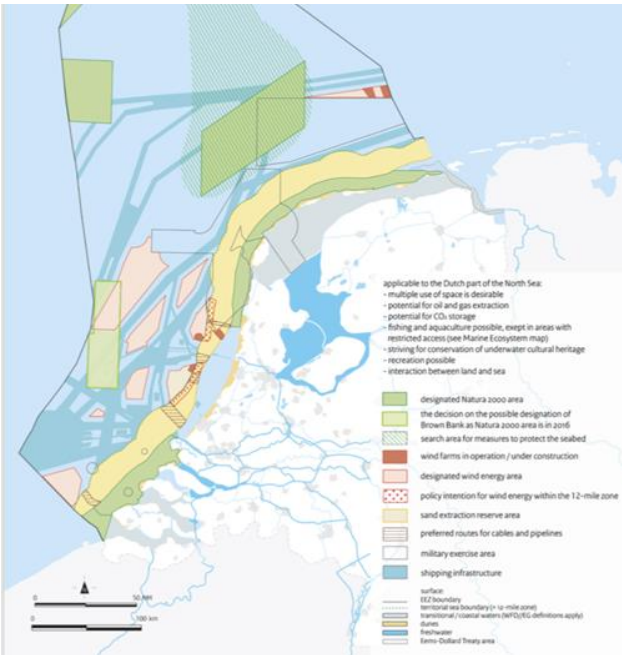


Figure 14: Legislation in the North Sea

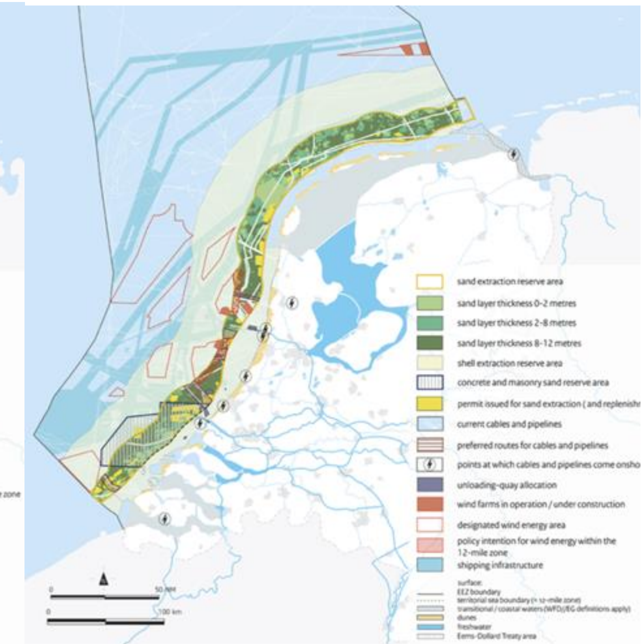


Figure 15: Dredging in the North Sea

2.4.2.2 Rotterdam port

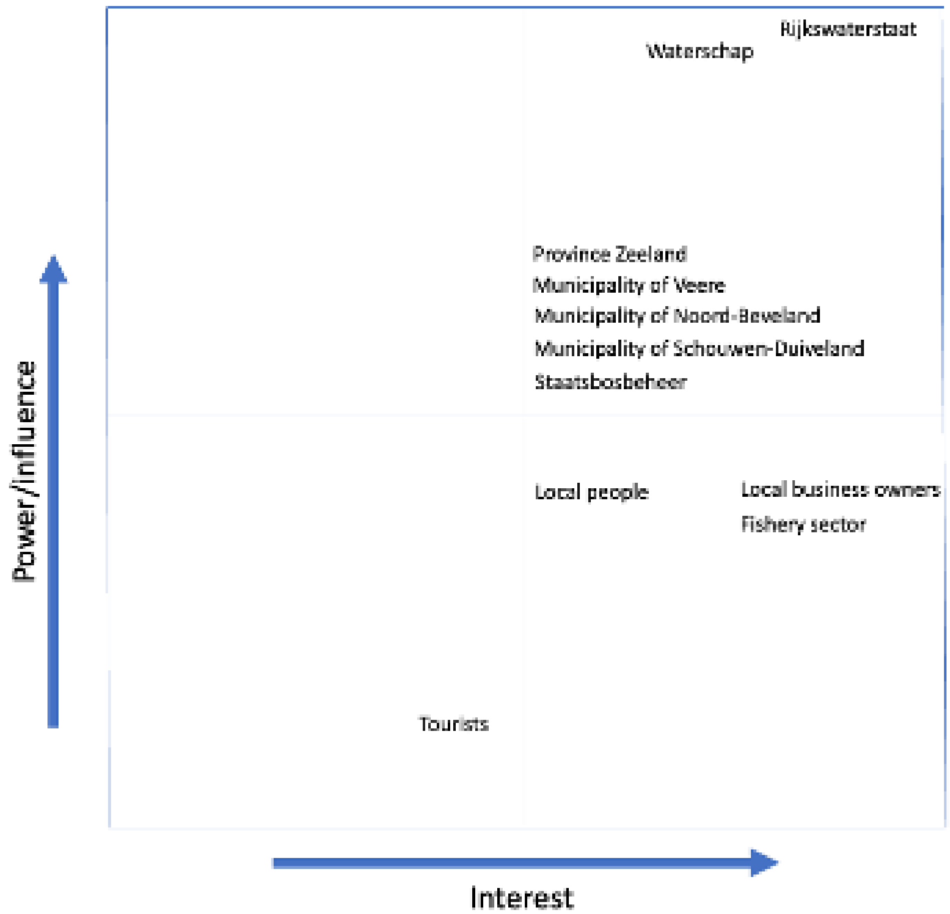
The port of Rotterdam needs a lot of dredging done to keep the canals deep enough for the large ships going to the port. However, heavy industry has caused the soil to be contaminated and that should be taken into account. Transporting the sediment can be expensive since it is far away from the project location of the Banjaard.

