HOLWERD-ON-SEA
Coastal design from an differented and integrated perspective

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ABSTRACT

Occasion
The local community network of Holwerd has launched the ambitious idea to breach the 'Sea-dike', which dams the village from the Wadden Sea. This is necessary to make Holwerd more attractive for tourists and decrease the economic decline of the region northeast Friesland. This paper shows the opportunities for redesigning 'Holwerd-on-Sea' in a more sustainable way. The plan made by students integrates spatial, natural and economic cycles in a climate proof design proposal. The approach is based on building with nature and economic value creation. The future plan increases the liveability of Holwerd, which can make the downward spiral an upward spiral.

Water system
The plan shows how Holwerd-on-Sea, instead of fighting against the water, 'embraces' the water of the Wadden Sea. A connection where seawater and fresh water can merge will be realized by an inland water retention reservoir. The water that flushes from the reservoir keeps the sea lane at depth, which results in a decrease of dredging costs. The water level in the area is controlled by sluice gates, which provide opportunities for offshore sailing and also protect the mainland from salinization.

Nature development
In this future plan, a system of fish ladders is designed that makes it possible for fish to migrate between the Wadden Sea and the domestic waters. Shell banks are used as natural building stones. They form the guiding system for the flush water. The saltmarsh located outside the dike fulfills the function of natural breakwaters. The quality of the existing saltmarsh is improved by filling up the artificial gullies. In combination with grazing by 'oxen', the natural succession of the vegetation will be extended. The newly formed natural environment will become an attractive destination for wildlife tourism.

Climate adaptation
Sustainable energy is hard to store, which causes the need for a natural battery in the form of a 'Valmeer'. The combination of using hydroelectric turbines in the water retention reservoir and the using of renewable energy makes Holwerd independent of fossil energy. Furthermore Holwerd-on-Sea can adapt to climate change and repair its own phosphor cycle by embracing siltation. Algae, mussels and seaweed are able to filter phosphor out of the water. By using these organisms in the food industry, the region is able to regain lost phosphate and create more economical chances in the area.

TABLE OF CONTENTS

1 INTRODUCION

Occasion

Northeast Friesland, located in the northern part of the Netherlands, is diminishing in economic activities and inhabitants. Within this part of the Netherlands there lies the village Holwerd (figure 1).

Figure 1 Map of the location of Holwerd

At this very moment, there are few jobs in the region, mostly due to a high reliance on agricultural companies, which require a very low amount of employees per square meter. So step one to put Holwerd back on the charts of The Netherlands is to create jobs.
The people of Holwerd concluded that this village and the region needs to reinvent itself. To reinvent the region, Holwerd needs to become a place to which people want to go to, so Holwerd has to be part again of the Waddensea area. Opportunities can be exploited by using an integrated approach, which will result in sustainable choices for the future. To restore the connection between the sea and the mainland Holwerd wants to make a gap in the dike and create a lake that goes from salt to brackish to freshwater.

In the past Holwerd had a connection with the sea, but in the last centuries Holwerd was getting further away from the Waddensea because of land reclamation as a result of the deposit of silt. The connection between the Waddensea and the mainland has been largely lost due to a dike that protects the inhabitants from the Waddensea. This large dike also prevents fish migrating from the salt seawater to the freshwater of the mainland. The village is characterized by population decline and uninhabited houses.

Besides that, positive factors can also be found, for example, the Waddensea area is an UNESCO World Heritage. The area also knows an increase of tourism and the area is also renowned for its big and diverse bird population. A lot of money is invested in this area.
A big part of the tourists want to visit the island Ameland. These tourists drive past Holwerd at this moment, but by making some changes to Holwerd people can visit the Waddensea from the mainland in all its beauty.

Method

To realise an integral design for Holwerd the following steps have been taken. At first students of the study Landscape and Environmental management have make an encyclopaedia about the village Holwerd. This encyclopaedia has handled subjects as history, land use, natural systems, water safety, economic and demographic situation. From here the students have made different scenarios for the village. In this report these scenarios have transformed into an integral vision and design for the area.

To create an integral vision different ideas from the scenarios have been used. To support the literature knowledge of the area there has been contact with the community group Holwerd-On-Sea and different experts on the subjects water safety, building with nature, reusing energy and climate change.

Tassel

This report will start with the vision for an integral redesign of the area. From the vision the report will go on with the measures that have to be taken. After that this report will handle the different subject from the vision. First up will be the water. After this the ecological measures will be described. Than the measures for the energy system will be mentioned. Followed by the food production. The last subject will be tourism and liveability. After the different subjects of this research the integral design will be explained. The report ends with the conclusions.

2 VISION

The region Holwerd-On-Sea is the unique connection between Waddensea and the main land. After the realization of a gap in the dike, the salt Waddensea is connected with fresh water, which resulted in an area with a high quality of biodiversity and the possibility for pleasure watercrafts to travel between fresh- and salt water. The transition of salt and fresh water leads to economical improvements by saline agriculture and tourism activities. The region is future proof because of the self-sufficient energy use. Furthermore provide the natural foundations that Holwerd-On-Sea is prepared for a sea level rise.

Objectives

Ecological

- *Fish can migrate between the fresh and salt water.*
  The dike also prevents fish migrating from the salt seawater to the freshwater of the mainland. New ways for migration of fish have to be realized.
- *A vegetation typical for a salt watersystem*
  The realisation of such a lake gives chances for the growth of brackish plants, which belong, in that region and not only on the cultivated salt marshes, which lay on the other side of the dike. The realisation of this lake alongside the creation of new salt marshes ensures Holwerd and the region is going to become an interesting area for nature.
- *Increase of breeding birds typical for the Waddensea region*
  The area is renowned for its big and diverse bird population. With the new organisation there will be more space for breeding birds.

