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Breakwater project 'De Banjaard'

Authers: Joost van Eenennaam, Stiaan Gerrits, Rachel de Groot, Rahaf Hasan, Tim Hoogkamp, Janneke Janssen, and Daan Woltjer

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Contents

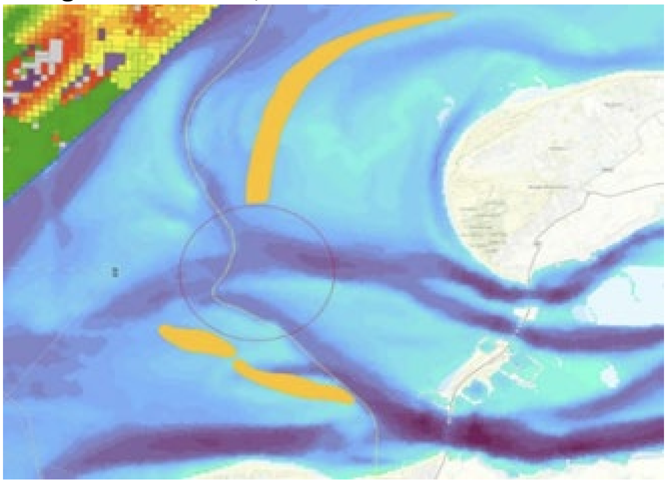
Abstract

Climate change is a global problem that also affect the Netherlands. An important factor impacted by climate change and thus sea level rise is flood safety. In the province of Zeeland flood safety is greatly enhanced due to the Eastern Scheldt Barrier, which in extreme conditions (water levels more than 3m above NAP) is able to close its 62 sluice gates to protect the land behind it. The area around the Eastern Scheldt Barrier is subjected to erosion by (on average) southwest winds and waves, and occasional Northwest storms. This barrier was only built to withstand a total sea level rise of 1 meter. Due to unfavorable prospects, it is necessary to explore options to reduce erosion by wave- and wind energy in both normal and extreme conditions. This research explores the option of a breakwater near the coast and the Eastern Scheldt barrier.

To be more specific, the optimal location, shape and design of the breakwater is researched, as well as the use of marine bio-builders and possible multifunctionality of a breakwater. The former was explored by researching three possible sites for the breakwater, where the following criteria were used to determine the suitability for reaching the desired results:

- Position and coastal protection
- Impact on tourism (Burgh-Haamstede)
- Impact on shipping
- Impact on flora and fauna
- Sustainability
- Cost

Using these criteria, it was found that variant 3 is the most favorable variant.



Moreover, research into bio-builders showed positive prospects for implementation of biobuilders in the breakwater. Bio-builders can be used to stabilize sediment on the leewards side of the island.

Concerning multifunctionality, there are chances for eco-tourism, energy and aquaculture.

Introduction

Problem statement

Climate change is a global problem that results in the sea level rising globally. A way to counter the effects of sea-level rise is by building or heightening dikes. The evolution of dykes from carefully stacked clay and sand into high-tech sensor dykes did not happen overnight. When the coast was comprised of natural embankments and dunes, 2000 years ago, the only habitable areas were the higher areas in the east and south, as well as on the dunes and embankments. As populations grew so did the amount and area of dykes that were constructed. However, by excluding land from the cycle of flooding by putting a dyke around it, sedimentation of silt no longer happened and thus the land started to subside. On top of this, drained soil consolidates much easier and peat decomposes, leading to land subsidence (up to 8 millimetres per year, dependent on the location within the Netherlands). In the Netherlands, the 'Delta Plan' was carried out after de Watersnoodramp in 1953, of which the Eastern Scheldt barrier was a part. The Eastern Scheldt barrier was only built to withstand a total sea level rise of 1 meter. However, currently, the sea level has already risen 24 centimetres from 1829 to 2018 (Rijksoverheid, 2018) and KNMI has predicted that will keep on rising by another 85 cm by 2100 (KNMI, 2014). This means that the Eastern Scheldt barrier's limit will already be met this decade. Breakwaters can help with dampening wave energy in both normal and extreme conditions. The Banjaard is an area in front of the eastern Scheldt which used to be a barrier island but got eroded.

Project objectives

The main project objective is to protect the coast from sea level rise and dangerous circumstances due to sea-level rise, for example, a storm and flooding of the coast. To protect the coast of Schouwen-Duiveland from flooding, an artificial island will be built before the coast of Schouwen-Duiveland.

The island must work optimally and efficiently against the battle of the sea. That is why several questions need to be answered around the island. Where is the optimal location of the island, so the island can protect Schouwen-Duiveland in the best way? When the best location is found, it is time to think of a design for the island. Dimensions, volume profile, erosion, and type of sand of the island needs to be determined, otherwise, it is not possible to make sure the main project objective will be reached.

Another objective is protecting the island from a lot of erosion. To find a satisfactory solution to reduce the erosion level, that will be done by researching the impact of bio builders placed on the coast of the island. That must reduce the power of the waves and therefore the rate of erosion.

Projects like these are not yet quite common, that is why it is important to know the impact of the island over time. What is achieved in the short-term when the island is placed and in a functional working habitat. Also, it is important to research the impact of the island in the long term and to make sure it has positive outcomes.

Another objective contains the sustainability of the project. The island will reduce the wave energy; however, this energy will be lost. Therefore, this question will be researched. Is it possible to convert the wave energy into usable energy? More questions will be answered around sustainability, for example, is it possible to grow crops on the island.

The main project objective is to protect the coast from sea level rise; however, this must be done sustainably. So, another important research question must be answered and that is: Is it possible to make and sustain the island without fossil fuels?

Main questions

1. What would be the optimal location, shape, and design of the breakwater to restore the Banjaard and be able to use the breakwater for multi-functions?
2. How can marine bio-builders be used to protect sand nourishment in the sea at location 'The Banjaard'?
3. How can the island of 'The Banjaard' be used in a multifunctional way?

Sub-questions:

Civil engineering:

- What location, shape and design would be optimal to protect the island 'Schouwen - Duiveland'?
- What volume of sand should be used for nourishment?
- How can the nourishment be carried out sustainably as much as possible?

Aquatic ecotechnology:

- How can marine bio-builders be used to protect sand nourishment in the sea at location 'The Banjaard'?
- What kind(s) of bio-builder(s) can be used for a natural barrier and what kind of functions does it have?

Delta Management:

- Which stakeholders are important for this project?
- What is the history of 'the Banjaard' can this tell us something about why the island disappeared?
- How can breakwater 'the Banjaard' be used multifunctionally?

Theoretical background

Morphological conditions

There are two types of coastal erosion. A fast, sudden erosion of the dune front during storm surges, causing a considerable loss of sand to deeper water. A slowly, chronic erosion, which is not so striking, is caused by sea level rise and morphological phenomena (Rijkswaterstaat, 1990). Due to chronic erosion sand disappears from the coastal zone. Since the sea levels are always on the rise over the years, it can cause an increasing chronic erosion. In that case, also the coastal profile will adapt to the new water level by moving in a landward direction.

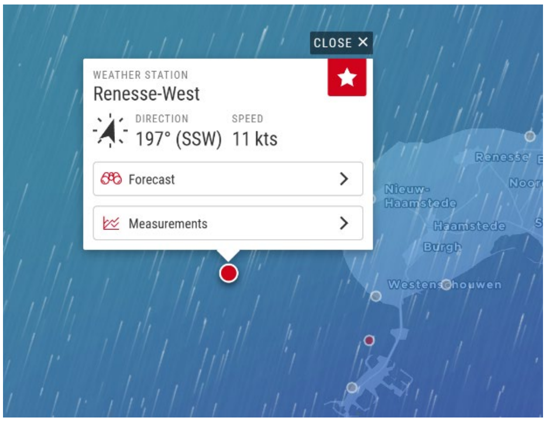


Figure 1 Wind & weather statistics, weather station Renesse-West -Windfinder, n.d.

The weather survey station of Renesse-West was used to investigate the morphological conditions of the Banjaard area since the station is located where the Banjaard was situated before its disappearance. Therefore, the results of the collected data will be as accurate and relevant as possible.

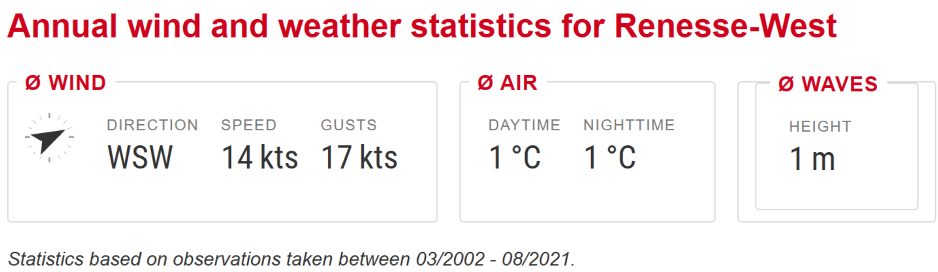


Figure 2 Annual wind and weather statistics for Renesse-West based on observations from 03-2002 - 08-2021 (Windfinder, n.d.)

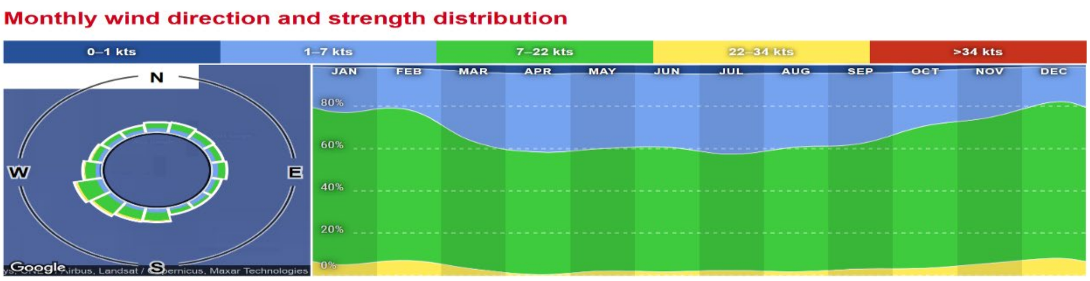


Figure 3 Monthly wind direction and strenght distribution measured at Renesse-West (Windfinder, n.d.)

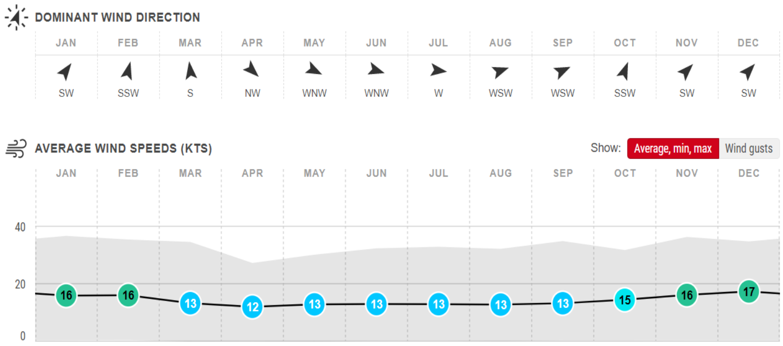


Figure 4 Statistics based on observations taken between 03/2002 - 08/2021 daily from 7 am to 7 pm local time. (Wind & Weather Statistics Renesse-West - Windfinder, n.d.)

According to www.windfinder.com, the average wind direction for the past 18 years in the Banjaard area is West-Southwest (WSW). In addition, the average wind speed calculated is 14 knots. As for the average wave height for the last 18 years, it was found to be around 1 meter according to the statistics on the website.

As such, it can be assumed that the Banjaard has disappeared over time due to the wave and wind direction West-Southwest, which are perpendicular to the island and as a result erosion is occurring and sand volumes are lost to the sea.

Bathymetry:

The North Sea is formed by the erosion of the earth's crust. This process is carried out in the south as the land has been deposited with mud and sand. In the north, erosion material is not available. As such the depth in the North Sea increases from tens of meters in the south to hundreds of meters in the north. In the southern part of the North Sea, the sandy sediments are exposed to more recent waves and tides. This region's bottom is composed of sandbanks and undulating sands.

According to the image below, the average depth in the area surrounding where the Banjaard island was positioned is -5 m NAP. In addition, the areas with deep blue have an average of -20m NAP, which are mostly used for shipping routes. This data will be used to design the different variants of the Banjaard.

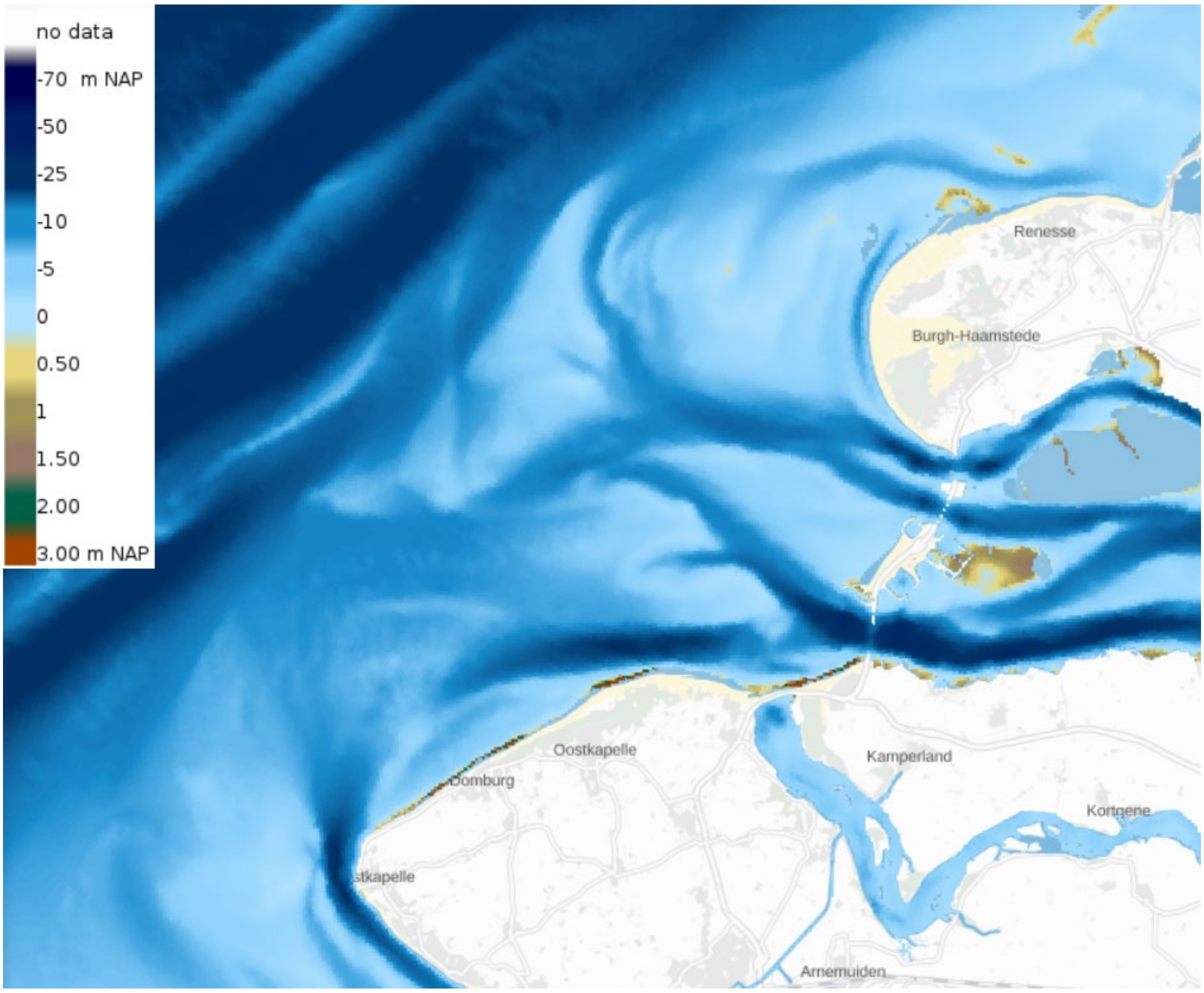


Figure 5 Bathymetry of North-Sea coast in front of the Eastern Scheldt measured in M NAP (IHN opendata viewer, n.d.)

Civil engineering:

For more than 30 years beach nourishment has been a key in the maintenance of the Dutch coastline. The main goal of beach nourishment is to prevent erosion on the coastline in such a way that it coordinates with the natural process of nature. Due to erosion of the sand can the coastline fail and that would mean a complete catastrophe. That is why each year only on the Dutch coastline 12 million cubic metres of sand is replaced (Informatiehuismarien, 2021).

Due climate change, the world must deal with extreme storms and sea level rise. Therefore, it is necessary to maintain beach nourishment, because it is one of the best ways to protect

the beach in a way that it controls coastal development without degrading the beach. Now it is especially important to minimize climate change at all costs. That is why there are many studies for eco–friendly beach nourishment.
There are diverse ways for beach nourishment, and this is mostly done from a ship. The 3 best existing ways are:

1. Klappen,
2. Rainbowen,
3. Pipelines

Klappen

When there is a lot of water depth in the area where beach nourishment is required. Then the best type of nourishment is to use a Dutch “sleephopperzuiger.” This boat ships to the area where beach nourishment is required. The load leaves the boat via the bottom doors at once. This is the most efficient way of unloading a nourishment boat. This way of sand nourishment is called “klappen.”