2.4.2.3 Westerschelde

For any volume of sediment taken from the Westerschelde the same amount must be returned as compensation (Rijkswaterstaat, 2000). This was implemented because the balance of incoming and outgoing sediment is neutral or negative, with often more sediment going out than coming in. Therefore, it is not feasible to use this location as a source of sand.

3.0 Stakeholders analysis

Stakeholder	Interests	Power	Involvement
Municipality of Veere, Noord-Beveland and Schouwen-Duiveland	Public safety and livability, climate adaptation, tourism, financing	Medium	Keep satisfied
Rijkswaterstaat	Spatial measures, granting permits, Natura 2000 targets, flood protection	High	Manage closely
Waterschap	Flood protection	High	Manage closely
Provincie Zeeland	Livability of the province, tourism, economic prosperity	Medium	Keep satisfied
Local people	Livability and protection of the area, aesthetic of the project	Medium	Keep informed
Staatsbosbeheer	Nature aspects and impacts of the island	Medium	Keep satisfied
Fishery sector	No interference with shipping routes and fishery areas	Medium	Keep informed
Local business owners	Area protection for steady stream of customers	Medium	Keep informed
Tourists	Area preservation	Low	Monitor



The stakeholders that should be involved as early as possible are Rijkswaterstaat, het Waterschap, all the municipalities, Province Zeeland, Staatsbosbeheer and the local people. These stakeholders can be of help when designing the island and can also be part of the financing of the project. The local people might not help with the financing of the project, but they know the area better than anyone and can help by sharing their ideas and concerns with us as early as possible. There are many different factors that are important to this project which is why the representatives from these organizations and the locals should often have a meeting about the project. This increases the chance of a project with a maximum result. The local people, local business owners and the fishery sector should also attend the meetings. Their input is very important and should be taken into account when designing and implementing the project. The tourists are not as involved in the design of the project, but they do play an important part in the area. They are the primary customers for the local business owners which is why they are a stakeholder in the project, and they need to be monitored.

4.0 Methodology

In the third week of the assignment project a visual site investigation was conducted. This was performed by viewing different sites along the coast in similar current conditions as to the Banjaard. The goal of the investigation was to understand the current situation to a greater extent.

Research articles concerning the current situation of the Banjaard were provided by the client. This research proposal is based on the articles and previous research given by the client. Furthermore, the bathymetry AutoCAD and QGIS document of the area of the second year of Civil engineering course was also used for this research.

The materials used for this research were documents and files from previous courses related to this problem. Also, as mentioned previously, the information provided by the client and lastly information gathered using the internet.

The methods used are mostly done through the internet and the lectures provided by the coastal challenge course. However, software such as QGIS, Microsoft Teams, Microsoft Word and AutoCAD are also being used to model design the Banjaard the third's solution.

4.1.0 Shoreline MCA

Multi – Criteria Analysis (MCA) provides a systematic approach for complex decisions making by pre-determining criteria and objectives.

	Criteria	*Definition*
1	Environment Aspect	Impact on the ecosystems, nature disturbance
2	Legal and finance aspect	Legal regulations for sand nourishment and the total cost for the dredging procedure
3	Sustainability	Maintenance of structure, durability of structure, effectiveness
4	Timeslot	Time period required to design, built, construct and maintain
5	Erosion	The amount of sediment that is being eroded by wave, current and wind impact
6	Social aspect	Aesthetics of the project

4.1.1. MCA weight

	Criteria	*Weight %*	*Definition*
1	Environmental Aspect	18	The environmental aspects of the barrier island are important for the island's surroundings and for its ecosystems.