Economic

- *An economic profitable saline agriculture system*
  Holwerd and the region northeast Friesland are renowned for their agricultural landscape. Even though agricultural landscapes do not harness many jobs, they do `pollute` the environment, with many nutrients which can be valorised and used for the growth of algae and seaweed. These cultivations are by far the most efficient in biomass production and components as phosphate and nitrate per square meter. Algae and seaweed are a source of feed supplements, (like omega 3 and 6) can be sold as food for humans, cattle and fish and can become a source of clean bio-energy in the future. The latest comes for a huge part out of former tropical rainforests, which has been burned to the ground to grow palms and harvest biofuells out of palmoils. Until the soil has been washed away by a storm and another part of the rainforest gets cut or burned away. At this very moment it’s yet to expensive to grow and convert algae into bio fuels, but the technology is ever evolving and a kg dry algae’s can already be made for €2 in the Netherlands, while using a minimal area of land. Projected is that in 2030 algae need seven times less the area to produce the same amount of biofuels in comparison to conventional plants.
- *An increase in the tourism acitvities for a more employment and benefits.*
  A lot of tourists past Holwerd on their way to the island Ameland. The plan is to make Holwerd a nice placet o visit and to make sure that tourists have reasons to stay in Holwerd for a while.
- *A decrease of dredging costs for the sea lane to Ameland.*

At the start of the sea lane to Ameland, the dredging issues are big. Everyday cost are incurred by dredging. This costs a lot of money.

Sustainbility

- *An self-sufficient energy system*
  A new development like these needs to be (environmentally) sustainable on the other hand, the era of linear production has to end. The European Union has declared that in 2020, sustainable energy sources need to deliver at least 20% of the total energy request in the EU. The Netherlands produces 92.8% of its energy by burning fossil fuels, The Netherlands imports 3% of its energy and produces a mere 4,2% of its energy out of sustainable sources. The Netherlands has specified it needs to produce 14% of all its energy in the year 2020 sustainable. Not using the chance of restructuring Holwerd towards a sustainable energy landscape would be a missed opportunity. Aside from producing sustainable energy the Netherlands also needs to find a way to effectively store this energy, without much height conventional difference pumped hydro storage seems impossible. But underground pumped hydro storage of energy alongside hydrogen might be the solution for this problem.
- *Reuse of residual flows in the region*
  To transit from a fossil-fuelled linear economy towards a sustainable circular economy a region needs to invest in the valorisation of “garbage” and the biobased economy.

Social

- *Create jobs*
  Population decline and the pauperization of uninhabited houses must be stopped by creating jobs. This will be realised with the increasing of tourism and recreation in the area.

Safety

- *Holwerd at Sea is protected for an increase of the sea level*
  The flow of incoming water from the sea needs to be mechanically regulated, the dike currently meets all demands to withstand the Waddensea, but with climate change on the rise it will remain to be seen for how long. The mechanical system that regulates the incoming and outgoing water needs to be flexible and ajustable.
- *Natural process are used for the water safety of Holwerd at sea.*
  Instead of fighting against the water, natural processes are used to protect the mainland against the water

3 MEASSURES

The measures that need to be taken in Holwerd are mentioned in this chapter. The measures are divided in five paragraphs. The first paragraph will be about water. Second part are the ecological measures. Third part are the measures taken for energy. Furthermore are the measures on the area of feed mentioned. And the last part is about the recreation and liveability of Holwerd.

3.1 WATER

The domestically located tidal reservoir is used to create a flush stream and to keep the sea lane at depth. This paragraph describes the measures that need to be taken in the context of water management. Sluices and water gates are realized to control the flush water and to protect the mainland from floods and salinization. With the plan 'Holwerd on sea' fishes are able to migrate between salt and fresh water and recreational crafts are able to travel to open sea. This paragraph describes the measures that need to be taken to realize this all.

3.1.1 WATERSAFETY

The new standard specifications for the Delta Decision 'watersafety' are recorded in the Delta Programme 2015 (Deltaprogramma, 2015). In the context of climate warming, the new standards for flood protection in the Netherlands are adopted in the Delta Decision 'Watersafety' . These standards are realized with the help of a risk approximation and are based on the expected situation for 2050.
Holwerd, located at dike in the range 6-4, has a standard specification of 1/3000, which means that the probability of flooding here ranges from 1/300 per year to 1 / 100,000 per year. In the context of water safety, for Holwerd an exploration plan has to be realized between 2016 and 2018. Between 2019 and 2020 the plans will be elaborated and between 2021 and 2027 the plans will be realized (Rijksoverheid, 2015).

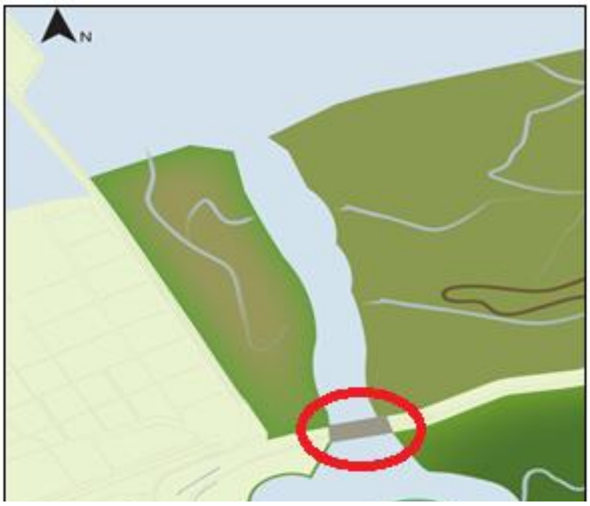

Figure 2 The sluice protects the mainland for floods and is used to control the flush lake

Construction Watergate

The first measure that needs to be taken is to place a water gate, at the point where the breach in the dike is made (figure 2). In the coming decades, the seawater level will keep on rising as a result of global warming (Kauwen, 2010). The main function of the gate is to protect the inhabitants on the mainland from floods. This water gate consists of two doors which are electrically controllable. The gate is open most of the time, but when storm threatens the mainland, this gate will be closed.
Besides protection against floods, this water gate can be used to control the flow of the effluent flush water which is originating from the domestically located tidal reservoir. At this place the flow of effluent flush water is very strong. The doors of the water gate are electrically controllable and this provides the possibility to control the flow of effluent flush water and protect the bottom against erosion (H. Vereecken, 2008). At high discharge these doors are used to slow down the flow of effluent water.