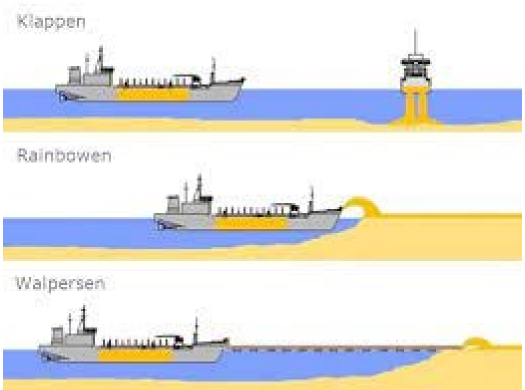


Figure 6 Klappen, rainbowen and pipe nourishment.

Rainbowen

This is the way where a mixture of water and sand is pumped from the ship and in a rainbow, a curve landed in the water. This method is mostly used for beach nourishment in areas where the ship close can come to the shoreline. This is mostly in shallow waters, where the material is already brought by “klappen.” From the money, perspective is “klappen” the most attractive method.

Pipelines

This method uses floating pipelines, the load leaves the ship due to a floating pipeline. On land, the floating pipeline transforms into a land pipe. When the sand is on land, bulldozers, and excavators’ level further the sand in a good profile (Stowa, 2021).

Western Scheldt

The Western Scheldt is close to the project, the Western Scheldt is an estuary and therefore it needs to be regularly dredged. In 2018, 600.000 cubic meters of sand and clay were dredged. After this was dredged it was used for beach nourishment for the coastline. Over the years, the sand and clay have silted up in the fairway and formed a barrier. The 600.000 cubic meters of sand and clay were only dredged in the debouchment of the estuary. By removing the sand and clay, the estuary will become more accessible for large ships. This is especially important for big harbour companies in Vlissingen, that is why the dredging will be continued. So, the large ships can go via the dredged fairways to the harbour of Vlissingen. The Western Scheldt has several fairway channels. Large ships going to Vlissingen, Gent, and Antwerp all use the main fairway. This channel is constantly being dredged and maintained, so the channel keeps the correct sailing depth. There are also smaller fairway channels in the

Western Scheldt, but these channels are not dredged, and nature determines the shape and depth of these channels. (Rijkswaterstaat, 2020)
In 2016 there was claimed that 2 dredging ships took away 9 to 10 million cubic meters of sand out of the Western Scheldt. This sand was placed in secondary fairway channels and on the edge of sandbanks. At that time there were important people every 2 months discussing the problem where they could deposit the sand. The people who make the decisions on where a deposit place could be said at that time that the Watershed needs more deposit places. Because sometimes now the deposit places are simply too full to put more sand on it. By law it is not possible to take sludge from the Western Scheldt, however, it would be a clever idea because it is nearby the Banjaard. (Baggeren en storten, 2003)

Sand and silt

The difference between sand and silt can be described in the behaviour of the particles during erosion, transport, and sedimentation. The fine silt particles stick to each other, so this makes them very cohesive, which makes them difficult to erode. If the fine silt particles float in the water column then it is quite easy to float a long time because they have an incredibly low fall rate. The silt particles are not only in size smaller than the sand particles but also, have a lower specific gravity and more irregular shape than sand. These two factors give the silt particles a lower fall rate than sand. If there are a lot of silt particles in the water, the particles get in each other's way. This is not good for transport and that means bad sedimentation. If the silt particles reach the bottom, it becomes an unconsolidated layer with a lot of water. After a while, this layer becomes firm and eroding becomes difficult. All this summed up above is not the case with grains of sand. Because the behaviour of silt-particles during transport, sedimentation and erosion are different from the behaviour of sand. The silt will react differently than the sand, so the sand and the silt will move to other places. This is called spatial differentiation. Particles bigger than 63 um are called sand and silt has a smaller particle than 63 um.
(Vlaams Nederlandse schelde commissie, 2013).

Choice of sand

Sand is used for many different purposes, there are also a lot of sand choices. Therefore, sands can be divided based on use. Below there are some examples discussed which are used in the Netherlands.

Embankment sand

Embankment sand is sand that is mostly used for raising soil, foundations or in the construction of building sites. It must therefore have a high load-bearing capacity to prevent subsidence. Aeolian, fluvial, and marine sand deposits are suitable for this coarse sand (diameter greater than 300 mm), this sand is also suitable as concrete and masonry sand. But this costs more money than filling up with sand. Therefore, finer-grained sand will be used to fill sand. The largest part of the fill sand (70%) is extracted from large national waters such as the North Sea. About fifty million cubic meters of embankment or fill sand is used in the Netherlands every year. (Geologische van Nederland, 2016).

Industrial sand/concrete and masonry sand

Industrial sand is exactly a collective name for sand for all different purposes. This sand is used for making concrete and asphalt, for bricklaying, plastering and even for filtering water. Industrial sand only can contain a small amount of fine material and especially not too many little parts like shells. The diameter of the sand grains for industrial sand may not be less than 210 mm. This sand is found in upstream parts of the rivers. Industrial sand is therefore mainly extracted in North Brabant, Limburg, Gelderland, and Utrecht. More than 20 million cubic meters of concrete and masonry sand is used annually throughout the Netherlands (Geologische van Nederland, 2016).

For this project to make an island, it is better to use embankment sand, because it has a high load-bearing capacity. And it is river sand with the source from the North Sea and western Scheldt.
Embankment sand is a high bearing capacity because it is not compressible. However, this sand is easy to work with. It can easily take out of the North Sea through dredgers, and when it is on the island machines can make a shape of the island.

Eco-friendly bio-based fuels

Since January, this year company Jan de Null group from Belgium has found a way to reduce significantly the CO2 emissions. The ship called Pedro Alvares Cabral will be working on 100% sustainable drop-in biobased fuels. This is a sustainable replacement for fossil fuels because bio-based diesel is made of waste streams. Drop-in fuels mean that the engines of the ships can stay, they do not have to be adapted.
These sustainable variant reducers not only a lot of CO2 emissions, but it reduces also a lot of particulate matter. The combustion of the drop-in fuels is way more efficient than the combustion of the original diesel – fuels. Because the drop-in fuels are used as waste material, this way of working is also a lot better for a circular economy.
Groundworks on the beach use Jan De Null the most advanced bulldozers and excavators. The material is all equipped with an exhaust filter. With these methods, Jan de Null reduces 90 % of his CO2 emissions. These ships with sustainable drop-in fuels are used for several ships at Jan de Null. Jan de null strives to a further to emission level of zero CO2 (Jan de Null Group, 2021).

Marker Wadden

The Markermeer has struggled for years with a sludge problem. The sludge is floating around in the water in which harms the marine species in the water. Because the Markermeer is a closet area the sludge cannot leave.
One of the aims of the construction of Marker Wadden is to reduce the amount of floating sludge and turbidity. The sludge settles down in gullies special made for this. Also, it settles down after the islands, because the water flow is there calm. Therefore, the sludge can settle down.
The layer of sludge that settled down in the gullies is around 20 cm to 50 cm per year. And on very local places the sludge layer is around 1 m. Researcher Thijs van Kessel says that the Marker Wadden also was meant as a study. The Marker Wadden are an enormous success, because of the sludge that settles down. In one year there is 200.000-ton sludge settled down. That is approximately as much sludge as there is in the whole lake. The Marker

Wadden influence the sludge balance of the lake in a way that it has a positive outcome on the turbidity (Natuurmonumenten, 2020)

Wooden groynes

Groynes are made to prevent that sediment moves along the shoreline. Groynes are a physical barrier to the movement of beach materials. Because of the wooden groynes becomes the tidal current is less strong. That is why less erosion will take place because more sand will stay on the beach.
The wooden groyne will keep the sand nourishment better on the beach. When there are no wooden groynes, sand can easily float away. With the wooden poles, the sand will stay better on the beach. (Application of timber groynes in coastal engineering, 2002)

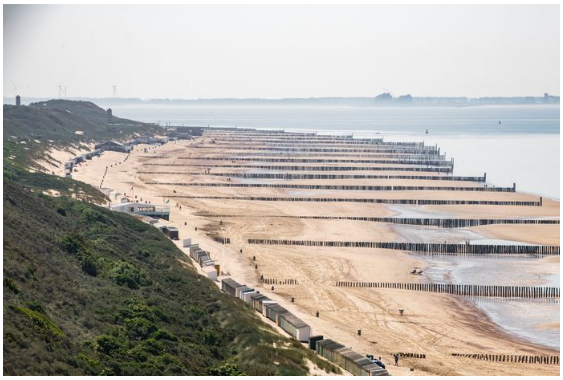


Figure 7: Wooden poles protecting coast of Walcheren.

Wood is a relatively light material and is also strong. The wooden poles can easily be constructed on the beach and have a high tolerance of loads that are short of duration. Wooden poles can easily be made from recycled wood, which is also good for the planet. (Design of timber groynes, 2002)

The sand engine

The sand motor is a peninsula before the Delfland coast. The sand motor is created in 2011 and became an island after 21,5 million of cubic meters sand nourishment. The sand motor was expected to have a lifespan of 20 years, however after research this the lifespan is much longer. Because of the influence of waves, currents and wind the sand of the sand motor move along the coast. This is in the northerly direction, but also in the southernly direction. The huge amount of sand makes the sand motor unique, just like the principle of nature doing its work. There are several goals of this project: Enhancing long term coastal safety, adding nature and recreation areas. And developing knowledge and innovation around this project.
(Rijkswaterstaat, 2021)

Sustainability of the project

To keep the island sustainable, it is signified important that various maintenance rules are applied. The island will have to deal with currents, tides, and other things. That is why the island must get regular beach nourishments from the dredging of the western Scheldt or the Eastern Scheldt. Also, the natural barriers must be preserved. That will be done with regular measurements, so the optimal circumstances will be maintained for the natural barriers. This can be written further in this report. The island is designed for sea level rise at the end of this century. That means that the lifespan must be 78 years, so maintenance is important. Maintenance is not only needed for the island but also the things on the island. For example, vacation houses need every year maintenance and the nature on the island must be maintained. This and other possible multifunctional uses will be elaborated on later in the report under the section ‘Multifunctionality.’

Aquatic ecotechnology

Bio builders

In many studies, the effect of the physical, chemical, and biological characteristics of the substrates on marine organisms has been studied. The main advantage to traditional (soft or hard) engineering is that the latter are over-dimensioned and static, hence not responding to fast-changing conditions. Integration of nature-based solutions into coastal protection allows a dynamic interaction between organisms and the natural evolution of the coastal system. In case of sea-level rise, nature-based solutions may be used to avoid if possible, and if not, delay the need for massive engineering measures for coastal protection. Thereby, organisms that trap sediment to keep up with long-term sea-level rise may provide long-term sustainable protection and might, at least locally, reverse or delay ongoing trends. Moreover, given the adaptive abilities of ecosystem engineering or bio-builder species, solutions could be less over-dimensioned compared to traditional engineering solutions, which reduces costs during deployment, monitoring and maintenance. Thorough knowledge of ecosystem functioning and ecosystem-based management is needed to make this approach successful (Sterckx, et al., 2020).

Shape and location of bivalve bio-builders on breakwaters

Ecosystem engineers (a synonym for bio-builders) need specific conditions to successfully establish. (Nioz, 2016) found that: 'Restoration of these ecosystem engineers has proven to be extremely difficult, with high failure of restoration efforts around the globe'. With the mention of the window of opportunity theory.

This is referring to the fact that bio-builders need to be able to establish a community of a certain size before, for instance, big storms start building to survive the first year. If a certain structural complexity of the oyster/mussel reef is not reached, the reef or bed will be destroyed by the winter storms, therefore, wiping out the mussels or oysters.

To increase the change of succession when implementing bio-builders, the concept of mimicry can be applied. Recreating the natural conditions and environment of bio-builders like mussel beds and oyster reefs will facilitate establishing for these bio-builders. Structural complexity and hard substrate to attach to are 2 crucial factors that can be used when applying mimicry. Most of this is in the form of a (natural) hard substrate such as other oyster shells, rocks, and stones or piers (NOAA, n.d). Adding shells of mussels or oysters in an area where an artificial mussel bed or oyster reef is going to be implemented will facilitate the establishment of a bed or a reef.

Reef balls may be one of the tools that can be used for mimicry to facilitate the establishment of a mussel bed or oyster reef. Reef balls mimic the function and structural complexity of a mussel bed or oyster reef while also providing a hard substrate to attach to for the bio-builders. Reef balls can be made from many different materials, but an important remark is to make sure that any additives that are added to the reef ball should have the same pH as the seawater and not have an ecotoxicological impact. As mentioned before, empty mussel shells or oyster shells can be added to the reef balls to make sure larvae from mussels and oysters will attach to the reef balls as the empty shells attached to the reef balls will give off chemicals that cause floating larvae to settle down and attack to the reef ball. The addition of hard substrate right from the beginning when the reef is formed means that the reef will be more resilient to storms in earlier stages making for more opportunities to successfully establish.


Figure 8 Showing on the left: reef ball used to facilitate an oyster culture, on the right: a reef ball (cbf.org, April 2019)

The pacific oyster can be used successfully to increase sedimentation in erosional conditions as well as prevent erosion (Salvador de Paiva et al. 2016). It was found that a reef with a lower width and higher length ratio resulted in a denser reef, therefore, trapping more sediment. Moreover, it was concluded that the construction of artificial pacific oyster reefs could be used as a crucial tool for tidal flat protection and conservation.
Mussels add the same values to their environment when placed on tidal flats and provide the same effect.
In collaboration with previous research by our supervisor João Salvador De Paiva to create a method to increase the likelihood of oyster reefs surviving the first 2 years and successfully establish, a method was sought to build on the previous knowledge with the inclusion of the Reef Ball method. The conclusion on Oyster reefs was that "reef length was the better predictor for both the area (p = 0.01) and maximum distance (p=0.00) of the influenced zone" The length showed the most influenced area. It was further shown that the pacific oyster has been found to perform best in erosional conditions with a low height to length ratio with a high density. This can be mimicked by the positioning of the reef balls (Walles et al. 2014).

Furthermore, research done by (van Belzen et al. in 2017) showed that "increased residence time of water due to higher water storage capacity within engineered landscapes is an important determinant of ecosystem functioning that may extend well beyond the case of shellfish reefs"

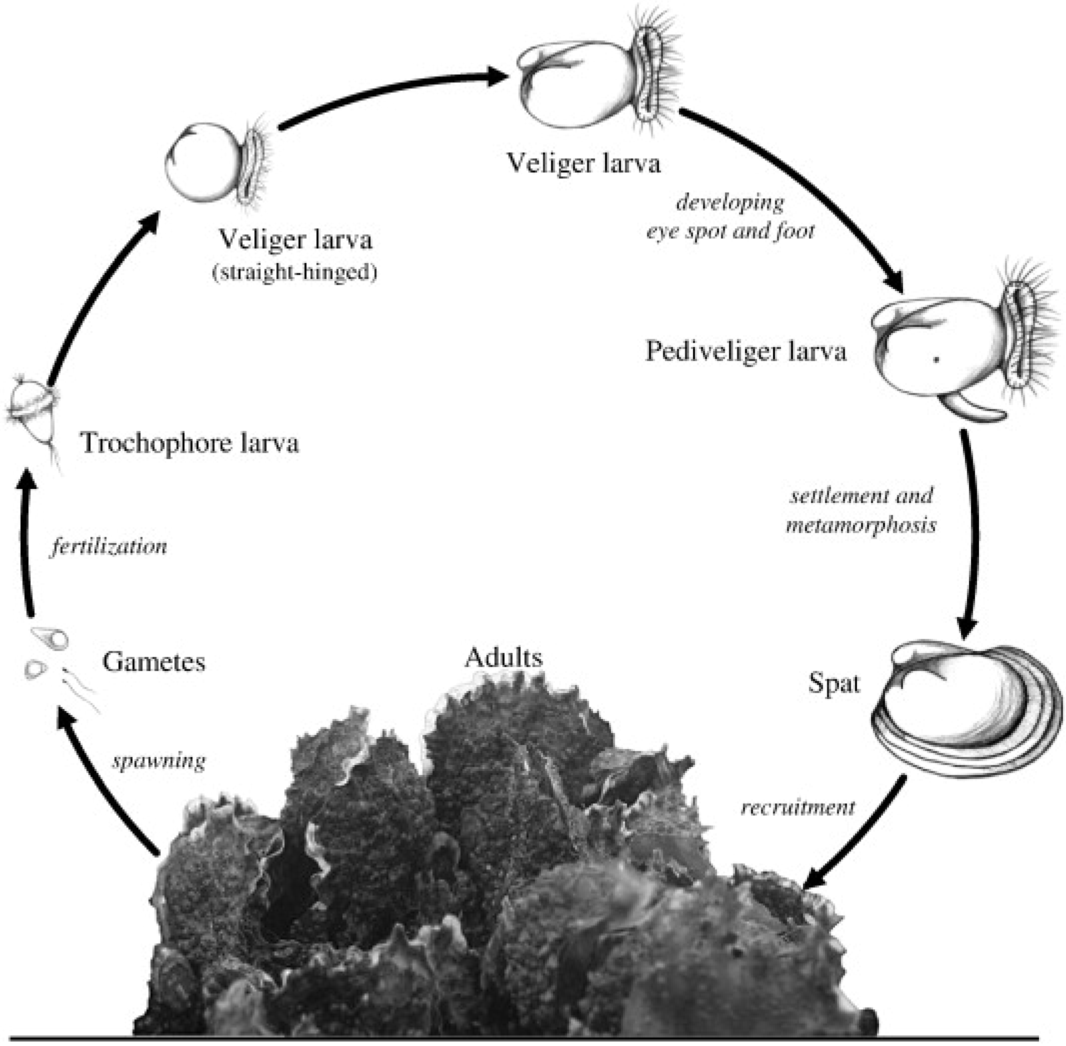


Figure 9 Life cycle of the pacific oyster (Wallace et al., 2008)

Living requirements and sustainability of marine bivalves, the blue mussels and Pacific oyster

Living requirements Mytilus edulis (blue mussel):

(McGrorty, et al., 1993), found that the optimal exposure time to increase the density of a mussel bed is between 30-40%. Above 50% exposure time the density of the mussel beds started decreasing. Furthermore, it was found that the variable exposure time explained 71% of all the variety in density within a mussel bed. This shows that exposure time is one of the most important variables to keep in mind.