2	Legal and finance aspect	20	Legal and financial aspects are vital to the project. They set the project boundaries and determine what is, and what is not possible with the project.
3	Sustainability	18	Having to do as little maintenance as possible is important to make the project self-sustainable and able to move together with the sea level rise.
4	Timeslot	12	The time it will take to design, build, construct and maintain the project. This influences the project's planning and completion.
5	Erosion	20	The aim is for the island to have positive sedimentation, so measures may have to be taken to prevent excessive erosion, especially in the beginning before the vegetation has grown.
6	Social aspect	12	Public opinion on a project is particularly important. It has a significant impact on the development and future of the project.
	Total %	100	

4.1.2 Calculation method

The Grading criteria works by defining the optimal coastal defense. The grading that Banjaard the third is using to grade the alternatives is from 1 to 5, as 1 being worst and 5 being the best. After the grade is given, it is then multiplied by the weight of the criteria and then by factor 10 to get the final score.

$$Final\ score\ = Grade\ of\ criteria\ \cdot weight\ of\ criteria \cdot 10$$

4.2.0 Sediment source MCA

	Criteria	*Description*
1	Contamination	How pollute the soil is and how it can impact the project location and the surrounding ecosystem
2	Legal aspects	Complexity of using sediment of the provided source.
3	Availability	How easy can the material be found and on which period is it available
4	Cost	What is the cost of dredging and transporting the sediment?
5	Particle size	What is the average size of the particles in the sediment?

4.2.1 MCA weight

	Criteria	*Weight %*	*Description*
1	Contamination	20	Contamination is a part of the environmental aspect, which is a big discussion in nowadays future and it also has a significant

			impact on the ecosystems in the surrounding areas of the project areas.
2	Legal aspects	12	The legal aspects set the boundaries of the project. The legal aspects are binding, and we must abide by them.
3	Availability	30	Sediment is needed to create the barrier island, so it is important that there is a source nearby that can provide the necessary material to construct and maintain the island.
4	Cost	30	To carry out the project, the cost of creating and maintaining the barrier island must be lower than the current measures.
5	Particle size	8	Particle size is important because the lower the particle size the higher the turbidity will be, which has an impact on the life around the barrier island.
	Total weight	100 %	

4.2.2 Calculation method

The Grading criteria works by defining the optimal coastal defense. The grading that Banjaard the third is using to grade the alternatives is from 1 to 5, as 1 being worst and 5 being the best. After the grade is given, it is then multiplied by the weight of the criteria and then by factor 10 to get the final score.

$$Final\ score = Grade\ of\ Criteria \cdot Weight\ of\ criteria \cdot 10$$

5.0 Results

5.1 Shoreline Results

Revetment Shoreline					
	Criteria	Weight %	Grading points	Final Score	Explanation
1	Environmental Aspect	18	3	5.4	A revetment will cover most of the shoreline and prevents most of the vegetation from growing.
2	Legal and finance aspect	20	3	6.0	A revetment requires a lot of material which increases the relative cost.
3	Sustainability	18	2	3.6	A revetment will require constant maintenance because of erosion.
4	Timeslot	12	3	3.6	Planning and building the revetment will cost more time than simply using only vegetation.
5	Erosion	20	4	8	It will prevent the shore itself from eroding quite well.
6	Social aspect	12	3	3.6	It will not interfere too much with the sea itself, but the shore will look unnatural.
Total		100	17	30.2	

Breakwater Shoreline					
	Criteria	Weight %	Grading points	Final Score	Explanation
1	Environmental Aspect	18	3	5.4	The breakwater shoreline is a mix between vegetation and hard infrastructure intervention. The hard intervention can be biodegradable which means it will still have an impact on the environment, but it will be limited.
2	Legal and finance aspect	20	3	6.0	The materials that are required for the hard infrastructure will increase the costs of the project.
3	Sustainability	18	2	3.6	The hard infrastructure can be sustainable depending on the material. But in general, the breakwater shoreline is less sustainable than the edging and vegetation only shoreline.
4	Time-slot	12	3	3.6	Implementing and the hard infrastructure will take longer than the edging and vegetation only shoreline. It will also take more effort to maintain.
5	Erosion	20	4	8.0	The hard infrastructure is a more radical and a more expensive solution, but It is very effective so the erosion will be decreased significantly.
6	Social aspect	12	2	2.4	The aesthetics of a breakwater shoreline will not be as good as it will be for a vegetation shoreline. People tend to like a nature solution more than infrastructure.
Total		100	17	29	

Edging Shoreline					
	Criteria	Weight %	Grading points	Final Score	Explanation
1	Environmental Aspect	18	4	7.2	Only a small strip of the island is altered, and this can be done with eco-friendly and biodegradable materials.
2	Legal and finance aspect	20	3	6.0	The materials that are required will increase the cost compared to using only vegetation and there will

					be legal limits to what materials can be used.
3	Sustainability	18	3	5.4	The materials used to strengthen the edge will require some maintenance.
4	Time-slot	12	3	3.6	The construction of the edging will cost some time but not as much as an entire breakwater.
5	Erosion	20	3	6.0	It prevents more erosion than vegetation only but less than breakwater and revetment.
6	Social aspect	12	3	3.6	The edging could be perceived as slightly unnatural and ugly.
Total		100	19	31.8	