The costs of produce, transport and place of a water gate with the size of 102,25m2 and electronically controllable doors are about €2.000.000,-. The cost per m2 are 2.000.000/102,25= €19559,90. The size of the water gate for the plan 'Holwerd on Sea' is 15x20= 300m^2. The total costs for the realization of this water gate in Holwerd are about: 300x19559,90= € 5.867970 (Prins, 2013).

3.1.2 WATER SYSTEM

The mainland right behind the dike will be excavated to realize the flush lake. Opportunities are created here for the development of new nature (paragraph 3.2). The plan shows how Holwerd-on-Sea, instead of fighting against the water, 'embraces' the water of the Wadden Sea. A connection where seawater and fresh water can merge will be realized by an domestically located water retention reservoir. The water level in the area is electrically controllable by sluices and gates, which protect the mainland from floods, salt water intrusion and it provides opportunities for offshore sailing and fish migration. A sluice connects the water from the domestically located retention reservoir with the so called channel 'Holwerder Feart'.

Construction Sluice
With the plan 'Holwerd on sea', fresh and salt will meet each other by making a breach in the dike. The sluice connects the domestically located retention reservoir with the fresh water from the 'Holwerter feart' (figure 3). The realization of a sluice makes it possible for recreational crafts to travel to open sea. The sluice is thirty meters long, ten meters wide and two meters deep and has electrically controllable gates..
This sluice is necessary because the Holwerter Feart has a constant water level of -0.52m NAP and the flush lake has a varying water level between +1.50m NAP and -1.50m NAP (figure 12) paragraph 3.1.4). The water level between the sluice gates is controlled by a pump.
Another function is that the sluice protects the agriculture from salinization (Innovatie Estafette, 2016). As a result off climate warming, seawater levels are rising. With a reduced river flow during dry periods, salt infiltration through estuaries and seepage in low-lying areas increases, which causes further salinization of freshwater and the agriculture. This is seen as one of the chemical effects of climate change (Kauwen, 2010).
'Fluid-mud' forms under various conditions. Research shows that high concentrations accumulate as 'fluid-mud' near the edge of the salt wedge, where fresh- and saltwater merge (Rijn, 2016).
The costs to build a sluice of 1925m^3 are about € 95.000.000,-. The sluice for the plan 'Holwerd on Sea' needs to be 30x10x2 = 600m^3. 95.000.000/1925= €49350,-/m^3. 600x49350= € 29.610.000,- (Kosten-batenanalyse sluizencomplex Kornwerderzand, 2016).

Figure 3 The sluice (and fish ladder) are located in the south west of the plan area.

Flush function
Obviously these measures have various socio-economic, natural and environmental effects, but an inland water retention reservoir does something else: The water from the domestically located tidal reservoir is used to decrease the dredging costs in the sea lane from Holwerd to Ameland. Reduce the dredging costs formed a boundary condition for this project.
At the very beginning of the sea lane to Ameland, the dredging issues are immense (figure 4) This area lays outside the dike, at the seaside. The cause of the increasing dredging volume seems to be the reduction of the retention area at 'het Kikkersgat'. The magnification and realization of a permanent retention area in the shape of a flush lake can form a

solution. The increase of retention area, results in a faster flow and less material is able to sediment in the sea lane (Veilinga, 2015).
The idea off the domestically located retention reservoir is that the collected water can be hold by a sluice and by opening the sluicegates at the right moment, the flush water will flush the sea lane at depth. At low tide the water will be sucked out of the flush lake and erode the gully. By using a flush stream, the effect of eroding will enhance the effect of erosion (Veilinga, 2015). Documentation on the operation of flushing lakes is scarce, but an example is found in Niedersachsische Nessmersiel, Germany. Research shows that when the flush function is used at low tide (just before high tide), the sedimentation decreases (Veilinga, 2015).

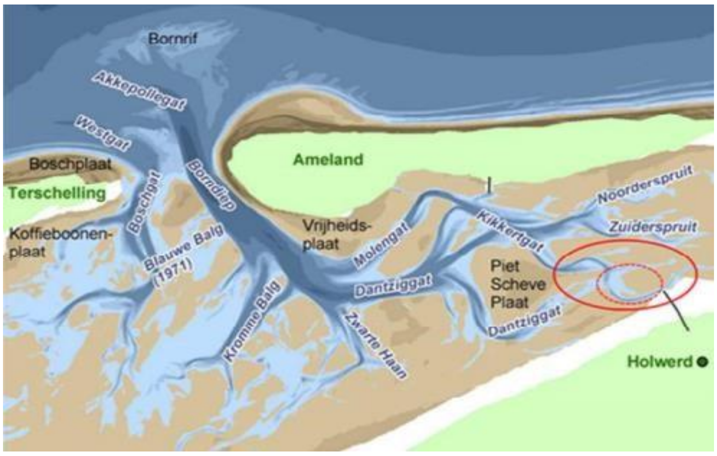

Figure 4 This figure shows the sea area between Holwerd and Ameland. The red circle shows the area where dredging activities take place. The small circle shows the area where most dredging activities are needed.