Moreover (Brinkman et al., 2002) found that wave action was another main structuring factor. A low flow velocity was preferred where an extremely low or maximal flow velocity was found favourable for mussel beds. A flow velocity of around 1,5 m/s is preferred for the mussels with M16 values of around porosity values of around 170 for the sediment. Silty sediments are not preferred.

Physical factors like currents and waves will affect losses within the mussel bed but will be less when the mussel bed is well established (McGrorty et al., 1990; Seed and Suchanek 1992). Currents can have an influence on the supply of food with a low flow velocity which can affect possibilities of growth and waves can remove substrate or bury the mussel bed with high flow velocities (Seed and Suchanek 1992). It is expected that sediment composition is of importance as well (van der Meer 1991). Waves can have an even bigger influence in the event of storms, with the effects of the storm being bigger in shallow areas (RIKZ 1998).

Living requirements Pacific Oyster:

An important trait of a successful colonist's species for successful natural spread is habitat generalism (Marvier et al., 2004). The pacific oyster will in the first instance settle onto hard substrate but can also settle onto other soft substrates by attaching to shells and stones (Quayle, 1988, Mann et al., 1991, Leewis et al., 1994, Wolff, 2005, Dankers NMJA et al., 2006). The range of abiotic conditions in which the pacific oyster can establish is largely resulting in a very wide native geographical range. The pacific oyster can survive with water temperatures of 40 °C (Shamseldin et al., 1997) And with low tide air temperatures of -5 °C (Korringa, 1952) With even lower temperatures that can be sustained with a higher salinity (> 75% survival at 30 PSU, at − 12 °C air temperature: exposure for 7 days, 6 h per day, mimicking tidal emersion. Wa Kang'eri, 2005). Growing occurs in the temperature window of 10-40 °C with spawning happening in the window between 16-30 °C between 10-30 PSU. "Larvae can sustain temperatures between 18 and 35 °C and salinities between 19 and 35 PSU (Mann et al., 1991 and references therein; Rico-Villa et al., 2009)."

Habitat occupation of native bivalves in Dutch estuaries

Table 3. Habitat occupation of native bivalves dominant in Dutch estuaries, and the introduced Pacific oyster *C. gigas* (From Korringa, 1952, Bayne, 1976, Hayward and Ryland, 1990, Mann et al., 1991, Gosling, 2003, De Bruyne, 2004).

	Crassostrea gigas	*Mytilus edulis*	*Cerastoderma edule*	*Mya arenaria*[a]	*Macoma balthica*
Tidal range	Low intertidal to subtidal	Mid intertidal to subtidal	High intertidal to shallow subtidal	High intertidal to shallow subtidal (to 200 m depth)	High intertidal to subtidal
Sediment	Attachment to hard surfaces, bed occurrence on any substrate	Attachment to hard and filamental surfaces, bed occurrence on any substrate	Sand, soft mud, gravel	Firm mud/sand	Mud to muddy sand
Salinity	Estuarine to fully marine	Estuarine to fully marine	Estuarine to fully marine	Estuarine	Estuarine to fully marine
Burrowing depth	–	–	< 5 cm	~ 15 cm	5–10 cm
Exposure	Semi-exposed to sheltered	Exposed to sheltered	Semi-exposed to sheltered	Sheltered	Semi-exposed to sheltered

As table 3 shows, the Pacific oyster (Crassostrea Gigas) performs better in the low intertidal area to subtidal area, whereas the blue mussel (Mytilus edulis) prefers the mid intertidal to the subtidal area. The pacific oyster attaches to hard surfaces and any substrate as opposed to the blues mussel that attaches to any substrate. Both can survive in estuarine and fully marine environments and the oyster thrives in semi-exposed to sheltered conditions with the blue mussel being found in exposed to sheltered conditions. These living requirements will be used in the design of the island to determine where the oysters can be implemented on the breakwater to reduce erosion. As well as the information stated below will also be used for the designs.

Impact of storms on the survival of Marine bivalves

Storms have a significant impact on all bivalves. (Charles et al., 1995) found that after hurricane Andrew the average oyster density in front of the coast of Louisiana dropped from between 20-140 m2 to 0-24 m2 with many areas seeing a mortality rate of over 75%. This was in conditions with wind speeds of 209 km/h for 5 hours. In the Netherlands, there are no hurricanes but big storms like storm Ciara with a maximum wind speed of 130 km/h (KNMI, 2021) do occur.

Sustainability of marine bivalves

The life cycle of the blue mussel is like that of the pacific oyster. If the hard substrate or reef structure is not destroyed or buried the reef/bed will continue to grow or change accordingly to the environmental conditions. Another threat next to storms can be disease.
If a destructive event like a storm causes high mortality in the oyster reef/mussel bed, restoration can be carried out. In case of a destructive event caused by a storm, two main objectives should be set to restore the bio builders. The first objective should be cleaning buried reefs/beds and replacing lost shells (Perret et al., 1995). This will facilitate larvae to attach again to the now cleaned reef/beds since the larvae will not attach to any substrate covered by losing sediment (Galtstoff, 1964). For the cleaning of these reefs/beds, the methodology described by (MacKenzie, 1977) should be used.

Effect of artificial oyster reefs on wave attenuation

A thesis study carried by (Sigel., 2021) at TU Delft found that the use of artificial oyster reefs in the following conditions, a reef of around 120 meters length, 8 meters width and 0.8 meters height. The reef crest 0.5 m above mean low water level and 2.3 m below mean high water, with average regular wave heights of 0.8 m resulting in the reef being submersed around 30% of the time. Attenuation was found at approximately 4 ds/Hm0 ratio compared to regular bare tidal flats in front of the reef. Furthermore, it was found that reef attenuated energy was up to 40 times more effective over distance. (Wiberg et al., 2018) found that with water heights of around 0.5 to 1 meter, the 4 artificially constructed oyster reefs were able to reduce wave energy by around 30-50%. With water depths ranging from 1.0 to 1.5, this number changed to 0-20 % with an impact of less than 10% being found at water depths greater than 1.5 meters depth this was however for the more landward oriented oyster reefs which were more sheltered on the exposed site. Here the oyster reefs had no measurable impact on the wave energy.

Shape, location and sustainability of seagrasses and salt marshes

Seagrass

Seagrasses are used in many monitoring programs worldwide as they are important components of coastal marine ecosystems and can provide an indication of environmental status (Mariscal, 1974) & (Costanza, 1997) and they are dominant in the marine eco- system of sandy coastal areas. They are highly productive, influence the structural complexity of habitats, enhance biodiversity, play important roles in global carbon and nutrient cycling, stabilize water flow, and promote sedimentation, thereby reducing particle loads in the water as well as coastal erosion (Marba, 2012). There are four species of seagrass in the European waters, including the small, fast-growing and short-lived *Zostera noltii*, which is the most universal, *Z. marina*, dominant in most European seas but rare in the Mediterranean (Den Hartog, 1970) & (Hemminga, 2000).

Seagrass grows in intertidal or shallow subtidal (*Z. noltii*) down to 5-15 meters depth in North European waters (Duarte C. M.-J.-C., 2007). Duarte (Duarte C. M., 1991) has found that the depth limit of seagrass communities distributed worldwide, showed that seagrasses may extend from mean sea level down to a depth of 90m, and that differences in seagrass depth limit are largely attributable to differences in light attenuation underwater.

There are different types of seagrasses used as a bio builder like a **Flora field** (shown in figure 10). A Flora field has a different kinds of organisms such as seaweed and seagrasses. In the area, Sugar kelps (*Saccharina altissimo*) can be grown which supports high primary productivity and creates a habitat structure for various marine organisms (Sterckx, 2020). In addition, it filters dissolved nutrients from the water column. Kelps (and in extension seaweeds) need a hard substrate (natural or artificial) to develop. Consequently, the ecosystem services from the kelp flora reef are not primarily coastal protection but in combination with other reefs, these reefs can increase the overall ecosystem services delivered. In contrast, other types of flora reefs, like seagrass-based reefs have added value by enhancing sedimentation, hence, coastal protection (Sterckx, 2020).

Figure 10 Conceptual reef-building ecosystem engineers (Sterckx, 2020)

Salt marshes

A salt marsh is an intertidal zone between land and open salt- or brackish waters which are regularly flooded by the tides. In these salt marshes a diversity of salt-tolerant flora grows i.e., grasses, herbs, and low shrubs and there are living different kinds of animal species e.g., birds. These plants have an important function for the area as they provide stability due to trapping and holding the sediment. The salt marshes happen on mud flats and sans flats. The mud flats are homed by algae and covered by algae mats. Through the meandering tidal creeks, the seawater drains in and out of the salt marshes. With this the channels transport sediments, detritus, dissolved nutrients, plankton, and small fish.

Salt marshes act as a nursery area for different kinds of species. The tidal marshes of the Westerschelde Estuary are used as a nursery e.g., by shrimps (*Crangon crangon*). Where the juvenile will grow up to a total length of 15 mm. Furthermore, shrimps are part of the diet of fish (Whitfield, 2016).

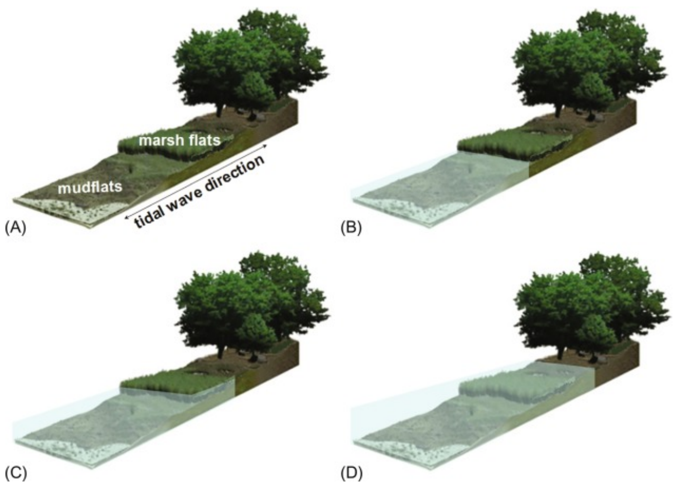


Figure 11 Salt marshes during a curtain period (Bellucci & Giuliana, 2019)

Living requirements seagrass

The seagrass habitats are different from the salt marshes since they grow under water. Seagrasses have a different kinds of requirements e.g., they grow in salt- and brackish waters. When there is enough light coming through the water, photosynthesis can happen. The light needs an excess of

11% of the incident light in the surface water, the clarity is important for the reason that the plants will die when the water becomes turbid by sediment suspension. The plants, therefore, grow in shallow regions along the coasts. The average depth is a few meters, but they are recorded down to 70 meters depth in clear water. Seagrass needs a soft substrate e.g., mud or sand yet some species can grow on rocky sediments. Additionally, they need a gentle slope with little or no tidal currents or strong waves (Morrison & Greening).

The seagrass habitats are home to a lot of fishes since there is a significant portion of macrophyte leaf biomass. Due to the structure of the seagrass, it provides a substantial and complex habitat for the fishes e.g., nursery rooms (Whitfield, 2016).

Living requirements salt marshes
Like seagrass, salt marshes have requirements to grow and develop. Salt marshes develop the best on fine-grained sediments, where no strong waves or tidal currents happen. They need salty conditions and need the temperate or cool temperature to grow yet, the freezing temperatures are not damaging the plants. Salt marshes need a wide tidal range with the purpose to limit erosion, making deposition of sediments possible and causing a well-marked zonation (Ecoshape, 2021).

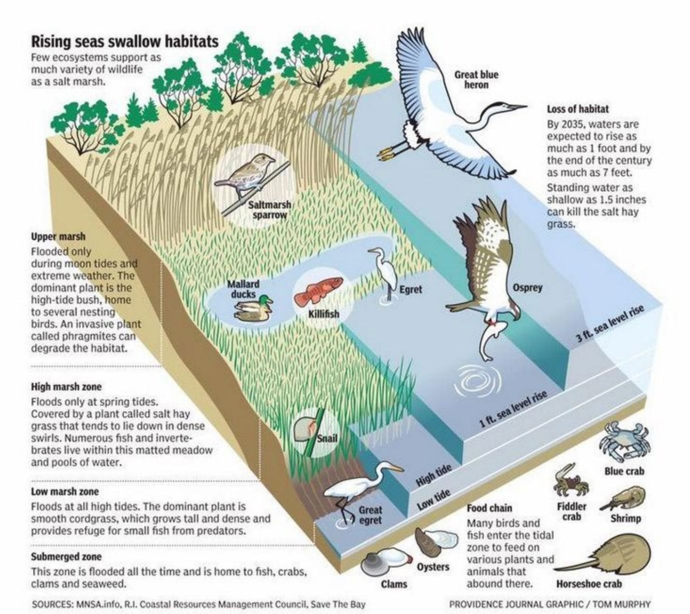


Figure 12 Variety in Salt marshes (R.I. Coastal Resources Management Council)

Threats on sea grass and salt marshes
Both, salt marshes and sea grass have a high change of impact since they are in the sea. Impacts such as a lowering salinity due to flooding also can cause a decrease in nutrient levels and an increase of turbidity. Including colder winters usually differ in their patterns of wind and precipitation (Mariscal, 1974). Furthermore, global warming is a rising challenge and can have a major influence on primary and secondary productivity within all estuarine habitats. In addition, potential sea-level rise will alter the occurrence, spatial extent and functioning of littoral macrophyte habitats in estuaries around the world.

Other threats to salt marshes are over-grazing (e.g., grazing by wild geese, crabs, and snails), eutrophication by agricultural effluents, urbanization, recreation, coastal erosion, industrial pollution and wastewater, species invasions and climate change (Mariotti & Fagherazzi, 2013).

Seagrass can act as a natural carbon sink, where CO_2 is absorbed through photosynthesis and stored as biomass is greater than that released through respiration and decomposition (Mazarrasa, et al., 2018). The seagrass can be stored above- and below-ground because it is stored in the soil compartment. However, the biomass is more liable above-ground due to the exposure to aerobic conditions and herbivory. Seagrass meadows have a high contribution and large aerial extent (Mazarrasa, et al., 2018).

Whitfield (2017) has found that seagrass beds are favoured by fishes as nursery areas in both estuaries and the nearshore marine environment. When there is a loss of habitat it can lead to a decline in juvenile fish diversity and abundance. Furthermore, salt marshes usually have a lower diversity of fishes than seagrass habitats as a result of the temperate location of salt marshes.