Vegetation only shoreline					
	Criteria	Weight %	Grading points	Final Score	Explanation
1	Environmental Aspect	18	5	9.0	When a vegetation only shoreline is implemented, multiple ecosystems will develop which will enhance the biological aspects.
2	Legal and finance aspect	20	4	8.0	The development of a vegetation only shoreline is relatively cheap in comparison to other shoreline options.
3	Sustainability	18	5	9.0	The vegetation only shoreline is very sustainable as it is very dynamic.
4	Time-slot	12	4	4.8	The development of a vegetation only shoreline costs less time than other shoreline options as it doesn’t need planning for hard construction.
5	Erosion	20	2	4.0	As the vegetation only shoreline consists of sediment only, this increases the risk of erosion.
6	Social aspect	12	5	6.0	A vegetation only shoreline is beneficial to the social aspects as it is aesthetically pleasing and might draw extra tourism.
Total		100	25	40.8	

5.2 Sediment source Results

North Sea					
	Criteria	Weight %	Grading points	Final Score	Explanation
1	Contamination	20	4	8	The contamination of the North Sea sediment is very low, as there is a lot of benthic life in the sediment.
2	Legal aspects	12	2	2.4	There are a lot of regulations for the dredging in the North Sea, due to Natura 2000.
3	Availability	30	3	9	There is a lot of sediment available in the North Sea, but this is also used for the heightening of beaches.
4	Cost	30	2	6	The cost for the dredging in the North Sea is relatively high due to the transportation costs.
5	Particle size	8	4	3.2	The particle size of the sediment of the North Sea is ideal for the construction of the island, since it is mostly sand.
Total score		100	15	28.6	

Rotterdam port					
	Criteria	Weight %	Grading points	Final Score	
1	Contamination	20	2	4	The port of Rotterdam is an extremely industrial area that has been there for decades. The sediment will be contaminated and will need to be cleaned.
2	Legal aspects	12	4	4.8	The port of Rotterdam needs to keep the port deep enough for large ships. Which is why a lot dredging is needed and therefore the legal aspects are in favor of dredging.
3	Availability	30	5	15	As mentioned, the port of Rotterdam needs to keep the canals deep enough. Therefore, dredging is a necessity for the port of Rotterdam.
4	Cost	30	1	3	Transporting the sediment from the port of Rotterdam to the Banjaard is very expensive.
5	Particle size	8	2	1.6	A part of the sediment could be river clay which is a smaller size than sand which
Total score		100	15	28,4	

Westerschelde					
	Criteria	Weight %	Grading points	Final Score	Explanation
1	Contamination	20	3	6.0	There are major chemical industries located along the Westerschelde and there is PFAS in the water. While it is not yet known if PFAS has an impact on the growth of vegetation there is still a moderate chance of contamination.
2	Legal aspects	12	1	1.2	By law any quantity sediment that is removed from the Westerschelde must also be returned which makes it difficult to acquire permits for dredging.
3	Availability	30	1	3.0	After removing the sediment, the same amount must be returned making it more logical to simply use that sediment in the first place.
4	Cost	30	1	3.0	Seeing as twice as much dredging must be done compared to the other locations the cost will always be more.
5	Particle size	8	4	3.2	The particles of the sediment will most likely be very similar to those of the proposed location of the barrier island.
Total score		100	10	16.4	

5.3 Conclusion

The vegetation shoreline scores the highest in the shoreline analysis and will be the main example for the design. Because of the location next to open sea some extra protection in the form of a breakwater might be required at least temporarily until the vegetation has fully grown.

The North Sea location has the highest score in the sediment source analysis, so that location would appear to be the best as a source of sediment. This is mostly due to the good location and the fact that sand is already sourced there for other projects.

6.0 Design

The design of the island will follow the guidelines from previous research report (C.Menheere, et al., 2022) (D.Cuna, et al., 2022). Thus, the island will consist of a crest moon shape with a radius of 2895 m and a width of 1200 m. The outer and inner slope will be 1:100 while the dune angle will be of 6:100, see figure 16 (C.Menheere, et al., 2022). The dune height will be 13 m so that during high tide the island will be 1.5 m above sea level while on low tide it would be 2 m above sea level.

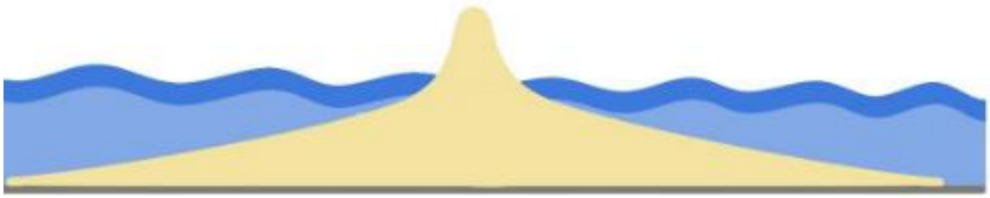


Figure 16: Cross-section of Banjaard barrier island

The Banjaard island will have a vegetation shoreline in combination with breakwater in the northwest part of the island. Banjaard the Third used figure 17 (ConservationGateway) as guideline to help layout the vegetation plants along the shoreline.