Bottom protection
Besides this water gate, there are other measures that need to be taken against the force of the effluent flush water. The water bottom needs to be protected against erosion from the flush water and against erosion which is generated by passing recreational crafts (Asplund, 2000). Geotextile is used here to protect the water bottom against erosion.
For this measure, a framework of ropes and brushwood (two layers of ropes and brushwood at right angles to each other) is assembled on top of a piece of geotextile (figure 5). This framework is filled up with cobalt stones. The framework prevents that the cobalt stones can roll and it will keep the geotextile at the desirable location. It protects the water bottom against erosion (Griendhout producten, 2016).
The same measure should be taken at the place where the sluice is built, which connects the domestically located tidal basin with the so called channel ‘Holwerder Feart’.

Figure 5 The framework of geotextile, brushwood, ropes and cobalt is used to protect the sea lane from erosion (foto:griendhouthandel.nl).

Analysis influence flush lake on dredging volume
For the project ‘Holwerd on sea’, an expert meeting was organized to find out in how far a tidal reservoir can fulfil a flush function. In this expert meeting the analysis are based on a tidal basin of 35 hectares. These dimensions are not exact the same as the dimensions for the plan ‘Holwerd on sea’, but this research will offers handles in order to create a good working flush function. The dimensions of the flush lake for the plan ‘Holwerd on sea’ are … hectares.
The results of the expert meeting describe that the flow of the flush water has a different efficiency on the dredging fractions ‘fluid-mud’ and ‘sand’. This ‘Fluid-mud’ fraction is a silt that consists of very small fractions of dust, which will sediment on top of the sand fraction. This phenomenon can be noticed around the sea lane Holwerd-Ameland since 2007 (Veilinga, 2015).
The efficiency of the flush lake has been estimated as follows:
- fluid-mud fraction: decrease of 50-100%
- sand fraction: decrease of 10-30%

Based on the findings from this expert meeting, researchers expect a substantial decrease of 500.000-1.000.000 m3 dredging volume a year. The total current dredging volume is about 1.600.000 m3. Both fractions have about the same contribution of 800.000 m3. The experts say that a permanent retention area in the shape of a tidal basin can be a technical realizable option and a decrease of a third to half of the dredging costs is realizable (Veilinga, 2015).
The dredging costs in this part of the sea lane are increasing fast since the year 2009 (figure 6). In the past dredging was not needed every day, but nowadays it is a Permanent ongoing occupation (Dijkman, 2013).

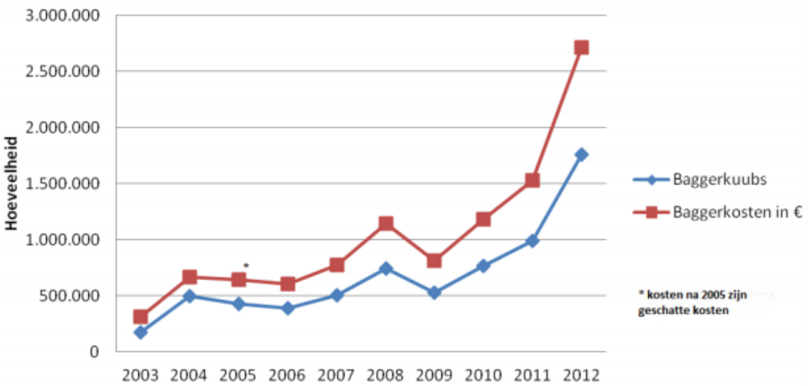

Figure 6 Dredging volume and costs in the sea lane Holwerd-Ameland 2003-2015 (Bron: Rijkswaterstaat).

Effects on the Saltmarsh

The saltmarsh is located outside the dike is a by-law protected area and also part of the UNESCO World Heritage (Unesco werelderfgoed, 2016). This saltmarsh fulfills the function of a natural breakwater (Doornbos, 2012).
For the implementation of the plan 'Holwerd on sea', there are some measures that need to be taken in the saltmarsh (figure 7). A part of the protected saltmarsh has to make space for the drain of the flush lake. Although there is a decrease of space from the current saltmarsh, new opportunities for nature are created by realizing a new domestically located saltmarsh right behind the dike. The sediment that comes free by excavating the lake, can perfectly be used for dike reinforcements in the region (Doornbos, 2012). The new ecological values that are realized with this measure are described in paragraph 3.2.

Figure 7 The current saltmarsh of Holwerd (source: waddenzeeschool.nl).

3.1.3 BUILDING WITH NATURE

The Wadden Sea area is in terms of security of great importance to the coast of the Netherlands. The outer deltas, the Wadden islands, tidal flats and salt marshes offer besides the high nature also an additional protection buffer for the coast of the Netherlands (van Loon-Steensma, 2015). The outstretched tidal areas provide protection against the high waves of the sea and without this buffer the dikes and dunes on the mainland and on the islands should be built more massive and stronger than they are now (van Loon-Steensma, 2015).
For the elaboration of the plan 'Holwerd on sea', use has been made by the concept 'building with nature'. 'Building with Nature' is an integrated approach in which water plays a major role. 'Building with Nature' is a climate adaptive system and is used for creating residential, work, tourism, recreation and infrastructure. At the same time it is aimed at preserving the expansion of precious natural resources, nature values and landscapes (Waterman, 2010)).
Three natural building stones are further elaborated with the plan 'Holwerd on Sea'. These are 'artificial oyster banks made of gabions', sandbanks and shell banks on 'Shoreline Gabion Matrasses'.