Delta management

Stakeholder analysis

Stakeholder interests, bottlenecks and obstacles

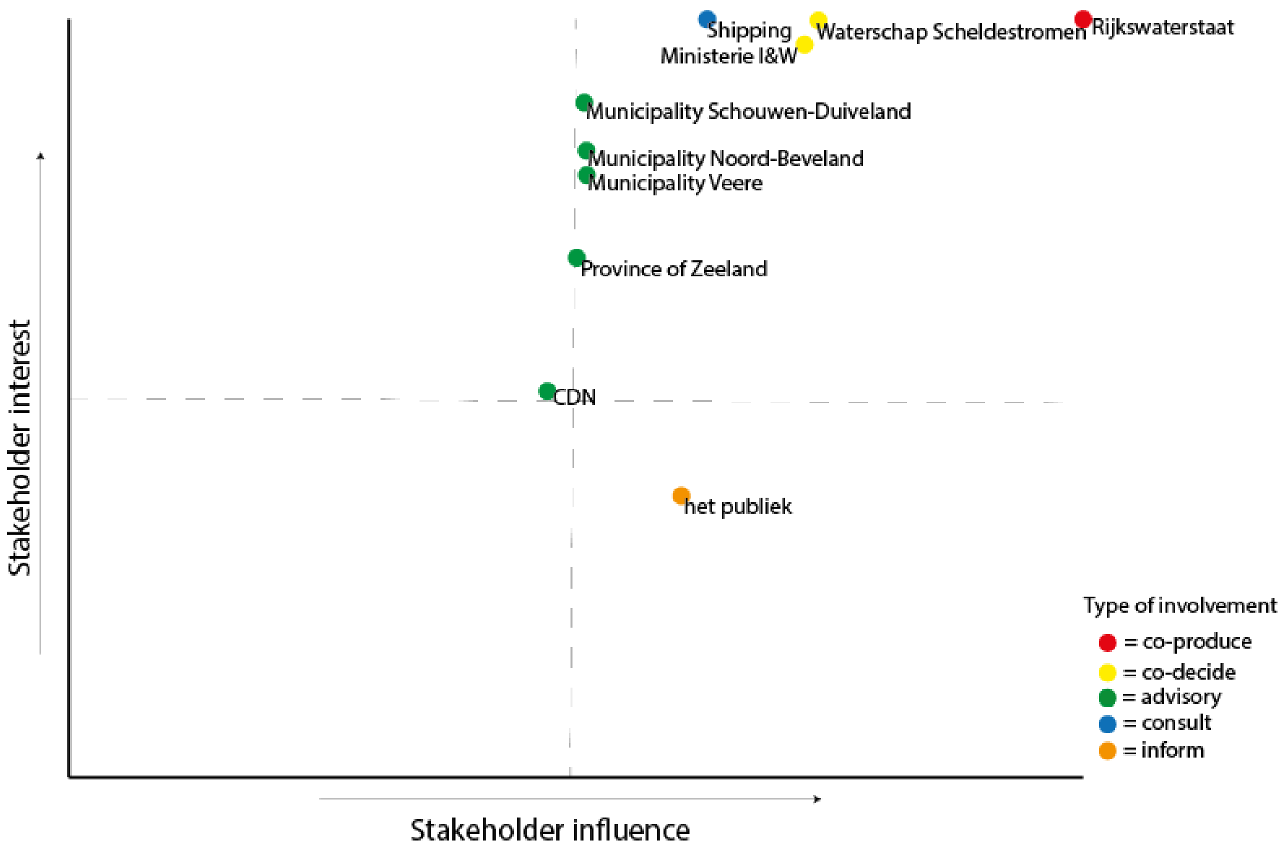
Stakeholder	**Interests**	**Bottlenecks**	**Obstacles**
Municipality Veere (Podemos, sd)	Economic prosperity, climate adaptation, monuments, tourism, the livability of the municipality, safety	Spatial planning, erosion of beaches and coastline, participation	Financing, prioritization
Municipality Noord-Beveland (ProDemos, sd)	Economic prosperity, climate adaptation, monuments, tourism, the livability of the municipality, safety	Spatial planning, erosion of beaches and coastline, participation	Financing, prioritization
Municipality Schouwen-Duiveland (ProDemos, sd)	Economic prosperity, climate adaptation, monuments, tourism, the livability of the municipality, safety	Spatial planning, erosion of beaches and coastline, participation	Financing, prioritization
Ministerie I&W (Rijksoverheid, sd)	Climate adaptation, (flood)safety, fresh water availability, water quality, natural values, shipping, infrastructure	Dike reinforcements, spatial planning, (limited) space, diversified interests, balancing the three pillars	(limited) space, diversified interests, political developments (and therefore policy changes), financing
Waterschap Scheldestromen (Waterschap Scheldestromen, 2019)	(Flood)safety, primary flood defences, agriculture and agricultural land Veiligheid, primaire waterkeringen , landbouwgrond	Landwards developments, sea level rise, dubbele dijken , surrendering productive agricultural land	Financing, climate change

Rijkswaterstaat (Rijksoverheid, sd)	Healthy ecological status of their jurisdiction, Natura-2000 targets, granting permits, spatial measures, smooth and safe shipping, safety (storm surge barrier is their jurisdiction), water quality, economy, uniting the three pillars	Accessibility, space and soil, financing, individual approach compared to an integrated approach	Financing, separating assignments, space
Provincie Zeeland (Provincie Zeeland, sd) (Provincie Zeeland, sd)	Economic prosperity, (flood)safety, tourism, the livability of the province, climate adaptation and mitigation	Space and soil, financing, political change	Political change and therefore policy changes, financing
Shipping	Safe and smooth shipping	Accessibility, safety	Silting, shifting of sediment, obstruction of shipping routes
CDN (Coalitie Delta Natuurlijk) (CDN, 2018)	Habitat and fauna conservation, climate adaptation and mitigation	Financing, space, integrated approach	Financing, lack of resources

Stakeholder	**Interest**	**Power**
Municipality Veere	High*	Medium
Municipality Noord-Beveland	High*	Medium
Municipality Schouwen-Duiveland	High*	Medium
Ministerie I&W	Medium-high	High
Waterschap Scheldestromen	Medium -high	High
Rijkswaterstaat	High	High

Provincie Zeeland	Medium	Medium-high
CDN (Coalitie Delta Natuurlijk)	Medium	Medium
Inhabitants Zeeland	Medium	Medium
Shipping	High	Medium-high

* = dependent on exact placement and effect of barrier island



Method

To be able to answer all the main questions, the following steps will be taken to get to the final product:

1. First, a multi criteria analysis will be made based on all the information that was gathered in the discovery phase of this project. This will include all the requirements from the stakeholders, the civil engineering side of the project as well as the bio-builder side of the project.
2. After this various design options will be thought up for both the nourishment and the bio-builder options
3. Multifunctional uses of the designs will be thought out
4. All designs will be tested against the MCA to determine which one is the best for our specific situation
5. This design will be fully worked out and become the final product

Project control

To make sure the project is on track weekly meetings will be held with Vana the project coordinator, here made progress is discussed as well as exchanging feedback to each other and asking questions if needed. As well as one representative of the group attending the closed meeting with the clients Mrs Renée Bron and Mr Idco Duijnhouwer.

Furthermore, weekly deadlines and task divisions will be made every Monday after the weekly progress meeting. This ensures sufficient progress towards the product and ensures the project gets finished in time.

MCA

Multi-criteria analysis aims to compare different designs or solutions for a specific problem mainly in projects, following a variety of criteria. This method is based on the evaluation of designs(in this case) or actions using a weighted average.

When taken into consideration, for every design that is being compared in Table x, the comparison is being evaluated by criteria for cost, position and coast protection, impact on tourism, impact on shipping, impact on flora and fauna, sustainability. For every variant, the score is estimated for each criterion and the information about the estimation is given.

The design with the highest overall score will be considered as the best possible solution to the problem. For every criterion the scale that will be used for evaluating will be from -2 to +2 where -2 will be considered as the least desirable result and in opposite +2 will be considered and the most wanted result for each of the criteria. The score of 0 will be considered neutral, which means that the criteria which have a score of 0 will not be affected by the outcome of the project. This MCA will aim to help the decision that has to be made regarding the best possible shape and position of the island.

MCA criteria list with explanation

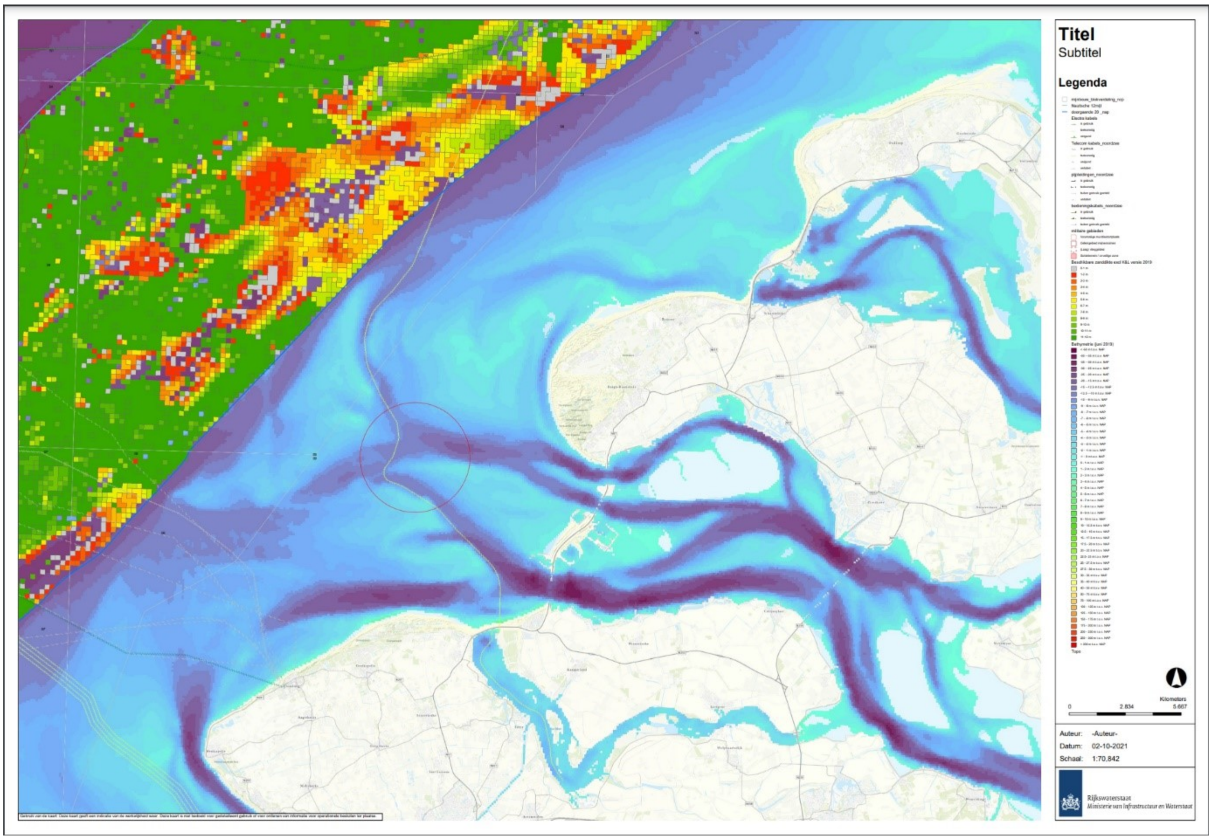
Position and coastal protection: These are the primary objective of the project. The envisioned final product, a breakwater landscape, should be able to provide benefit to the flora, fauna, and human communities of Schouwen-Duiveland. At the very least, the final design of the barrier island(s) must be sufficient to protect the more vulnerable inland areas against ever-increasing wave erosion. The criterion weight of 30% is chosen because it is the focal point of this research.

Impact on tourism (Burgh Haamsteede): The overall aesthetics of the beach area are ideal to be maintained to interfere as minimally as possible with the recreation activities in Burgh Haamstede. A score of 10% is accorded as this stakeholder is of low importance and low interest.
Impact on shipping: The proposed site of the island(s) must allow shipping to continue without interference, and so the existing shipping lanes have been considered such that the breaker islands are designed around them. The same as with cost, a weight of 15% is given as this is a high-interest stakeholder in the project but whose importance is lower than that of coastal protection.
Impact on flora and fauna (Natura 2000): The Natura 2000 network is of crucial importance for the protection of biodiversity. Not only for the species for which the areas were designated but also for many other threatened and non-threatened Dutch species of flora and fauna. This is considered in the project as the proposed building sites must provide an overall benefit to the flora and fauna in the area, considering the initial setback from construction. This criterion is therefore accorded a weight of 15%, as this is a high-interest stakeholder in the project but whose importance is lower than that of coastal protection.
Sustainability: The ability of the island to provide energy-producing functions is addressed here. The island variants have different areas, shapes and/or materials that allow for different combinations of renewable energy generators to be installed. Energy production is an important aspect of the MCA due to the multifunctional requirement it serves to fulfil. Again, a weight of 15% is given as it is not the primary objective of the project but whose importance is nevertheless considerable.
Cost: This refers to the total amount of capital spent on procuring all the products, services, and resources needed to bring the project to completion. It is included in the MCA as the cost is an integral part of any project. Without adequate monitoring and controlling of the funds available, the project may not be completed according to schedule or up to the desired quality. It is given a sub-average weight of 15% as the project is not intended to draw profit.

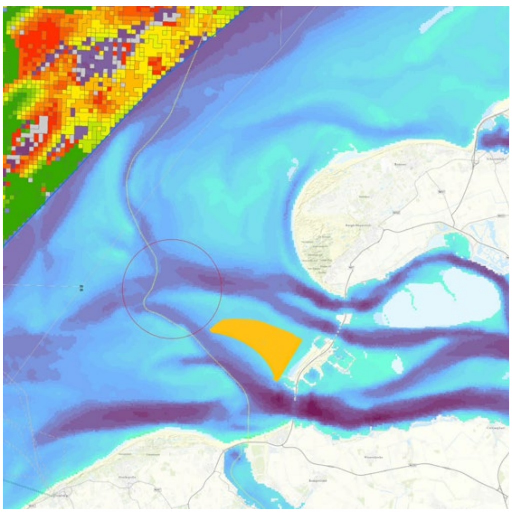
Requirements for designs breakwater ‘the Banjaard’

- The breakwater position in respect to the coast should not be close, since placing the breakwater near the coast will result in the formation of parallel currents to the shoreline of Schouwen-Duiveland.
- The existing pilot project along the coast of Burgh-Haamstede (Pilot slim omgaan met zand) should not be affected by the placement of the breakwater because the idea was to skip one regular scheduled nourishment to stimulate beach erosion and sand sprays. Therefore, the location of the Banjaard should not intervene with that project.
- The breakwater should not be connected to the coast of Burgh-Haamstede as it will result in sediment transport along with the connecting structure.
- In the case of multifunctionality, the energy produced must be green and sustainable. This energy could be produced using wind turbines, tidal power plants, energy from seawater, etc.
- Construction of the breakwater must not affect the attractiveness of the Burgh-Haamstede coast.
- It is important when choosing sand extraction sites to regard the chain of extraction, transport, and nourishment. (Programme & Coast, n.d.)
- The choice of route for electricity networks and the choice of location for a connection to the high-voltage grid are also key factors to be considered.
- The construction of the breakwater should not have negative effects on the navigability of the ships/vessels, the quality of the water and the ecology. (*Coastal Developments - Deltares*, n.d.)
- Hard engineering to stabilize the nourishment should only be used if no other natural solutions like bio-builders are possible.

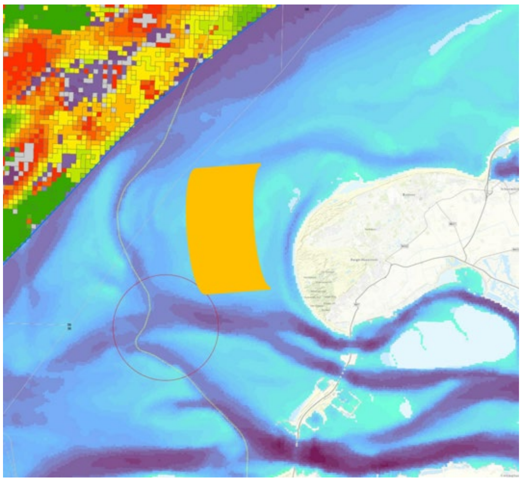
Selection of variants



To select the possible locations were the new Banjaard island can be located, a process of elimination was implemented to exclude all the locations where the island cannot be placed. Shown in the figure below the relevant activities in the area, where for example the island cannot be placed in the areas where sand is being extracted, major cables and pipelines, military areas, …etc.
After excluding the areas where the island cannot be placed, the rest of viable options were taken into considerations:

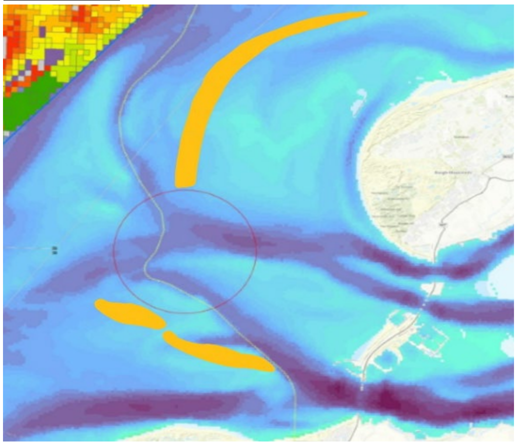


Variant 1:
This island design was chosen for its ability to cut off the waves coming from the southwest. The location provides shallow water for the construction of the island, meaning overall project costs would be low. In addition, it is placed well out of the way of major shipping routes and is therefore favourable.



Variant 2:
This variant was selected because it offers satisfactory coastal protection in the way it 'wraps' around the promontory of Schouwen-Duiveland. This provides a barrier between the incoming waves and the island behind. It is also located in a shallow stretch of the North Sea, which reduces the overall cost in terms of sand used. Moreover, the island variant is designed in such a way that it does not interfere with coastal traffic.