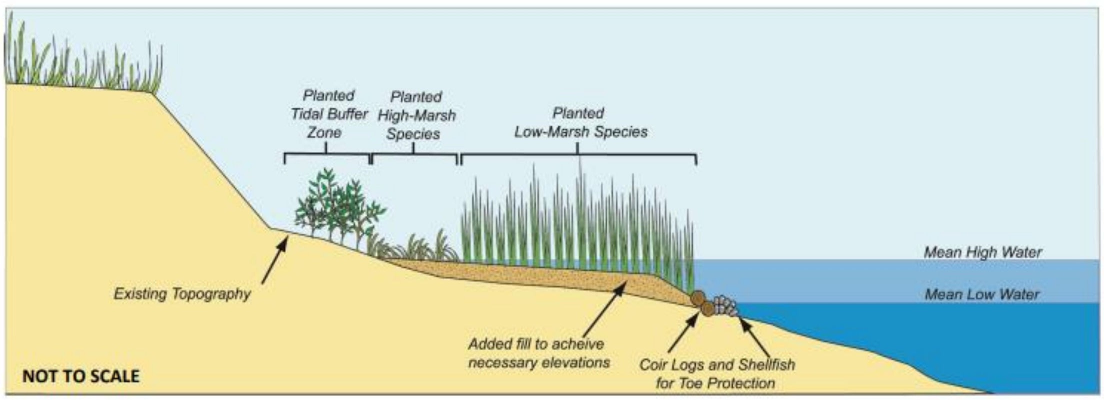


Figure 1717: Example of a vegetation shoreline

Figure 18: Sea buckthorn

For the Tidal Buffer Zone, bush vegetation like sea buckthorn (*Hippophae rhamnoides)* can be planted as this plant species grows well in dune areas and can reduce the wind velocity, which can help reduce the erosion. In the High-Marsh area of the island, plants like dune grass (*Ammophila arenaria*) can be planted as these also thrive in these areas and can hold down the soil with their roots. In the Low-Marsh area plants like Salicornia (*Salicornia europaea*) and sea lavender (*Limonium vulgare*) can be planted as these plant species are widespread in tidal flats.

Figure 19: Dune grass

Figure 20: Sea lavender

Figure 21: Salicornia

As for the toe protection stones will be place parallel to the waves in order to stabilize the bank of the shoreline. Using stones will stabilize the slope by sediments deposition behind and in between the row of stones.

Lastly, reef ball breakwater will be use as coastal protection of the Banjaard island. Reef ball breakwater are designed so that larger waves are force to break on the structure, reducing the wave energy that arrives the shoreline. Tidal range is also an important factor when it comes to reef breakwater. As submerged breakwater works best if the tidal range of the location is lower than 2 meters. As for the Mirror project, the tidal range is 2.899 meters which means that the placement of reef ball breakwater should be above the tidal line.

Figure 19: Reef ball breakwater

The reef ball has a width of 1.83 meters and a height of 1.22 meters with 22 to 34 holes (Harris, 2007). Banjaard the third will be placing reef ball along the coast of Banjaard island with a distance of 10 meters. The total length of the coast is equal to (3.14 * 2* 2895 m)/ 2 which gives a value of 9095 meters. The total amount reef ball required for the Mirror project is 9095 m / 1.83 m which is equal to 4970 breakwaters.

6.1 Legal analysis

The Netherlands has implemented coastal policies and strategies to ensure coastal protection. The motto of these strategies is, soft where possible, hard where necessary. In short, this means that a nature-based solutions will be the number 1 priority, but a hard engineered structure will be used when it is absolutely necessary. Four national coastal strategies have been developed while sticking to two main principles, the principle of natural dynamics and spatial quality. The four coastal strategies based on these principles are the following: Smart exploitation, this strategy aims to keep investments to a minimum. The second one is Joint reinforcement and prioritizing land, which focusses on creating an economically viable coast through public and private collaborations while managing the impacts on nature. The third strategy is smart exploitation, this strategy aims to keep investments to a minimum. The fourth strategy is sustainable choices, this strategy aims to focus on choices that will have an added ecological, social, and economic value. In order to design and implement a successful Banjaard Island, the coastal policies and strategies will need to be followed. (Rijksoverheid, 2013)

De Banjaard is located in a Natura2000 area, it is labelled as a Voordelta area as can be seen in figure 23 The area has been assigned number 113 and it is a dynamic area of tidal zones, salt water and beaches. The area of the Banjaard has been changing heavily over the past years due to sedimentation processes. The Oosterscheldekering has played a big role in the rapid change of sedimentation in the area. The changes in sedimentation have impacted the entire ecosystem of the Banjaard. In order to preserve the species living in the area, Natura2000 have policies in place for areas such as the Banjaard. (Natura2000, 2022)