Artificial oyster banks made of gabions

The course of the flush stream will be guided by using shell banks, which is in line with the concept of building with nature. Shell banks will be grown in this part of the Wadden Sea and will give a more natural view than using cobalt or concrete. Shell banks are used to narrow the sea lane, which has to result in a more effective flush function (Veilinga, 2015). Shell banks in combination with the saltmarsh and corresponding vegetation are giving support as natural coastal defense and research also shows that opportunities for natural improvement can specially be found for recovery of shell banks with corresponding communities (Rijkswaterstaat, Natura 2000-doelen in de Waddenzee, 2011).
At this very beginning of the sea lane, the water flow of effluent flush water is very strong. A strong guiding system which is resistant against strong water flows is needed here. For this measure, a fence of

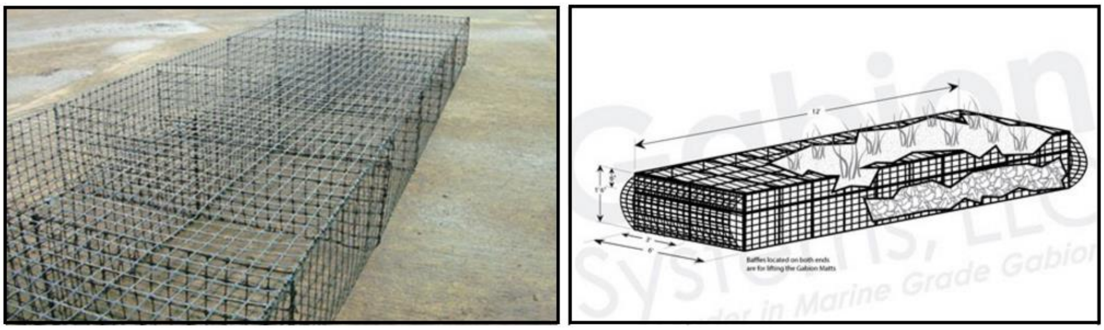

Figure 8Artificial oyster banks made of gabions are used to guide the flush water at the very beginning of the sea lane Holwerd-Ameland (source: gabionsystems.com).

artificial oyster banks made of gabions is realized here to guide the flush water (figure 8).
Critical places are the locations where the flush water has to make some curves. Shoreline T-Gabions are used here (figure 9). Shoreline T-Gabions are specially designed to deflect tidal flows and are also used for sea lanes and are giving oysters a safe place to grow (OysterProducts, 2016).

Figure 9 Shoreline T-Gabions are used at critical locations in the sea lane. These locations are the sharpest turns at the beginning of the sea lane (source: gabionsystems.com).

Sand- and shell banks on 'shoreline Gabion Matrasses'.

Further seawards the guiding system will consists of shell banks which are developed on Shoreline Gabion Matrasses (These matrasses are specially made for the establishing of artificial reefs and oyster beds. These construction looks more naturally than shoreline gabions and shoreline T-gabions. The mattresses are filled with concrete, stones and oyster shells. Shoreline gabion matrasses conform to the contour of the sea bed and allow oysters to attach itself to the matrasses (Gabionsystems LCC, 2016) (Figure 10).

Figure 10 Shoreline T-Gabions are used at critical locations in the sea lane. These locations are the sharpest turns at the beginning of the sea lane (source: gabionsystems.com).

Shell banks are used to capture sand and settle the sediment at the desirable locations. These shell banks will also help to clear the water (Natuurtypen, 2016). With the plan 'Holwerd on sea', 'fences' of shell banks are connected with the already existing sandbank, the so called 'Piet Scheve Plaat' (figure 11).
This measure will result in a larger area of shell banks, silt- and sand plates. This is desirable because sand- and shell banks are both part of the national conservation objective: Conservation of dispersion and conservation of current space and quality improvement of habitat type 'Silt- en sand plates in tidal areas' (habitat type 1140, subtype A) (Rijkswaterstaat, Natura 2000-doelen in de Waddenzee, 2011).

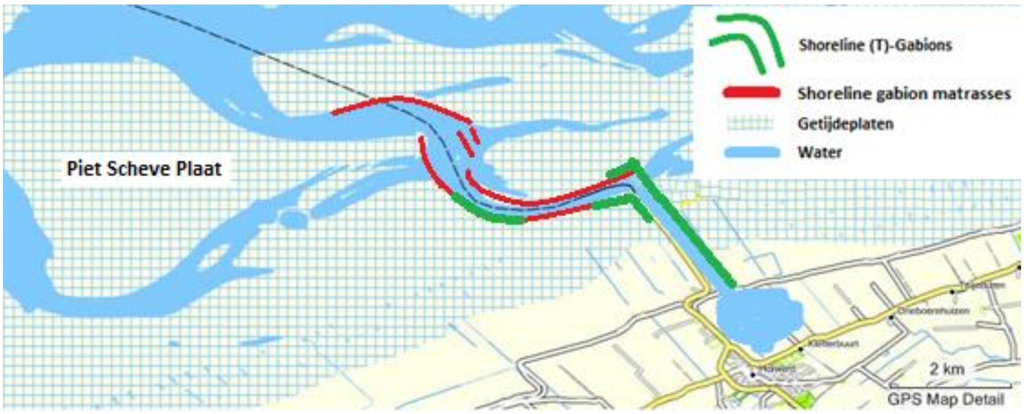

Figure 11 Different ways of artificial oyster gabions are used to guide the flush water. The shell banks are connected with the already existing tidal plate, the so called 'Piet Scheve Plaat'.