Variant 3:



Finally, the last variant is placed in similar locations to the last two: in shallow waters and outside of shipping lanes. Multiple, slender islands were chosen for this variant in order to increase the overall wave-breaking perimeter in a way that does not compromise project cost. The islands to the southwest serve to absorb wave energy coming from the same direction, whereas the larger island to the north breaks waves coming in from the west.

Scoring variant 1:

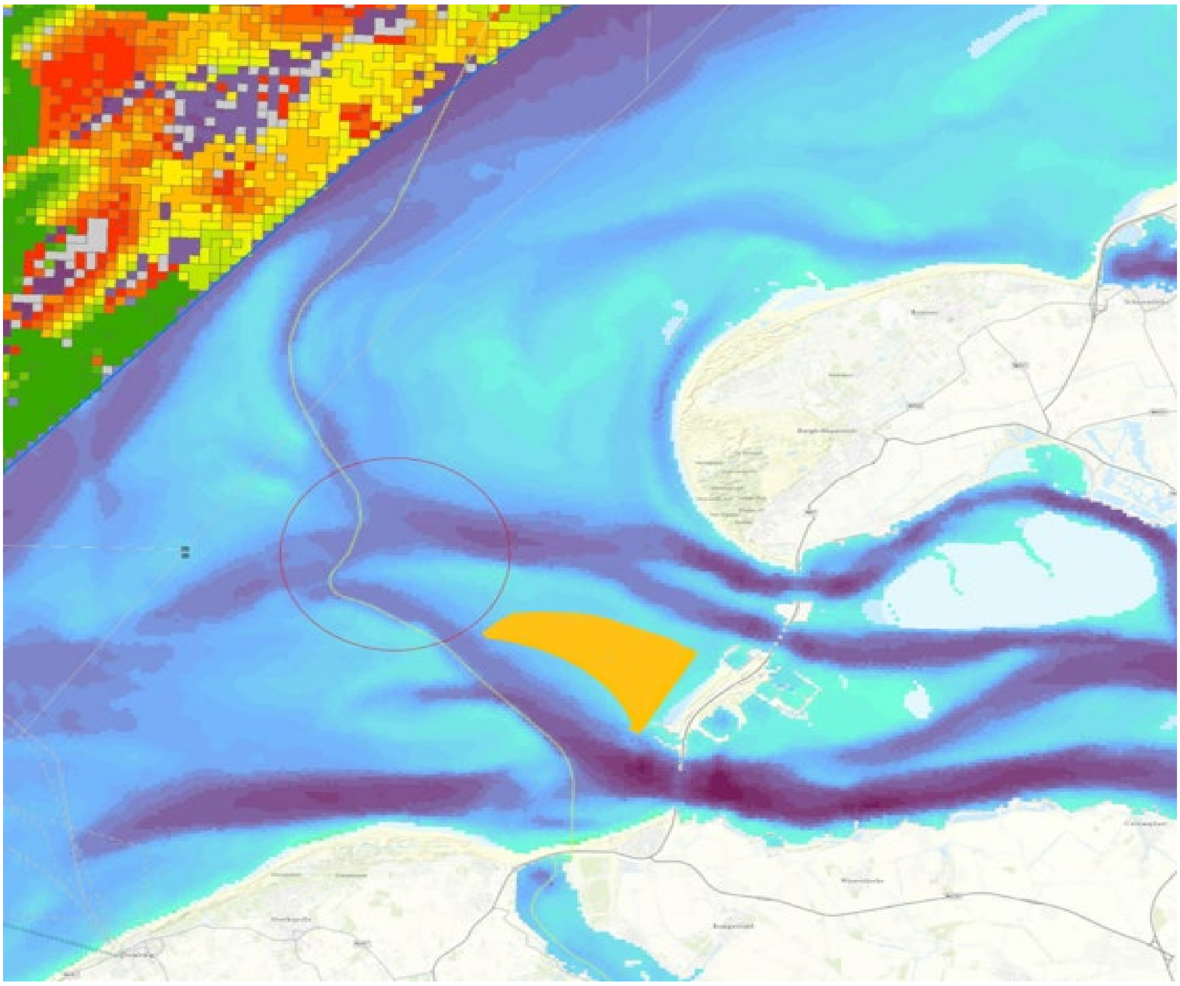


Figure 13

Cost:

Due to the small size of the island, less sand is needed to create it. In addition, the sand needed for the island can be extracted from the yellow areas indicated in figure 19, which are near the position of the breakwater. Thus, the cost of the creation of the Banjaard is low compared to the other variants. As such these variant scores +1 regarding costs.

Figure 14

Position and coast protection:

In terms of coastal protection, this variant is in the ideal position to prevent the wave attacks that are occurring on the coast of Schouwen-Duiveland, especially at the coast of Burgh-Haamstede. Since the mean wave and wind direction is from the south-west, placing the island at the indicated position, can make sure that the coast of Schouwen-Duiveland is protected from these attacks and such reducing the number of nourishments needed at the coast. Although, on the other hand, the erosion that is prevented at the coast of Schouwen-Duiveland, will be transferred to the Banjaard since the

island will be placed perpendicular to the wave attacks. Hence, hard measures are needed to prevent the loss of sand.
Regarding the position of the island, according to the bathymetry map, the island will be located where the seabed is shallow to reduce the amount of sand needed to create the island. However, the island in this variant is located where ships are passing. Therefore, this variant scores 0.

Impact on tourism (Burgh Haamstede):

During the construction and execution of the island, tourism along the coast of Burgh-Haamstede might have to be halted until the end of construction for safety purposes. In addition, according to www.sciencefocus.com, the average height person can see 4.8 km into the horizon and since the distance of the island from the coast of Burg-Haamstede is approximately 4 km, most tourists will have an obstructed view of the ocean. Thus, placing the island will have an undesirable impact on tourism, resulting in a score of -2 for this variant.

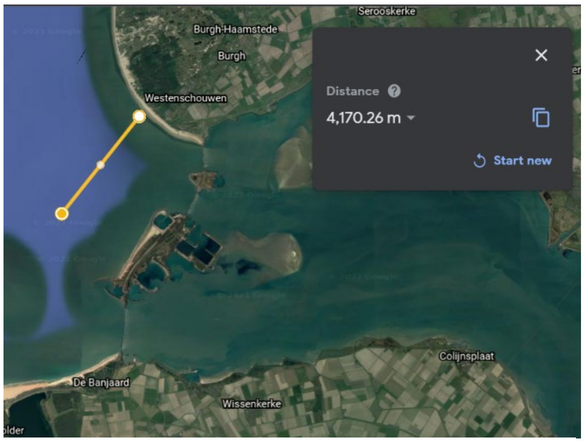


Figure 15

Impact on shipping:

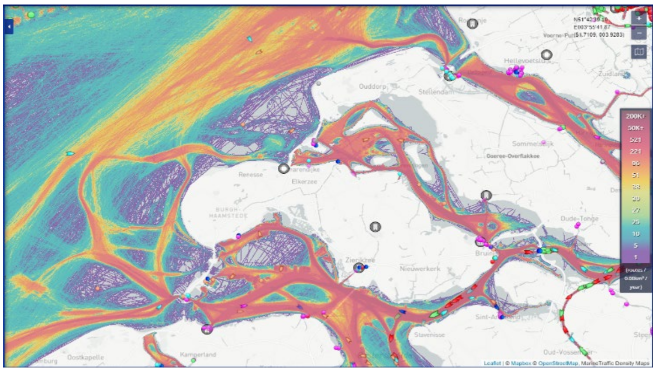


Figure 16

As mentioned previously and, the island is positioned where a shipping route exists and is used heavily (indicated in figure 21). As a result, ships must be rerouted to different areas, which can be difficult as the island is located next to an existing storm surge barrier and at the entrance of the Oosterschelde. Due to the negative impact on shipping, this variant scores -2.

Impact on flora and fauna:

To construct the island substantial amounts of sand are needed. The sand will therefore be dredged from the seabed and disposed of at the desired location. This will affect the ecology and marine species at the dredging and deposition location. Short-term increases in the level of suspended sediment can affect marine flora and fauna, by increased turbidity and the possible release of organic matter, nutrients and or contaminants. Settlement of these suspended sediments can result in the smothering or blanketing of subtidal communities and/or adjacent intertidal communities (CEDA, 2020). However, in the long term, the island will create new habitat for existing species not limited to the island itself, but also the coast of Burgh-Haamstede will provide additional space for ecology to thrive as the island will prevent erosion and constant need for nourishments, and the continuous burying of ecology. This variant scores +1.

Sustainability:

During the construction of the island, measures will be utilized to mitigate the negative environmental impact that the construction will create. For example, using sustainable fuel for the dredgers, limiting the number of times the dredgers are going to the extraction and deposition site, …etc. In addition, in the long run, the island will help sustainability by reducing the number of nourishments needed at the Schowen-Duiveland. In conclusion, this variant scores +1.

Scoring variant 2:

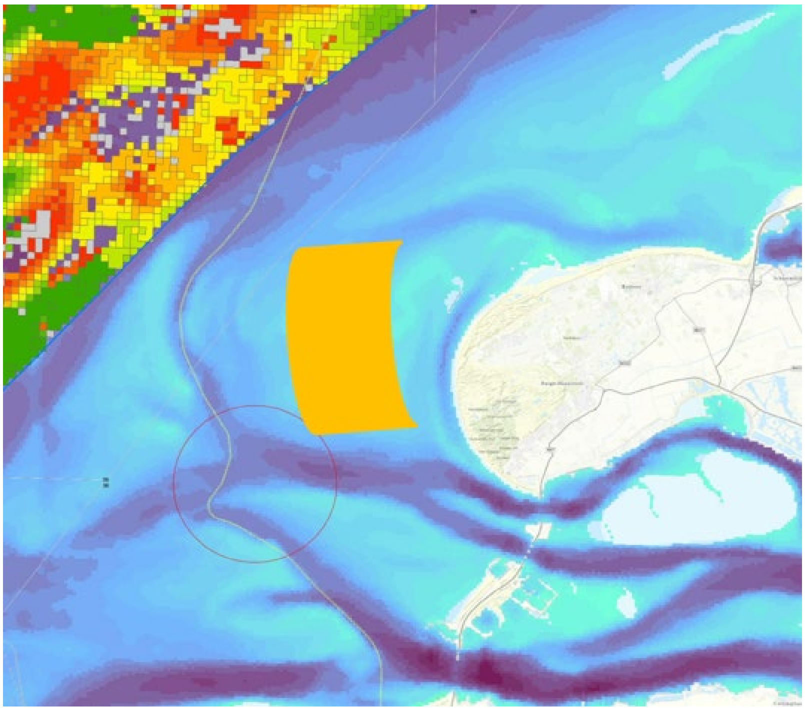


Figure 17

Cost: -2
The cost of the island is foreseen to be high, based on the following facts:
A large volume of sand will be required for the construction of the island. The costs of dredging, transport, and nourishment will be high relative to the two other variants. This is because much more overland transport of the sand (via pipeline) will be used, which needs more labour and equipment than the simple rainbow deposition that would be primarily employed in the other two variants.

Position and coastal protection: -2
The island is slightly out of line with the waves that come from the southwest. This leaves the southern tip of Schouwen exposed to wave action. In addition, for the amount of sand used, the protection offered is not sufficient. A different layout in which the breaker island wraps around the tip of Schouwen would offer better efficiency.

Impacts on bird species
The proposed island is expected to have a positive impact on the seabirds in the area as they would then have a massive amount of land to be used as nesting and breeding grounds.
This is especially important in an age where wild animals are facing increased habitat loss through increased urbanisation, intensified agriculture and industrialisation, competition from invasive species, disturbance at breeding grounds and other forms of human-caused pressure.

Sustainability: +1
The island is planned to be used partly as an energy island, with wind, solar and tidal energy being investigated. These establishments aim to compensate for the negative effects otherwise caused by the construction of the artificial island.

Impact on tourism: 0
As explained above, the island would be located quite a distance away (~2 km) from the nearest beach, and so the aesthetics of the coastline would remain mostly unaffected. Beachgoers would still be able to partake in their preferred activities without interference. In addition, the island may provide recreational activities in the form of bird and animal watching, but also interfere with the wave energy received at Burgh Haamstede, therefore limiting sea sport activities.

Impact on shipping traffic: 2
Shipping would remain unaffected as no major routes go through the proposed site, except for smaller privately-owned vessels.

Scoring variant 3

In the figure, 23 is a sketch shown of variant 3

Position and coast protection:

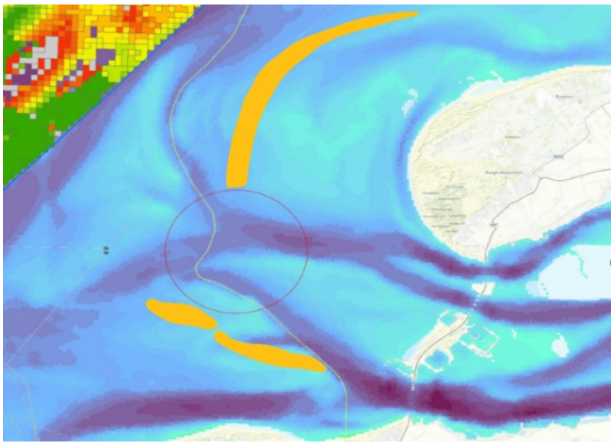


Figure 18

In every month of the year, the wind is mostly coming from the southwest. That means that the islands are defending the coast from the waves that are made from the southwest wind. The island could not be connected, because there are shipping routes between the islands. In figure x, the shipping route is shown in dark blue. The islands may result in rapid water speeds between the island; however, this has not been investigated. The islands are protecting the waves that are coming from the southwest. Not very often the wind is coming from the northwest in the Netherlands, however, when it does it is mostly a heavy storm. In history, numerous examples are there that also was catastrophic in 1953. That is why the island is located to protect also Schouwen-Duiveland from a north-wester storm. The location of the islands is chosen because they are very protective of the coast Schouwen-Duiveland and the location are not placed in busy shipping routes. For these reasons, this variant scores +2 on position and coast protection.

Impact on tourism: (Burgh-Haamstede)
The building of the island with heavy machines and ships may be in the first week interesting, but after the week it is annoying for tourism of Burg-Haamstede. Because of the noise that comes from the construction side. The noise will be the main thing, however when the island is constructed there can be new possibilities for tourism, so that's a plus for the situation, the total score is -1 for the tourism.

Impact on shipping:
The location of the islands is chosen in a way that the main shipping routes are not interrupted. This is also shown in figure x. So, the high-density routes can still be used when the islands are placed that is why this subject scores +2.

Impacts on the flora and fauna:
The marine species that are living on the bottom of the North Sea, where the location of the islands is. Have no chance of surviving the construction of the islands. The flora is also destroyed by construction. However, when the island is constructed, the island will contain a lot of flora. With this information is chosen to give this subject -1.

Sustainability
The main plan of the island is to protect the shore after the islands from big waves. However, the island also will be used to generate green energy. The construction of the islands is of course not good for the planet, however, when the islands are producing a lot of green energy it can after time be a promising investment for the climate. That is why the sustainability scores +1 in this variant.

Cost:
The islands are small, compared with variant 2. The location where the islands are being placed is the water depth low. That means that there is not that much sand is needed. In this project sand and dredging will be the most important subjects. This variant keeps these two subjects low, that is why the variant scores +1 for costs.

	Variant 1	Variant 2	Variant 3
Position and coast protection – 30%	0	+1	+2
Sustainability – 15%	+1	+1	+1
Impacts on flora and fauna – 15%	+1	0	-1
Impact on tourism – 10%	-2	0	-1
Impact on shipping traffic – 15%	-2	+2	+2
Cost -15%	+1	-2	0
Total value of the final score	-0.05	0.45	0,80

Figure 19 MCA scoring the 3 different design variants

Volume calculation for best MCA design

In figure 2 is sketched the winning variant. The island is very protective of the coast of Schouwen-Duiveland because it protects the coast effectively from the waves that are created in a southwest direction. Also is the wind in most cases coming from this direction. The island will not contain hard structures such as dykes but will contain a lot of sand and on the foreshore, oysters will be placed to reduce the power of the waves. The island also must protect Schouwen-Duiveland from north westers storm, that is why the upper island will contain a lot of wooden poles. These wooden poles keep the sand on the beach and prevent a lot of erosion. The poles also will reduce the wave energy that will hit the island.