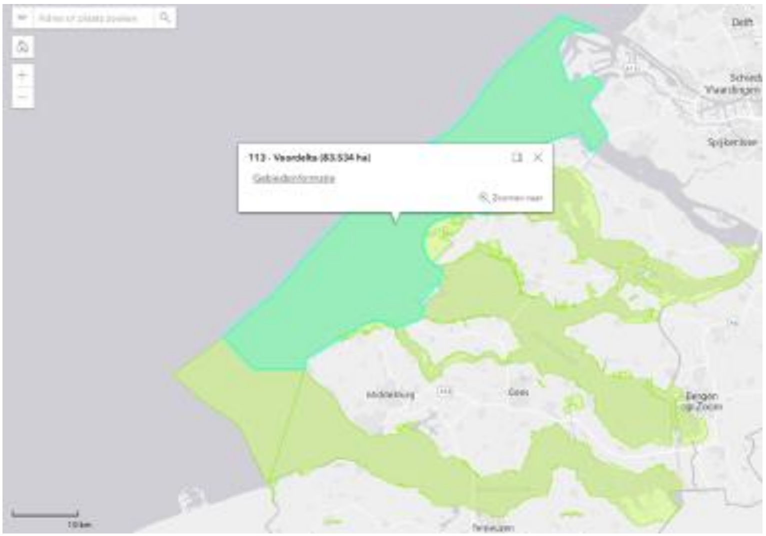


Figure 23: Natura 2000 area

Natura 2000 has named some key requirements for the future of this specific area. The requirements are: (Natura2000, 2022)

- Preservation of sea-ecosystem with permanently subdued sandbank, important as habitat for the ‘zwarte zee-eend’, ‘roodkeelduiker’, ‘topper’,’eider’ where it is important to have soil of different ages and a natural transition to benefit fish populations.
- Diversity in tidal sand banks, and preserving and restoring mudflat and salt marshes, in order to protect and enhance biodiversity
- Resting and foraging areas for birds; preservation of mudflats and salt marshes for resting and foraging birds and seals

Furthermore, there are various specific habitats that occur and species that live in the area of the Banjaard. These habitats and species are the reason that the area has been classified as a Natura2000 area. These habitats and species should be protected at all times. The impacts the island might have on these habitats and species should be carefully evaluated before constructing the island. Figure 24 and figure 25 show the list of habitats and species. (Natura2000, 2022)

Habitattypen

Habitattype	Habitatsubtype	Status doel	Oppervlakte	Kwaliteit	Relatieve bijdrage	Kernopgave
H1110A - Permanent overstroomde zandbanken	getijdengebied	definitief	=	=	C	
H1110B - Permanent overstroomde zandbanken	Noordzee-kustzone	definitief	=	=	B2	1.01,W
H1140A - Slik- en zandplaten	getijdengebied	definitief	=	=	C	1.10,W
H1140B - Slik- en zandplaten	Noordzee-kustzone	definitief	=	=	A1	
H1310A - Zilte pionierbegroeiingen	zeekraal	definitief	=	=	C	
H1310B - Zilte pionierbegroeiingen	zeevetmuur	definitief	=	=	C	
H1320 - Slijkgrasvelden		definitief	=	=	C	
H1330A - Schorren en zilte graslanden	buitendijks	definitief	=	=	C	1.06,W
H2110 - Embryonale duinen		definitief	=	=	B1	
H2120 - Witte duinen		definitief	=	=	C	

Figure 24: Habit types that are present in the area of the Banjaard

Habitatrichtlijnsoorten

Soort	Status doel	Populatie	Omvang leefgebied	Kwaliteit leefgebied	Relatieve bijdrage	Kernopgaven
H1095 - Zeeprik	definitief	>	=	=	A	1.06,W
H1099 - Rivierprik	definitief	>	=	=	B	
H1102 - Elft	definitief	>	=	=	A	1.06,W
H1103 - Fint	definitief	=	=	=	A	1.06,W
H1351 - Bruinvis	definitief	=	=	>	C	
H1364 - Grijze zeehond	definitief	=	=	=	B1	1.11
H1365 - Gewone zeehond	definitief	>	=	>	C	1.11

Figure 25: Species that are present in the area of the Banjaard

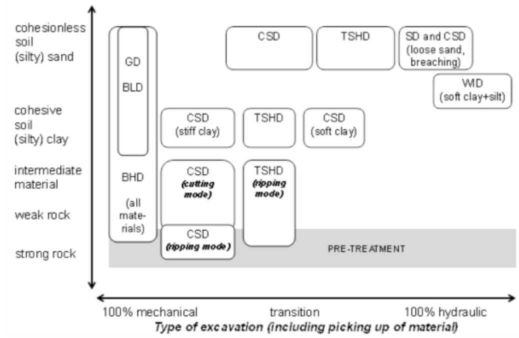
Next to the Natura 2000 policies and coastal strategies in the Netherlands that aim to protect nature and coastal areas, there are also regulations that apply to every country in Europe. These regulations are made by Europese Kaderrichtlijn Water (KRW), these have been created since water is transborder mostly transborder. The KRW has been in place since 2000 and the following regulations are included; (Rijksoverheid, 2021)