The habitat forms a rest place for seals and it has an important function as habitat for young fish to grow up. The rich biodiversity of bottom fauna, makes these sand plates indispensable feeding grounds for migrating birds (Ministerie van E (Ministerie van Economische Zaken, 2016).
Shell banks in combination with the saltmarsh and corresponding vegetation are giving support as natural coastal defense and research also shows that opportunities for natural improvement can specially be found for recovery of shell banks with corresponding communities (Rijkswaterstaat, Natura 2000 doelen in de Waddenzee, 2011).
This habitat type is characterized by a high biodiversity, but the conservation of this habitat type for the future is assessed as unfavorable. In the long term a seawater level increase of more than fifty centimeters, may reduce the size of this habitat type. Because the ecosystem is large and complex, it is difficult to predict how certain developments will proceed and what effects will occur by gradual changes (Habitatrichtlijn, 2008).

3.1.4 FISHMIGRATION

The water system of the Netherlands consists of huge quantities of 'water islands' rivers, canals, lakes and ditches that are separated by dams, dikes and sluices. These measures are necessary to protect areas for floods. These measures allow Dutch inhabitants to live in the deltas. These measures have resulted in a fragmented landscape and led to changes in the composition of flora and fauna (Ministerie van de Vlaamse Gemeenschap. AMINAL, 2005).
For the plan 'Holwerd on sea' a fish ladder is built next to the sluice. The dike and the sluice form a barrier for migrating fish, but with the plan Holwerd-on-Sea, fishes are able to migrate again between salt and fresh water. A solution is found by the realization of a 'fish ladder', next to the sluice (figure 12) he fish ladder is giving fishes the possibility to travel between salt and fresh water, 24 hours a day.

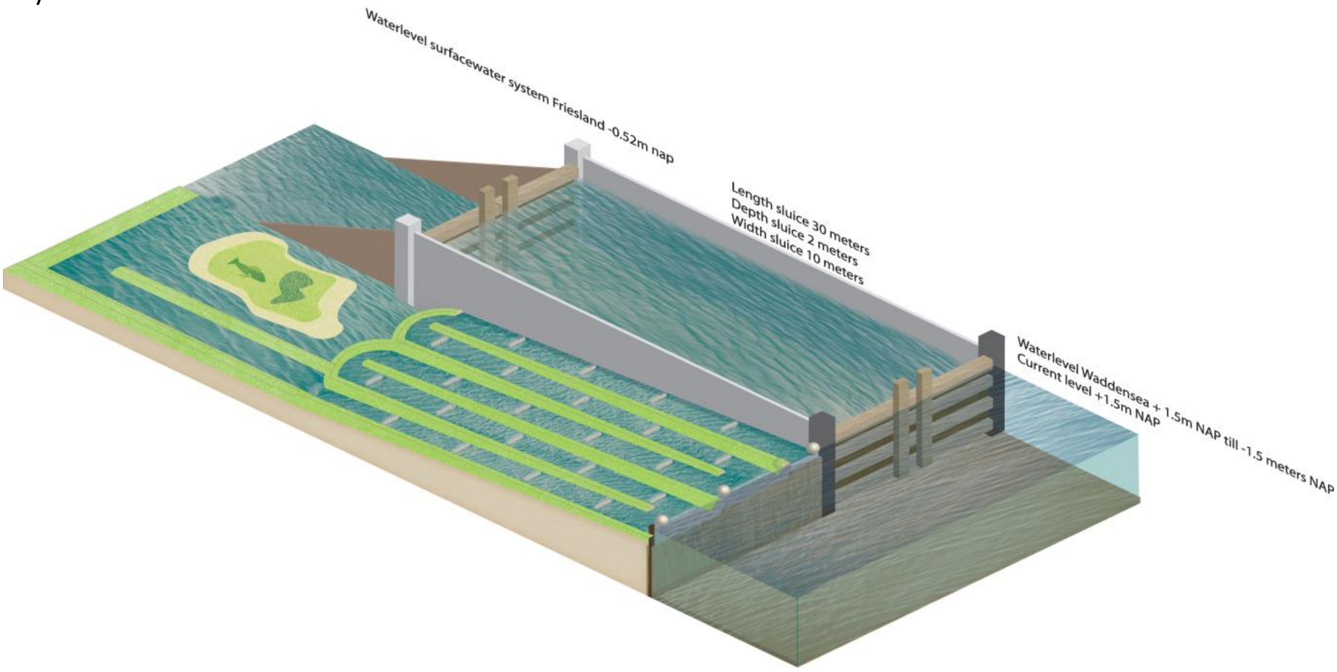

Figure 12 The sluice gives pleasure crafts the possibility to travel to open sea and fish can migrate again between salt and fresh water.

For the design of the fish ladder, use has been made of the 'manual fish migration'. Natural or semi-natural solutions seem to be impossible (Ministerie van de Vlaamse Gemeenschap. AMINAL, 2005).
In order to regulate the flow rate as a result of changing seawater levels, three valves are designed that move along with the movement of the constantly changing sea water levels. These valves give

catadromous species such as eel (*Anguilla anguilla*) and flounder (*Platichthys flesus*) the possibility to migrate from fresh to salt water.
Anadromous species like can easy travel from salt to fresh water. The fish will be collected in a reservoir to a point where is no turning back. This reservoir is emptied every six hours by an automatic valve. Species like Salmon (Salmo salar), sea trout (Salmo trutta trutta), three-spined stickleback (Gasterosteus aculeatus), smelt (Osmerus eperlanus), river lamprey (Lampetra fluviatilis), sea lamprey (Petromyzon marinus) and sturgeon (Acipenser sturio) have profit from this measure. Another measure to control the flow rate are the bulkheads which are placed into the fish ladder (Ministerie van de Vlaamse Gemeenschap. AMINAL, 2005). These bulkheads form the steps of the ladder and fishes can rest behind the bulkheads and climb up step by step. Gravel and stones are used to cover the bottom of the fish ladder. The pump which controls the water level between the sluice gates is used to create a stream to attract the fish.