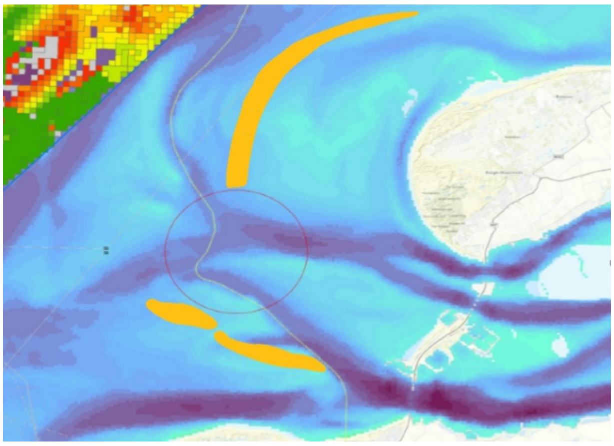


Figure 20

In figure 26 is the map of the density of shipping traffic in the area shown. The legend shows that the dark red areas are busy routes of shipping traffic. Also shows the figure that the very blue and purple routes have an exceptionally low density on shipping traffic. That is why the islands are placed in the blue and purple areas. During construction, there is a chance that there is any hindrance, however when the islands are constructed the ships will not be interrupted, according to figure 26.

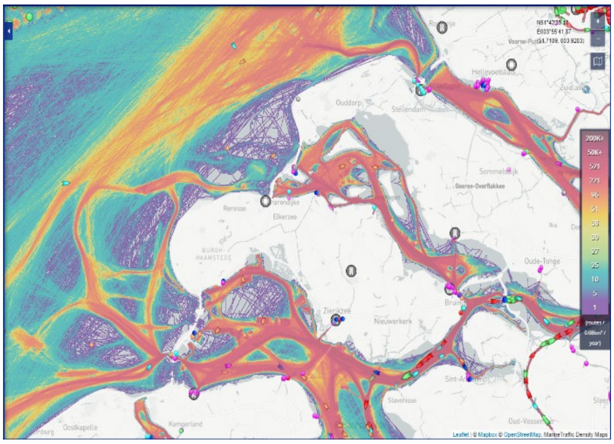


Figure 21

In figure 27, island 1 of the winning variant is shown. In Google Earth, it is possible to draw lines and create a sketch of the islands. On the polygon tab on the ribbon, it is possible, when the drawing is fully closet like in figure 27. To calculate the area of the island, this is shown in the left corner of the figure. The total area of this island is 6.93 km^{2,} which is equal to 6.93 x 10^6 m^2.

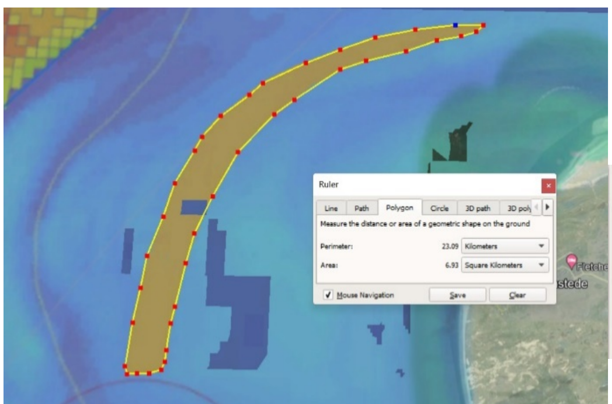


Figure 22 area calculation of island 1

To calculate the total volume it is important to know the average height in the area where the island is being placed.

The winning variant has 3 islands, the areas of the other 2 islands are calculated with the same programme. Island 2 has an area of 1.73 km^2, which is equal to 1.73 x 10^6 m^2. Island 3 has a total area of 2.30 km^2, this is equal to 2.30 x 10^6 m^2.

Figure 28 can be used to calculate the complete volume of the islands. The figure shows that the bottom heights in the project area are between 5 to 10 m below sea level. To be on the safe side, a conservative approach is used. Chosen is that everywhere 10 m sand is needed. With that in mind, the volume calculation is now complete.

(6.93 + 1.73 +2,30) x 10^6 m^2 x 10 m =
10.96 x 10^7 m^3 sand is needed.

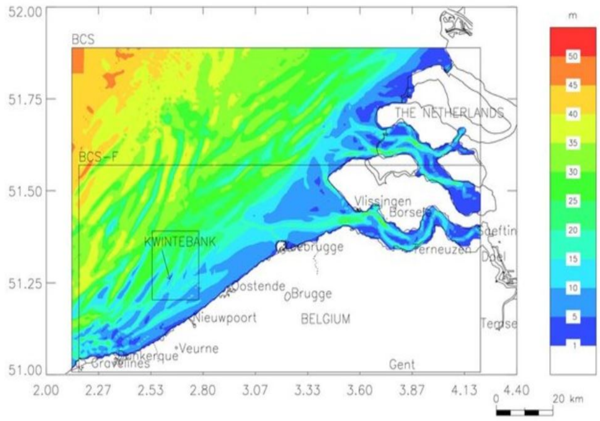


Figure 23 Map with bottom heights in the area.

The calculation above shows the volume of sand that needs to come to make the island. However, in this calculation, the slope of the island is not taken into account. A good suggestion is to calculate the slope with the Bruuns rule, however, this has not been done, because the suggested was to use rough assumptions to calculate the volume of the sand volume. For several reasons, a slope is needed for an island. A slope before an island reduces the strength of the wave. It gives stability to an island, in short, a slope is crucial for an island. The slopes will be constructed on the sides where the waves will hit the island. The shape of het slope is shown in figure 29. It is a rather faint slope, with sand obstacles what are called longshore bars. The slope will have a length of 100 m to the island and will rise 10 m over this 100 m length, this gives the slope an angle of 5,7 degrees. With this information, it is possible to calculate the sand volume of the slope. In figure 27 there is has been an area calculation, however, the shore that will have this slope has a length of 6,5 km.

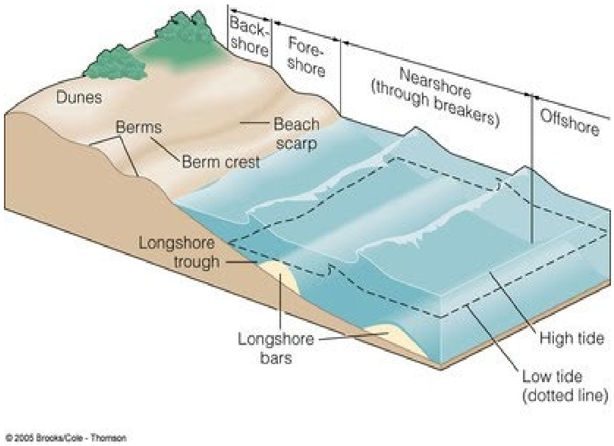


Figure 24 Sketch of the slopes of the islands.

The total volume of sand is: $0,5\ x\ 10\ m\ x\ 100\ m\ = 500\ m2$
This times the total length of the shore of island 1 and that is 10.500 m than the total volume is:
5,25 x 10^6 m^3 sand.
The same slope will be used by the other islands, so when the total length where the slope will be constructed is known. The volume calculation of the slope can be made.

The total perimeter is 6.17 km, which means that the side where the waves will hit the island has a length of approximately 3.0 km. With this information, it is again possible to calculate the total sand volume of the slope. The total area is again the rising 10 m over 100 m. To calculate the area the formula of a triangle is used. Then the total area is the same as the first island 500 m^2. The total volume is then: 500 m^2 x 3000 m = **1,5 x 10^6 m^3**.

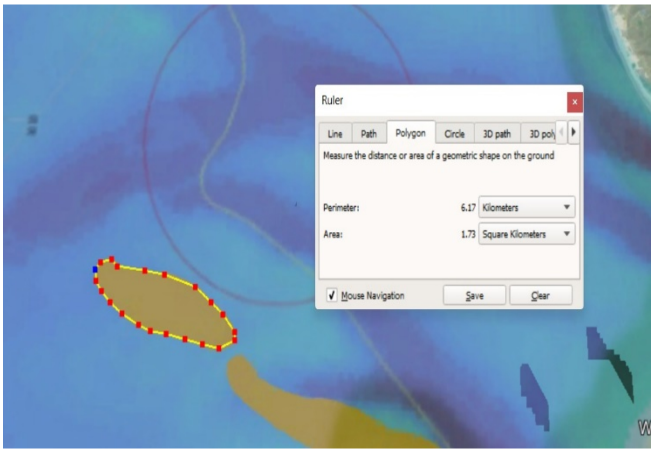


Figure 25 Island 2 of variant 3.

In figure 31 the perimeter of island 3 shows a value of 9.36 km. This island is also will be constructed to protect Schouwen-Duiveland from the waves that are created of the south – wester wind. The total area of the slope is also like the other islands equal to 500 m^2. The total length that will have this slope is roughly 3,0 km. Then the total volume of the sand is 500 m^2 x 4500 m = **2,25 x 10^6 m^3** sand.

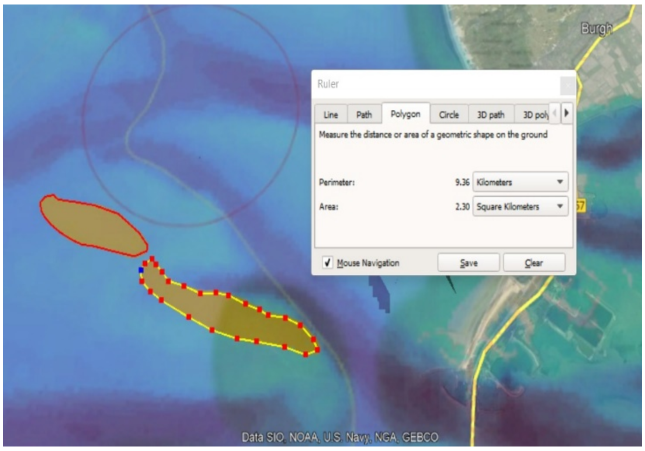


Figure 26 Island 3 of variant 3.

The total volume sand is now easy to calculate this comes to a total of: **10.96 x 10^7 + 5,25 x 10^6 + 1,5 x 10^6 + 2,25 x 10^6 = 11.86 x 10^7 m^3.**

Erosion on the beach

A quarter of all the beaches in the world are slowly caving in, according to Dutch researchers. Other beaches are stable or just growing. For this study millions of satellite images are used, the images show that around the world there is a sandy coastline of 300,000 kilometres. Since the year 1984, there is around 70,000 kilometres of coastline reduced. Some parts of the world show that the coastline every year erodes by 5 meters per year.

The sand particles are taken away through the currents and the waves of the sea or blown away by the wind. When the sand particles are not returning erosion has taken place. (De Morgen, 2019)

Coastal erosion means that the volume of sand reduces as a function of time. Typical volume reduction is around 10 m^3/m till 50 m^3/m. And structural coastal loss is around a few meters each year. (Coastal dynamics, 2021)

Suppose the waterline has a recession of y - meters per year. Then would be the annual loss of volume be V (m3/m/year). The annual loss volume could be calculated with the help of figure 32. The lost volume per year would be the recession y times (h + d). In figure 32 the definition could be found of h and d. The dune height d is easy to determine, however, the underwater part h is not easy to determine. The underwater height is often be determined by empirical models. And for many beaches, the outcome of the annual loss volume calculation comes out on 20 m3/m/year. (Coastal dynamics, 2021)

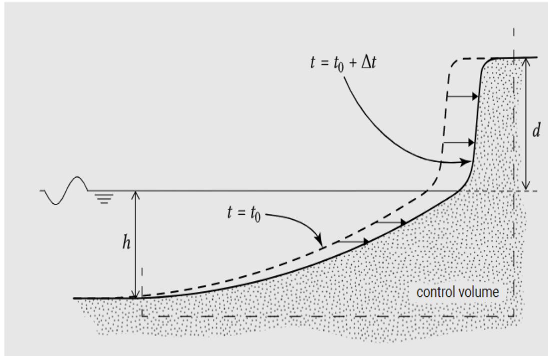


Figure 27 Illustration of erosion.

The defence that will break the waves is oysters. The oysters give a serious reduction factor to wave energy. Due to the oysters, the waves lose 30 % of their energy. This means that the island less sand loss will suffer due to oysters.
The erosion rate after placing the oysters will be on the shore of the island: 20 m3/m x 0,7 = 14 m3/m. On the southwest side of the island, every year beach nourishment of 14 m3/m must take place to keep the island in good shape against the rising water level.
On the upper island, there will be a lot of wooden poles constructed. It is not clear how much this will reduce the erosion rate, however, these wooden poles must protect the coast from a heavy north-wester storm and are an alternative for hard structures. With the wooden poles it the erosion rate probably will be less than 20 m^3/m, however, it is hard to say how much it will reduce the erosion rate.

Impact on stakeholders

Stakeholder	**Interests**	**Bottlenecks**	**Obstacles**	**Effect of variant 1**	**Effect of variant 2**	**Effect of variant 3**
Municipality Veere (Podemos, sd)	Economic prosperity, climate adaptation, monuments, tourism, the livability of the municipality, safety	Spatial planning, erosion of beaches and coastline, participation	Financing, prioritization	Neutral	Neutral	Neutral
Municipality Noord-Beveland (ProDemos, sd)	Economic prosperity, climate adaptation, monuments, tourism, the	Spatial planning, erosion of beaches and coastline, participation	Financing, prioritization	Neutral	Neutral	Neutral

	livability of the municipality, safety					
Municipality Schouwen-Duiveland (ProDemos, sd)	Economic prosperity, climate adaptation, monuments, tourism, the livability of the municipality, safety	Spatial planning, erosion of beaches and coastline, participation	Financing, prioritization	Positive on safety, negative on tourism	Neutral (still partly exposed to wave action, neutral on tourism)	Positive (positive on safety, short-term negative on tourism, long-term positive on tourism)
Ministerie I&W (Rijksoverheid, sd)	Climate adaptation, (flood)safety, fresh water availability, water quality, natural values, shipping, infrastructure	Dike reinforcements, spatial planning, (limited) space, diversified interests, balancing the three pillars	(limited) space, diversified interests, political developments (and therefore policy changes), financing	Positive (positive adaptation and safety, negative on short-term for natural values, positive on long-term for natural values)	Neutral (coast and storm surge barrier still partly exposed to wave action)	Positive (positive on safety and adaptation, negative on short-term ecology, positive on long-term ecology)
Waterschap Scheldestromen (Waterschap Scheldestromen, 2019)	(Flood)safety, primary flood defences, agriculture and agricultural land Veiligheid, primaire waterkeringen , landbouwgrond	Landwards developments, sea level rise, dubbele dijken , surrendering productive agricultural land	Financing, climate change	Positive	Neutral (coast still partly exposed to wave action)	Positive

Rijkswaterstaat (Rijksoverheid, sd)	Healthy ecological status of their jurisdiction, Natura-2000 targets, granting permits, spatial measures, smooth and safe shipping, safety (storm surge barrier is their jurisdiction), water quality, economy, uniting the three pillars	Accessibility, space and soil, financing, individual approach compared to an integrated approach	Financing, separating assignments, space	Neutral (positive on safety and storm surge barrier, negative on shipping, negative on short-term for ecology, positive on long-term ecology)	Positive (positive on safety and ecology)	Positive (positive on safety and adaptation, negative on short-term ecology, positive on long-term ecology)
Provincie Zeeland (Provincie Zeeland, sd) (Provincie Zeeland, sd)	Economic prosperity, (flood)safety, tourism, the livability of the province, climate adaptation and mitigation	Space and soil, financing, political change	Political change and therefore policy changes, financing	Neutral (positive on flood safety, negative on tourism, positive on adaptation)	Positive (positive on safety, neutral on tourism)	Neutral (positive on safety, negative on tourism in short-term, positive on tourism in long term)
Shipping	Safe and smooth shipping	Accessibility, safety	Silting, shifting of sediment, obstruction of shipping routes	Negative	Neutral	Neutral

CDN (Coalitie Delta Natuurlijk) (CDN, 2018)	Habitat and fauna conservation, climate adaptation and mitigation	Financing, space, integrated approach	Financing, lack of resources	Neutral Short-term negative, long-term positive	Positive (mainly for birds)	Neutral (short-term very negative, long-term positive)

Recommendation on stakeholder strategy and participation

Stakeholder	Interest	Power	Advised participation level*
Municipality Veere	High	Medium	Advisory
Municipality Noord-Beveland	High	Medium	Advisory
Municipality Schouwen-Duiveland	High	Medium	Advisory
Ministerie I&W	Medium-high	High	Co-decide
Waterschap Scheldestromen	Medium -high	High	Co-decide
Rijkswaterstaat	High	High	Co-produce
Provincie Zeeland	Medium	Medium-high	Advisory
CDN (Coalitie Delta Natuurlijk)	Medium	Medium	Advisory
Inhabitants Zeeland	Medium	Medium	Inform
Shipping	High	Medium-high	Consult

*= see appendix 3 for clarification

Results

Multifunctionality

The different ways the island could be used in a multifunctional way apply to all the designs. In this section, the use that could fit on all the different island designs is worked out. Two more multifunctional uses were explored, but as these were more experimental and circumstantial these have been added in the appendix.

Eco-tourism

The Oosterschelde is a nature area with a variety of wildlife. There is potential multifunctional usage for the breakwater Banjaard project. First a unique spot for a different island that gives room for nature and small-scale tourism. The island can be a bird breeding hotspot and fish spawning area on the natural foreshores of the island (Royal HaskoningDHV, n.d). Areas rich in nature will attract people. Same for the Banjaard project. Furthermore, small islands or sand banks can be a new target for small boat tours. Close target is suitable for day tours for tourists who want to spot birds.