- Protection of all water; rivers, lakes, coastal waters, and groundwater.
- Setting goals to make sure all water is in good condition by 2027.
- Setting up a management system per flow area.
- Keeping into account international influences and politics.
- Making sure that all members of society have a chance to participate in water management.
- Reducing and limiting pollution, regardless of source.
- Keeping the interest of nature and humans in balance.

6.2 Materials and equipment

When selecting the dredging equipment several factors need to be considered:

- Soil conditions of the area
- Available transport options
- Dredging area configuration
- Placement of equipment



After performing the site investigation, it was discovered that the project area mainly consists of fine to coarse sand layers while in some places loam can be found. To minimize the cost of the project the distance between where the material is to be dredge and location where the dredged material is to be place should be between 5 to 10 km away. The North Sea will be the source for the dredge material while the placement will be on a Natural 2000 location, thus certain licenses and permits need to be considered beforehand.

The more effective dredgers for the Mirror project are mechanical or mechanical/hydraulic dredgers. There are many options available dredgers that can be used, however for this particular project it is concluded to use the trailing hopper dredger. The trailing suction hopper dredger is a self-propelled ship with hoppers and articulated dredging pipes that extend to the bottom of the sea, see figure15. The material is transported hydraulically through suction lines passing through the centrifugal pump into the hopper. The dredged material can be transported to the deposition site in the hopper within the vessel.

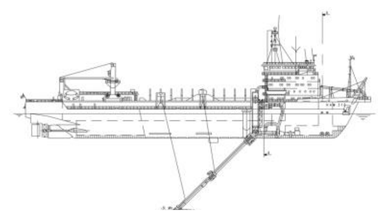


Figure 2720: Trailing hopper dredger

6.2.1.Time cycle for dredging equipment

The trailing suction hopper dredger that will be used for construction of the island is the Queen of the Netherlands TSHD provided by Boskalis (Boskalis, 1998;2009). The cycle of a trailing suction hopper dredger can be divided into four sections:

- **Sailing empty phase:**
- Since the sailing speed loaded is 16 knots it is assumed that the sailing speed unloaded is 17 knots.
- Sailing distance of 15 nm
- Calculation:

$$15\, nm \,/\, 17\, knots \;=\; 0.88\, h \;-> \; 0.83\, h \;*\; 60\, min = 53\, minutes.$$

- **Dredging phase:**

- The dredging process takes approximately $\sim 1\; hour\; and\; 20\; minutes \;=\; 80\; minutes$
- Vessel load $33425\; m^3$
- The dredging production:

$$33425\, m^3 \,/\, 80\, min = \; 417.8125\, m^3/min \;\rightarrow\; 25068.75\, m^3/hr$$

- **Sailing loaded phase:**

1. Sailing speed loaded is 16 knots

2. Calculation:

$$15\, nm \,/\, 16\, knots \;=\; 0.9375\, h \;{-}{>}\; 0.9375\, h \,*\, 60\, min \;=\; 56.25 \;\sim 57 minutes$$

- **Discharge phase:**
- The discharge process takes around $1.5\, hours \;=\; 90\, minutes$
- Discharge production:

$$33425\, m^3 \,/\, 90\, minutes \;=\; 371.38\, m^3/min \;\rightarrow\; 22283.3\, m^3/\, hr$$

Estimation of weekly production of Trail suction hopper dredger

Hopper size: 35500 m^3	
Vessel load: 33425 m^3	Sailing distance: 15 nm
Dredging time: 80 minutes	Dredging production: $25068.75\, m^3/hr$
Sailing time empty: 53 minutes	Sailing speed unloaded: 17 knots
Sailing time loaded: 57minutes	Sailing speed loaded: 16 knots
Maneuvering time: 10 minutes	
Connecting to floating lines time: 20 minutes	
Discharge time: 90 minutes	Discharge production: $22283.3\, m^3hr$
Cycle duration: $80 + 53 + 57 + 10 + 20 + 90 = 310\, minutes \;\rightarrow 5.2\, hrs$	Cycle production: $25068.75\, m^3\, /hr \;-\; 22283.3\, m^3/hr = 2785.45\, m^3/hr$
Operation hr/week : 125 hrs /week, * 4 cycle per day , 6 days a week **delays due to weather conditions, breeding season and transportation*	Weekly production: $2785.45\, m^3hr \,*\, 125\, hr/week = 348181.25\, m^3/\, week$
Project duration: $4914307\, m^3\, /348181.25 \frac{m^3}{week} \;=\; 14.11\, weeks \;\sim 15\, weeks$	

6.3 Environmental analysis

Current situation

The seabed of the North Sea on the site of the project contains many forms of benthic life. This mostly includes shellfish and worms (Rijksoverheid, sd.). These forms of benthic life are a vital prey for other species such as fish, birds, and sea mammals, and thus are an important part of the food web in the North Sea. They also contribute to the recycling of nutrients in the water. They also provide aeration of the benthic soil, which makes the soil more livable and prevents the forming of an anoxic layer.