3.2 ECOLOGICAL

this paragraph the measures for ecological improvement are explained. on the entire ecosystem of the Waddensea. And therefore these are important for protecting this world heritage. The redesign of the area offers new opportunities for nature. The gap in the dyke will restore fish migration from fresh to saltwater. To compensate the effects of the sea lane through the salt marsh measures need to be taken (European Commison, 2013). Therefore it is necessary to take measures for recovery the existing salt marsh and creating a new salt marsh.

3.2.1 SALT MARSHES

The area north of the sea dike is a salt marsh. The salt marsh is a unique ecosystem of salt tolerating vegetation. The saltmarsh by Holwerd Is part of a larger area of salt marshes. The Dutch salt marshes are at the south side of the Waddensea at the northern part of Groningen and Friesland. The saltmarshes are part of UNESCO World Heritage area the Waddensea (UNESCO, sd). In figure 13 the natural vegetation type of a salt marsh is visible.

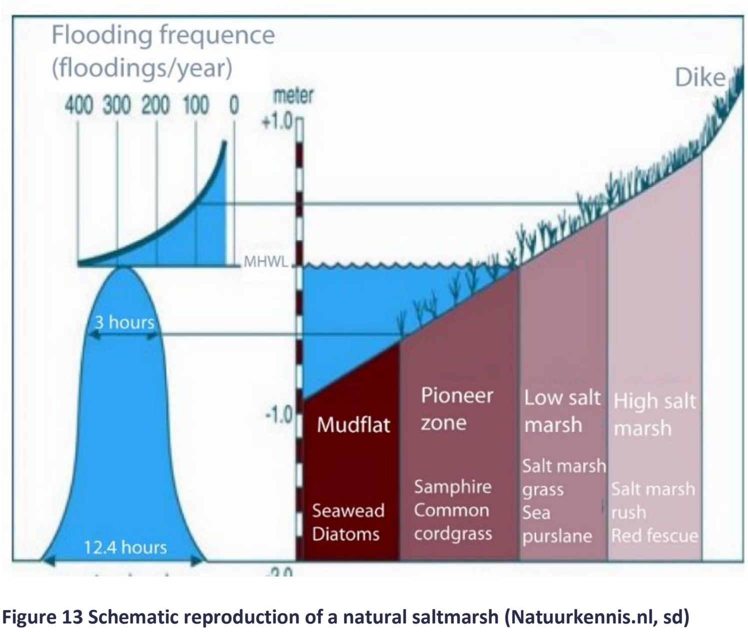

Figure 13 Schematic reproduction of a natural saltmarsh (Natuurkennis.nl, sd)

However the ecological quality of the salt marsh is decreasing (European Commison, 2013). There are different causes for the decreasing of the ecological quality of the salt marsh. One of the main reason for the decreasing is the drainage system that has been created for agricultural means. The drainage system causes a decrease in the influence of the salt water. This lead to the disappearing of pioneer vegetation and an increase of climax vegetation. The existing drainage ditches in the area are not in relation with a natural situation. In a natural salt marsh area the drainage system consists of creeks (Bakker, Esselink, Van Der Weal, & Dijkema, 1997).

To improve the ecological quality of the area, the influence of the sea needs to be bigger. Closing the current surface water system will increase the influence of the sea (Bakker, Esselink, Van Der Weal, & Dijkema, 1997) (De Groot, Van Wesenbeeck, & Van Loon-Steensma, 2013). The vegetation of the salt marsh has aged and is in the climax stadium. The salt marshes were used for agricultural activities. The farmers used the land for the cattle. The cattle increased the number of pioneer vegetation in the area (Bakker, Esselink, Van Der Weal, & Dijkema, 1997) (Bakker J. P., Restoration of salt marshes, 2012). The intensification of the agricultural activities in the area lead to a larger cattle in the saltmarsh. These large cattle's had an effect on the vegetation. The number of flora species were decreasing (Bakker J. P., Restoration of salt marshes, 2012) (Dijkema & Van Duin, 2007).

Recent decade the use of salt marshes for agricultural purposes has decreased. The cattle's disappeared out of the salt-marsh. This had an large impact on the ecosystem. The salt marshes recovered and the numbers of vegetation species grown (Bakker J. P., Restoration of salt marshes, 2012) (Bakker, Esselink, Van Der Weal, & Dijkema, 1997). However the effect of the disappearing of cattle's on the long term was different. The speed of succession of the area was increased. Pioneer vegetation disappeared and Sea couch (*Etrygia atherica*) dominated the salt marshes (Bakker J. P., Restoration of salt marshes, 2012) (Bakker, Esselink, Van Der Weal, & Dijkema, 1997) (Bakker, et al., 1993). The increasing succession even leads to vegetation types with species that are not typical for the saltmarsh like Common reed (*Phragmites australis)* and Creeping thistle (*Cirsium arvense)* (Dijkema & Van Duin, 2007) (Esselink, Zijlstra, Dijkema, & Van Diggelen, 2000). To stop the rate of succession in the salt marshes grazing cattle's were re-introduced. In most salt-marsh areas there has been chosen for horses but also sheep and oxen were used. The results of the introduction of these grazing cattle's were a decreasing of the rate of succession and more horizontal structure in the vegetation (Bakker J. P., Restoration of salt marshes, 2012) (Dijkema & Van Duin, 2007) (De Groot, Van Wesenbeeck, & Van Loon-Steensma, 2013) (Bakker, et al., 1993) (Esselink, Zijlstra, Dijkema, & Van Diggelen, 2000).