Bio-builders

As stated in the introduction and the requirements, bio-builders will be implemented where possible in the design to stabilise the sediment. Below an example slope is shown on which bio-builders will be used at which depths to stabilise the sediment on the coastal side that is shielded from the direct wave impact as the bio-builders cannot survive on that side.

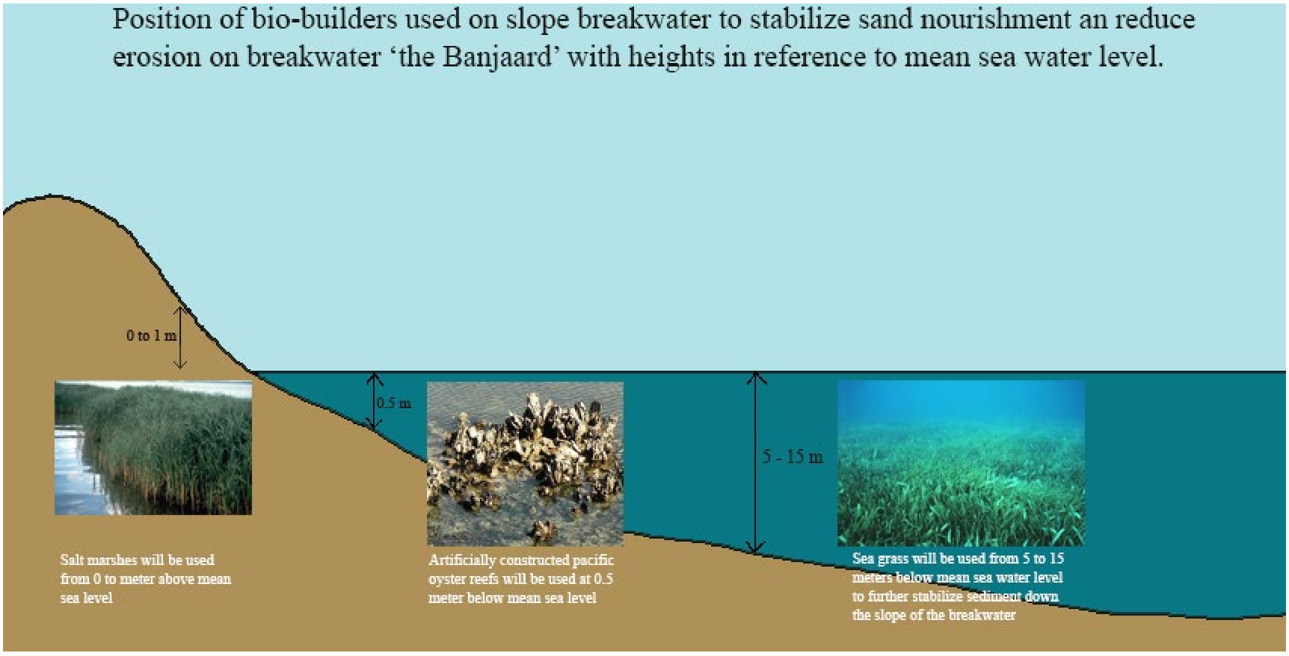
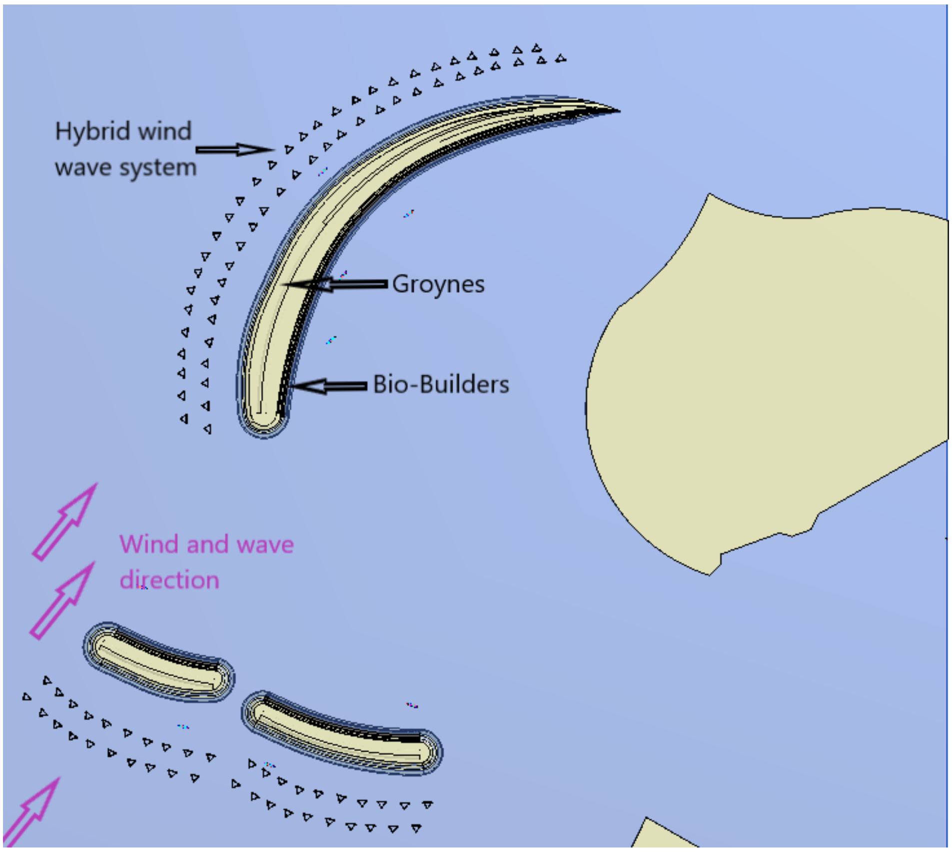


Figure 28 Slope of breakwater 'the Banjaard' on the side with low wave energy illustrated with which bio-builders will be used at what depths to prevent erosion on the breakwater island

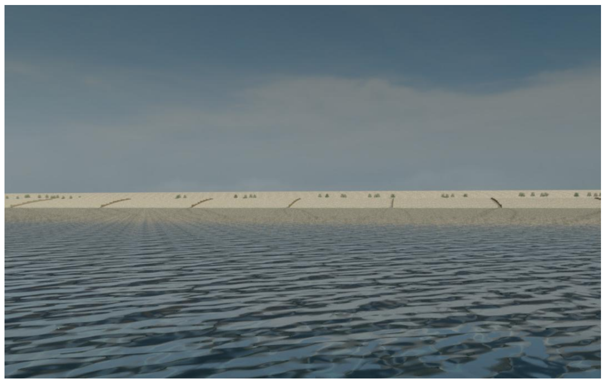
Figure 13 shows salt marshes will be used from 0 to 1 meter above mean sea-level, followed by artificially constructed pacific oyster reefs at around 0.5 meters below mean sea level resulting in around the optimal exposure time of 30%. Sea grass, in this case, the sugar kelp will be placed at 5 –15 meters below mean sea level. This slope will be on the sheltered side as mentioned before. This slope will be used for all the different design variants the slope of the sheltered site from the island will be designed in this way for all the designs so that the maximum potential of the bio-builders to prevent erosion can be realised.

Detailed design

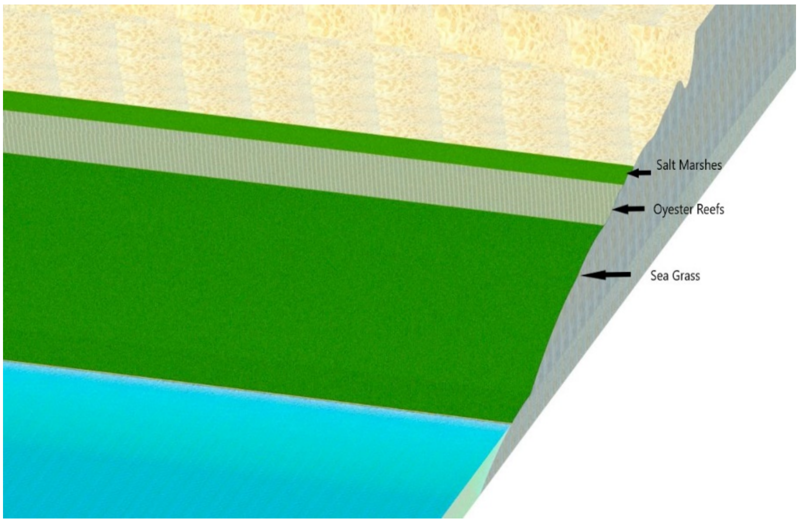
A Multi-Criteria Analysis has been conducted, it was discovered that variant number 3 is the highest scoring variant. As such, in this chapter, the detailed design of the variant will be discussed and further elaborated.



In the picture above, the position of the hybrid, wind, wave, system can be seen. By placing the hybrid wind wave system on the further left and the south of the two smaller parts of the island, the energy system will not only produce clean energy, but also, they can help the attenuation of wave and wind energy.



Groynes are made to prevent erosions caused by the rising tide. They act as a barrier to prevent the movement of sand and other materials from the beach. When used properly, wooden groynes will keep the sand nourished and will prevent it from floating away. In addition, wood had a relatively high strength and is a light material. Therefore, it was decided to place the wooden groynes where the hydraulic conditions are the harshest. Duo to the groynes position and the small slope of the shore, the energy from the wave attached will be reduced further. Moreover, the groynes presence will retain the sand for longer periods and thus prolonging the lifetime of the island.



According to what was mentioned earlier regarding bio-builders and their usage, different bio-builders were located at various depth along the slope to reduce wave energy and therefore erosion, resulting in stabilizing the existing sand along the shore. After establishing a sheltered side, the sugar kelp and saltmarshes were be placed at varying heights below sea level. These were then be followed by artificial Pacific oyster reefs at about 0.5 meters below sea level.

At last, in terms of multifunctionality,

- The main function of the breakwater is to protect the coast against climate change and sea level rise.
- The breakwater will be used for eco-tourism to capitalize on the fact that the island will be a habitat for many species.
- The Island will be used to create clean energy by utilizing hybrid wind and wave energy.
- Aquaculture is also one of the function the island will perform, which will be placed on the leeward of the island.

Conclusion and recommendation

Main questions

The main question what this report had to answer on the civil engineering part was: *What would be the optimal location, shape and design of the breakwater to restore the Banjaard and be able to use the breakwater for multi-functions?*

In this report, thorough research has been done to answer this question. The location of the islands is chosen in a way that there is protection for Schouwen -Duiveland, but also a restoration of the area “the Banjaard”. Due to the location of the islands, the vegetation can restore. The islands are located in parts where the water depth is minimum, therefore minimum sand is needed to construct the islands. A variant study has been made by using Multi-Criteria Analyses, the winning variant 3 shown in figure 23 has 3 islands. From those islands, 2 small islands protect the Banjaard area from the south-west waves and 1 big island is protecting Schouwen – Duiveland and the Banjaard from the north-western waves. The islands provide a moderate wave energy for the area the Banjaard.
The islands have a slender shape therefore not a lot of space and surface is being used. This is favourable for the amount of sand that is being used for the project. The slender shape ensures that a larger surface behind the islands is protected from high wave energy. Because the waves are reduced over a larger area.
On the islands hard structures like dikes are not being used, for the design of the island only soft structures were taken into account, like big builders. After much research wooden poles must be placed on the sides of the islands where the waves will hit the island the hardest. Because of the wooden poles, the sand on the islands will stay longer on beaches. On the backside of the islands, the waves will hit the islands not as hard as on the front side. However, also on this side of the islands, there will be a defence for the wave reduction. It is highly recommended that on this side oysters will be placed.
Recommend is that the islands are not only used to break the water. The islands can be used as a harbour for sailors who have a long trip but have a rather small boat for this trip. Also, the islands will produce green energy at various ways. This is recommended because the construction of the islands are not good for the environment. When the islands produce green energy the islands can be on the long term actually a good investment for the environment.
On the islands there will be a lot of trees planted, this will give the islands a fresh look and it will be very attractive for ecotourism. Because the islands will contain a lot of trees and vegetation, it is recommended that the islands become a nature reserve. The islands become in a way very multi-functional: 1. Coastal protection, 2. Green-energy, 3. Eco-tourism, 4. Nature-reserve.

Civil engineering

For the civil engineering part, there were several sub-questions to answer in this report. The first question was: *what location, shape and design would be optimal to protect the island ‘Schouwen-Duiveland’?*
To find the answer to this question a Multi Criteria Analyses was made. One specific item in the Multi Criteria Analyses was Shape and Coastal protection. The design must be sufficient to protect the more vulnerable island areas against ever-increasing wave erosion.

Variant 3 of the study was the best solution according to the Multi Criteria Analyses. The location of the island is optimally chosen because the island is not in the way of busy shipping routes, the ships can still use the shipping routes at all costs. The islands 2 and 3 of the variant are located at a distance of 6 kilometres from the shore of Schouwen – Duiveland. This protects the island Schouwen – Duiveland by reducing the wave energy. Also when there is erosion on the islands, the sand will go to the coast of Schouwen – Duiveland and also island 1. That means that the sand will remain a meaningful purpose to coast defence. This principle is based on the sand motor effect, which is used on the Dutch Coasts. The shapes of the islands are rather slender this has a positive outcome for the nourishments because less sand needs to be brought on the islands. The slender shapes of the islands provide a significant wave energy reduction. This is also the whole point of the islands because the islands only need to cover the waves in a way that the coast of Schouwen – Duiveland the remaining wave energy can resist.

The designs of the islands are really helping to protect the coast of the islands itself and also the coast of Schouwen – Duiveland. Because in the design there are coast protectors included. First of all before the islands there are foreshores constructed, this will reduce the strength of the wave. On the beaches there are wooden poles constructed in a row, this will hold the sand on the beaches and again reduce the strength of the wave energy. On the back of the islands will oysters will be placed on the beaches, this will reduce the wave energy significantly.

Another sub-question for the civil engineering part was: *what volume of sand should be used for nourishment?*
To answer this question several recourses were used. First of all the Google Earth, with this programme, the area of the island could be determined. By placing the contours of the island in the programme Google Earth the area and perimeter became known. When the area is known, only the height is missing for a volume calculation. A depth map with the bottom heights was used to perform the volume calculation.
The above mentioned was one part of the calculation, because the island also has a foreshore. For the volume calculation of the foreshore, it was assumed that the shape of the foreshore was like a triangle. This is of course not a good match with reality, however, this gives good guidance for a foreshore volume calculation of this report. For the dimensions of the foreshores of the islands, the perimeter was used with the help of Google Earth. The total volume of sand that can be found on page 47 of this report is rather based on good estimations than exact numbers. However, it gives a good impression of how much sand is needed for the realization of the islands.

The last sub-question for the civil engineering part of this report was: *How can the nourishment be carried out sustainably as much a possible?*
In modern days this becomes a relevant question. More and more companies are working with this question to work as sustainably as possible. Soon the nourishment will probably be carried out with electric driven machines. However, this is still in its infancy when it comes to the subject of beach nourishment or in making artificial islands. Therefore, no longer was looked to the electrically driven way of working, but rather to recycled ways of working. This is literally on what material or recourse the ship is powered to do the beach nourishment.

After more research the answer was clear, the best way is to use biobased fuels. This material is lanced as a sustainable replacer of fossil fuels because biobased fuels are waste fuels and produce almost no CO_2 emissions. For now, this is the best opportunity to work as eco-friendly possible, however, as said soon electric solutions are even better for the environment.

Discussion of civil sub-questions

To determine the erosion rate that would be on the islands, the programme Morphan was used in the first place. This is a complicated software used by the Dutch government to maintain the basic coastline. The authors of this report have tried to work with this programme; however, it was too difficult with no explanations of this programme. Morphan could have been a valuable addition to this report, however in this report erosion rates from the literature were used instead of calculating with the programme.

For the sand volume calculation, Google earth and a depth map were used, this gives a global overview of how much volume sand is needed. However, nowadays there are software and programmes that can calculate the volume of sand in a much more precise way. A good programme that can help with a more exact calculation of the sand volume would be ArcGIS. Unfortunately, the authors of this report had not enough knowledge to work with this programme. Therefore, a simple volume calculation was applied.

Bio-builders

To answer the three questions, a study of different types of bio-builders was carried out. The main area considered were mussel, oyster reefs, seagrass, and salt marshes. Due to the various types of bio-builders, there are different requirements and aim for each. However, a general requirement is that bio-builders do not grow in an area where direct wave impact happens; they cannot survive on that side.

How can marine bio-builders be used to protect sand nourishment in the sea at location 'The Banjaard'?

To use marine bio-builders to protect the sand nourishment different kinds of organisms can be used. Salt marshes are intertidal zones between land and open water and grow various flora which provides stability due to trapping and holding the sediment and slowing down the waves which reach the shore. In addition, oyster and mussel reefs can be used in different ways to prevent sedimentation at around 0.5 meters below mean sea level (resulting in the optimal exposure time of 30%). Research has shown that the use of reef balls is well suited to prevent sedimentation, make a new habitat and it is more resilient to storms which means that there is more opportunity that the establishment is successful. Furthermore, seagrass can be planted at 5 – 15 meters below mean sea level. Due to its high productivity and growth, they stabilize the water flow (waves) and promote sedimentation; thereby, reducing particle loads in the water as well as coastal erosion.