Changes

With the construction of the barrier island, vegetation will be planted on the island to keep the sediment in place, which provides a habitat for different species of birds and insects. Marine vegetation like seaweeds will also be planted off the shore of the island in the intertidal zone, which provides new food sources for species like fish and mollusks. The new sediment will provide a new habitat for the benthic species present, which will then again be an important food source for other species. When sediments like rocks or shells deposit at the shores, oyster reefs may form, which also provide a habitat for a lot of different species like crabs, shrimp, small fish and species of seaweed. This all has a positive impact on the developing of a dynamic and healthy ecosystem.

Impact

The impact on benthic organisms will be severely negative as they will be covered with meters of sand. Some mobile species may be able to migrate to other parts of the soil and because the nearby area is not too different this might not be an issue for them, but most of the non-mobile species on the location of the island will perish. The creation of different habitat types will however provide opportunities for new species of flora and fauna and in the end the ecosystem is replaced by different ecosystems and if this approach reduces the necessity of sand dredging in other areas the result for the ecosystems will be positive.

6.4 Financial analysis

The following costs are an estimation of the costs, the eventual costs can vary from these results.

The time it takes to dredge and construct the island has been calculated, this came to.15 weeks. The cost of one full week of dredging is € 619. 040, - The total costs of dredging for this portfolio comes to 619.040 x 15 weeks = € 9.258.600, -

Reef balls will be placed around the island, there will be 4970 reef balls. The costs of one reef ball is €800, - (Reefinnovations , 2022)

This comes to a total cost of 4790 x €800,- = €3.975.000

€ 5,10, - per square meter Dune grass or similar for non-tidal area

9 per square meter (Directplant, 2022)

The area of the island is 9095 m x 200m = 1.819.000 m2

Which comes to 1.819.000 m2 x € 5,10, - = €9.277.000, -

€ 3,75, - per square meter sea lavender or similar for tidal zone

7 per square meter (directplant, 2022)

Which comes to 1.819.000 m2 x € 3,75, - = €6.820.000, -

€ 56 - € 92 euros to place one meter of stones. These will be placed along the island 5 times which comes to a total length of 9095m x 5 = 45.475m

The average price to place one meter of stones is 74, - which comes to;

45.475m x €74 = € 3.365.000, -

The total estimated costs are € 32.700.000, -

Benefits of the project

There are many benefits to this project, it will take some time for some of the benefits to have an effect.

- Coastal protection, decrease in coastal erosion
- Nesting place for bird species, increased biodiversity
- Livability of the area surrounding the Banjaard
- Tourist attraction which is huge benefit to local business owners
- Business remains for the local fishery sector

It is very difficult to convert the benefits into numbers, but it is clear that this project will have an extremely positive influence on the local area. However, the uncertainty of the project should be taken into consideration when looking at the benefits of the project. It is impossible to predict the future and therefore, we cannot ensure that all the benefits that were mentioned will actually be benefits of the project.

The monitoring of this project will be done by studying the area with researchers and involved stakeholders. The island will need time to have an effect on the surrounding area. The monitoring will need to be done in order to keep everyone involved updated on the progress and impacts of the project. There are many aspects like the level of erosion, sedimentation, biodiversity, tidal changes and improved coastal protection that need to be monitored after the island has been implemented. The aesthetics of the project will also need to be monitored. The local people have been involved in the start so therefore they should be content with the island. However, that needs to be monitored since local people are key members of the local community and it is vital to keep them content with the project.

7.0 Conclusion

North Sea sediment will be used to construct a barrier island at the location of the Banjaard sandbank. This barrier island will be protected from erosion by a combination of vegetation in the intertidal zone and above and a breakwater constructed from reef balls to protect the island in the starting phase when the vegetation has not grown yet, and during storms. The barrier island should improve the sedimentation around it and remove the need for sand suppletion. For the creation of the island $4914307\ m^3$ sediment is needed, and this will be sourced from existing sand extraction locations in the North Sea. The time required to construct the island will be at least 14-15 weeks.

The stakeholder analysis showed that many stakeholders are involved in this project. The local people play a big role and need to be included from the start and need to be included during the implementation phase as well. As mentioned, it is critical to the project to involve stakeholders and keep them involved in various different ways. Finally, there are many legal aspects that should be taken into account during this project. The area of the Banjaard is the habitat of countless species which is why it is a Natura2000 area. This automatically means many laws and regulations which the project needs to abide by. As well as the coastal strategies, policies and regulations for dredging.

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