What kind(s) of bio-builder(s) can be used for a natural barrier and what kind of functions does it have?

As mentioned before a combination of species such as oysters, mussels, sea marshes and seagrasses can be used together on a slope as shown in the results section. Salt marshes have the function to be regularly flooded by the tides, as they are an intertidal zone

between land and open water. The florae that grow in the salt marshes are diverse and transport all kinds of nutrients and fauna. Salt marshes can act as a nursery area e.g., fish and shrimps.
In addition, oyster […] Moreover, seagrasses have been proven to be very productive, influence the structural complexity of habitats, enhance biodiversity, and have an important role in the global carbon and nutrient cycle.

It is recommended that extensive pilot research be carried out on the use of the bio-builders looking at what works best, different species for different parts of the island or putting them all together on one slope like mentioned in the results. Furthermore, research into what factors can aid the likelihood of successful establishment of bio-builders, like for instance using a hard substrate to facilitate oyster reefs is highly recommended.

Multifunctionality and stakeholders

From the estimated effect of the variants on stakeholders, it is clear that variant 3 has the smallest amount of stakeholders it affects negatively while having the largest number of stakeholders it affects positively. Therefore, this variant is the most favourable to minimize resistance among stakeholders. Stakeholders should be approached according to the advised strategy, and societal acceptance can be enhanced by given strategies and safeguarding the given requirements.

Multifunctionality is also a way to minimize resistance as when applying multifunctionality, more than one interest and more than one party stand to gain benefit from the project. For this project, the following function may be combined:

- Energy: A floating hybrid wind-wave solution is recommended for the Banjaard project. It makes a power source that can be generated and used locally. At last, the advantage of combining wind and wave on the same platform is that provides less viewed impacts than wind turbines.
- Aquaculture: It is worth researching what possible combinations with aquaculture are possible, as the leewards side of the island may pose suitable conditions for aquaculture.

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Appendix 1 mitigating measures for flora and fauna

Impact on flora and fauna: 0

Impacts on marine species

The negative effects faced by the local fauna and flora in the project area may be summed up as follows, with respective mitigation measures against them:

I. Hazardous substance spills

Spills may occur, causing immediate contamination of the adjacent area. This primarily occurs in the form of fuel, used oil and chemical spillage.

Mitigation measures against this are as follows:

- Chemicals should be safely stored and checked for leakage regularly.
- Machinery and equipment are to be regularly serviced.
- Oil spill containment kits are to be provided at regular stations such that they may be easily accessed in the event of a spill.
- The dredging vessel shall undergo routine inspection, service and maintenance.
- A chemical spill and oil spill contingency plan shall be drafted and enacted when needed. Offshore emergency response procedures appropriate to the project phase will be established in the spill response plan and will include informing workers of their responsibilities under the plan. This will include identification of all risks and application of appropriate control or clean-up equipment appropriate to the situation.
- Inventories of high-risk substances will be low.

II. Sand plumes

Plumes are large underwater clouds of fine silt that form as a result of deliberate deposition by the dredging crew, leaks due to faulty mechanics or due to inefficient dredging practices whereby more sediment is loosened than is pumped. These plumes may cover large distances before finally settling.

Corals, seagrasses, mangroves, and other sensitive receptors may be influenced by such changes in turbidity and sedimentation

This may be curtailed by the following measures:

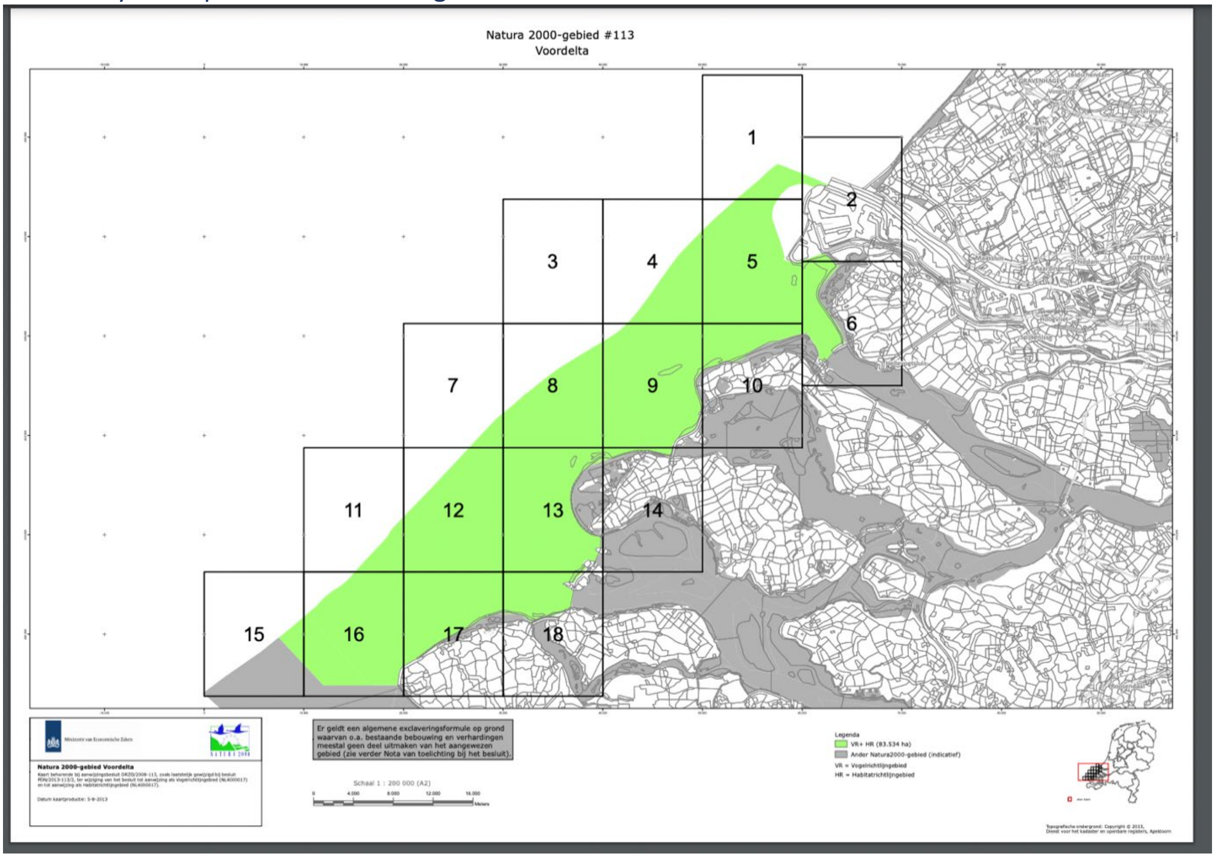
- Reducing the speed of a dredging vessel maintains equilibrium between its cutting and pumping rates.
- Reducing the cutting depth of a dredging vessel's cutters maintains equilibrium between its cutting and pumping rates.
- Continuous measurement of the consequent turbidity by dredging crews aids them to monitor and thus control the creation of plumes.
- Containment bunds constructed around the perimeter of the artificial island will minimise the risk of silt escaping into the open sea. The bunds will be made primarily of large size armour rocks and an underlayer of smaller rock that separates the rock from fill maternal and a layer of geotextile. The primary function of the geotextile will be to prevent the fill from escaping through the void space in between the rocks and into the sea whereas the function of the geotextile is to control the sediment while allowing water to pass through.
- Moreover, silt curtains will be installed to contain any plumes that may be created in the vicinity of the construction site.

III. Noise

- Noise caused by dredging activities may have adverse effects on the indigenous fauna and that of migratory species. As such, the following measures have been proposed:
- Regular maintenance of machinery.
- Acoustic shields will be used where noise levels are found to be above the allowed threshold.
- The construction of the island will be carried out in phases so that the noise is "spread out over a longer period".

Appendix on Natura2000 and other legislations

Area analysis: important laws and legislations



De Banjaard sandbank is located in the Natura2000 area ‘Voordelta’.

- The border of this Natura2000 area lays at the 10 meters isobath.
- This Natura2000 area is marked by a diverse and dynamic habitat of salt water, tidal zones and beaches. This habitat is a transitional area between the North Sea and the estuary.
- This part of the Delta has been subject to heavy changes over the years due to erosion and sedimentation processes (see history). The Delta Works certainly had an impact on the ‘Voordelta’.
- Because the rivers the Muse, the Rhine and the Scheldt have their mouths in the North Sea here, the water of this Natura2000 area is very nutritious, making the area ecologically valuable. The combination of nutritious water and the shallowness also provides for ideal habitat for primary production, with nearly twice as many soil organisms as in other comparable areas in the North Sea.
- The habitat is severely subjective to tidal forces and wave energy. After the construction of the Delta Works, wave energy has gotten the upper hand in forming the Voordelta, because tidal differences and sedimentation have decreased.
- Seabed disturbance in the northwestern part of the Voordelta must be limited or prohibited, and there should be rest areas for seals and birds.

Key requirements for the future of this natural area are:

1. 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.
2. Diversity in tidal sand banks, and preserving and restoring mudflat and salt marshes, in order to protect and enhance biodiversity

3. Resting – and foraging areas for birds; preservation of mudflats and salt marshes for resting and foraging birds (see species) and seals

(Natura2000.nl, 2006)

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Habitat that needs to be protected according to the natura2000 law and regulation:

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		ontwerp	=	=	C	

Which species are important to consider in the project according to the natura2000 law and regulations?

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	ontwerp	=	=	>	C	
H1364 - Grijze zeehond	definitief	=	=	=	B1	1.11
H1365 - Gewone zeehond	definitief	>	=	>	C	1.11

Soort	Status doel	Populatie	Populatie waarde	Instandhoudingsdoelstelling	Omvang leefgebied	Kwaliteit leefgebied	Relatieve bijdrage	Kernopgaven
A001 - Roodkeelduiker	definitief	behoud	n.v.t.	Foerageergebied	=	=	A1	1.01,W
A005 - Fuut	definitief	280	gemiddelde	Foerageergebied	=	=	C	
A007 - Kuifduiker	definitief	6	gemiddelde	Foerageergebied	=	=	B2	
A017 - Aalscholver	definitief	480	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	B1	
A034 - Lepelaar	definitief	10	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	C	
A043 - Grauwe gans	definitief	70	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	C	
A048 - Bergeend	definitief	360	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	C	
A050 - Smient	definitief	380	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	C	
A051 - Krakeend	definitief	90	gemiddelde	Foerageergebied	=	=	B1	
A052 - Wintertaling	definitief	210	gemiddelde	Foerageergebied	=	=	B1	
A054 - Pijlstaart	definitief	250	gemiddelde	Foerageergebied	=	=	B1	
A056 - Slobeend	definitief	90	gemiddelde	Foerageergebied	=	=	B1	
A062 - Toppereend	definitief	80	gemiddelde	Foerageergebied	=	=		1.01,W
A063 - Eider	definitief	2500	midwinter aantal	Foerageergebied	=	=		1.01,W; 1.11
A065 - Zwarte zee-eend	definitief	9700	midwinter aantal	Foerageergebied	=	=	C	1.01,W
A067 - Brilduiker	definitief	330	gemiddelde	Foerageergebied	=	=	B2	
A069 - Middelste zaagbek	definitief	120	gemiddelde	Foerageergebied	=	=	B1	
A130 - Scholekster	definitief	2500	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=		1.11
A132 - Kluut	definitief	150	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	C	

A137 - Bontbekplevier	definitief	70	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	B1	
A141 - Zilverplevier	definitief	210	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	C	
A144 - Drieteenstrandloper	definitief	350	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	B1	
A149 - Bonte strandloper	definitief	620	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	C	1.11
A157 - Rosse grutto	definitief	190	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	B1	1.11
A160 - Wulp	definitief	980	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	C	
A162 - Tureluur	definitief	460	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=	B1	
A169 - Steenloper	definitief	70	gemiddelde	Slaap- en rustplaats en foerageergebied	=	=		1.11
A177 - Dwergmeeuw	definitief	behoud	n.v.t.	Foerageergebied	=	=	B2	
A191 - Grote stern	definitief	behoud	n.v.t.	Foerageergebied	=	=	A2	
A193 - Visdief	definitief	behoud	n.v.t.	Foerageergebied	=	=	A2	

Europese Kaderrichtlijn Water (KRW)
The regional policy for water quality has been based on the European ‘Kaderrichtlijn Water’. These agreements are international, as water is transborder. Since 2000 the European ‘Kaderrichtlijn water’ is in place. This regulation includes the following:

- 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

Important requirements to consider:

- Nature friendly shores
- Reduce downsides of unnatural situation
- Try to fulfill the Ecological Maximum Potential (MEP). However, in most cases this is not realistic without giving up other functions such as safety, therefore Good Ecological Potential is also acceptable (GEP).
- Chemical quality requirements
- Ecological quality requirements

Appendix 2: other possible multifunctional uses of the breakwater

Wave energy could be a solution for the island energy need. This could be in a combination of wind and wave energy. Wave energy is predictable when and how much energy it shall generate because waves depend on the ocean tides with can be forecasted. Making it a suitable supplement to fill the gaps when the wind turbines do not generate power. Furthermore, wave energy systems are at this stage small and are not suitable for powering large structures or building (Just Energy, n.d). It is therefore advised to seek a hybrid solution like wind and wave. Wave energy is at this moment still in the pioneering phase. Therefore, there are multiple wave technologies which can be chosen for this project. With hybrid solutions their systems like the W2Power hybrid wind wave system by pelagic power or the Poseidon hybrid wind wave system by Floating Power Plant. The advantage of combining wind and wave on the same platform is that provides less viewed impacts than wind turbines (McTiernan & Sharman, 2020). This is a key factor for our stakeholders since coastal region and the village Burgh-Haamstede is financially depended on tourism with their beaches as attraction factor. Moreover, the main advantage is that these hybrid systems are a local power source. Offshore wind turbines may need local power for operating the ballast and control system. Although these hybrid platforms are in an early stage of research development, they can offer a potential solution.

Figure 29 Poseidon Hybrid Wind Wave System by Floating Power Plant

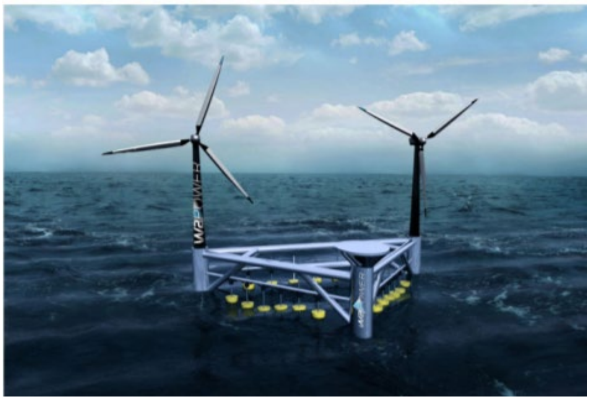

Figure 30 W2Power Hybrid Wind Wave System by Pelagic Power

Multifunctionality with aquaculture

The island may also pose an oppurtunity for aquaculture, specifically seaweed cultivation and shellfish farming. This can take place at the leewards side of the island. (Source energie-eiland onderzoek – to be confirmed if I can use it). This fits within the ambition of the municipality Schouwen-Duiveland and the Province of Zeeland to expand the current aquaculture sector in an integrated manner (Living Lab Schouwen-Duiveland, sd).

Appendix 3: clarification on participation levels

Clarification participation level

The different participation levels define to which extent a stakeholder should be involved in a project. This is dependent on the stakeholders' interests and power, keeping bottlenecks and wishes in mind. The participation level determines how much and in which way a stakeholder is involved and participates. The participation levels are:

1. Inform:

This is the lowest level of participation, often chosen as a participation strategy for the public. The public is informed about the proposed action. Nothing is expected from the public but taking in the provided information. In doing so, a few factors are important:

a. Reaching as many people/parties as possible. The means of communication is dependent on the target audience. Therefore, a communication strategy is advised.
    i. How to reach as many people/parties as possible?

b. The transparency in communicating. By being transparent resistance can be prevented. When people feel fooled or surpassed, the resistance of this fuel.
    i. How do you communicate as transparently as possible?

2. Consult:

The stakeholder is consulted about proposed plans. The more different options presented, the greater the openness to content. This form of participation can be very non-binding; in fact, only the opinion of the stakeholder is taken into account, and this opinion does not necessarily have to have consequences.

3. Advise:

The population is given room for discussion and allowed to propose their solutions. The citizen is therefore allowed to advise. For example, the citizen has more say because their opinion is taken into account more and this option of participation is less non-committal.

4. (Co)decide:

Some of the decisions are to be made by the stakeholder. A large degree of participation must be requested. It is necessary that the entire process from start to finish is actively followed, and that sufficient knowledge is available to participate in decision-making in a fully-fledged and responsible manner.

5. Coproduce:

Both (or all) parties have an equal position and role in the project.

(Lodewijckx, 2021)