To improve the quality of the ecosystem at the salt marsh by Holwerd-on-Sea the reintroduction of a grazing cattle is necessary. Grazing cattle's clearly have positive effects on the salt-marsh. However there are some risks. The cattle's mainly graze of Sea couch (*Etrygia atherica*). But cattle's also graze the pioneer vegetation. Therefore zoning of the cattle is necessary to protect the most vulnerable vegetation at the lower part of the salt-marsh (Bakker J. P., Restoration of salt marshes, 2012). Another risk of grazing is trampling of vegetation and nest by the large herbivores (Bakker J. P., Restoration of salt marshes, 2012) (Bakker, Esselink, Van Der Weal, & Dijkema, 1997) (De Groot, Van Wesenbeeck, & Van Loon-Steensma, 2013). Especially horses have a large effect on the vegetation and breeding success because of trampling (De Groot, Van Wesenbeeck, & Van Loon-Steensma, 2013) (Mandema, 2014). Because oxen have a smaller negative effect on the breeding bird success than horses, grazing with oxen is preferred. Because of the wet circumstances of the salt marsh Galloway oxen are the preferred choice (IPC Groene Ruimte, 2016) With the reintroduction of cattle Galloway oxen in the salt marsh the rate of succession will be decreased. These measures will lead to a dynamic and vital saltmarsh vegetation. The different stages of the natural succession will be visible. There will grow a salt and grazing tolerating vegetation with species like Sea lavender (*Limonium vulgare)*, Sea thrift (*Armeria maritima)*, Sea couch and Saltbush (*Atriplex spec)* (Schaminee, Sykora, & Horsthuis, 2010).

3.2.2 NEW NATURE

To create a sea lane in the existing salt marsh compensation is necessary (European Commison, 2013). To compensate the loose of salt marsh area there will be a new nature area behind the dyke**.** The agricultural area at the eastside of the lake will be redesigned as a salt marsh. This is possible because of the influence from the salt water off the new lake. The ground will be levelled to increase the influence of the salt water. The new nature will develop into salt tolerating vegetation. With the introduction of salt water into an system it is possible to create a salt tolerating ecosystem (De Groot, Van Wesenbeeck, & Van Loon-Steensma, 2013). In figure 14 is a map of the new nature area.

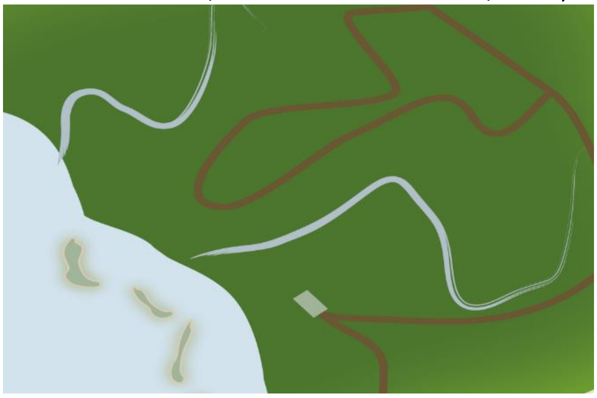

Figure 14 Map of the new nature area at Holwerd-On-Sea

There are examples In the Netherlands of agricultural areas that transform into salt-tolerating ecosystems. The influence of the salt-water into an agricultural area will re-introduce salt tolerated vegetation species. Especially the lower parts of certain areas will transform in a salt tolerated vegetation (Van Duin, et al., 2007). To prevent a high succession rate this area will be grazed too (Van Duin, et al., 2007) (Bakker, Esselink, Van Der Weal, & Dijkema, 1997) (De Groot, Van Wesenbeeck, & Van Loon-Steensma, 2013). Within in four years in the research area from Van Duin et al the area did transform into a salt marsh like vegetation (Van Duin, et al., 2007) . Within ten years the 23 target species for a salt marsh grow within the new salt marsh area. The development of this area is visible in figure 15 (Van Der Eijk & Esselink, 10 jaar kwelderherstel in Noord-Fryslan Butendyks, 2014).

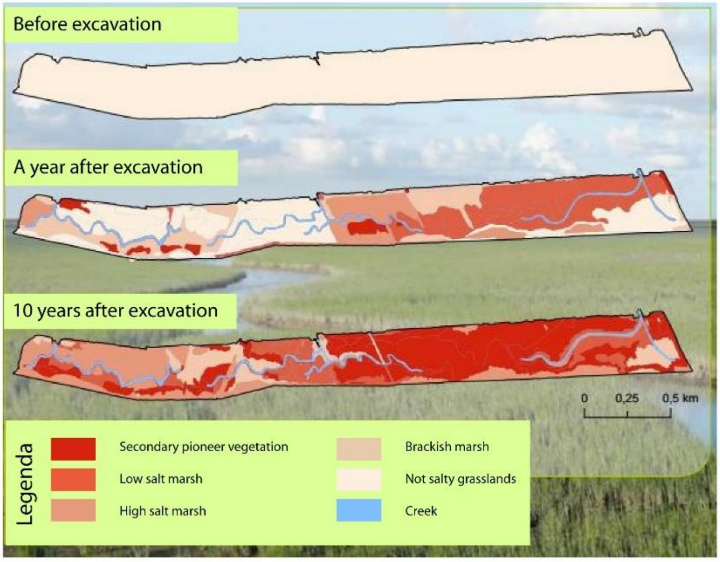

Figure 15 Vegetation development in a new salt marsh (Van Der Eijk & P, 2014

3.2.3.BIRDS

The Waddensea is a unique area for bird species. It is used as rest place for migrating birds. But it's also a hatchery for a lot of birds. Especially the sandbanks in the "Wadden sea" are important for species like eider (*Somateria mollissima*), sandwich tern (*Thalasseus sandvicensis*), artic tern(*Sterna paradisaea*) en common tern (*Sterna hirunda*). These species show all a negative development in the period off 1990-2014 (Netwerk Ecologische Monitoring, 2014). These species have in comment that they breed and foraging on the sandbanks. Because of higher sea levels and more extreme floods these areas are endangered (Ecomare, sd) . To compensate the loss of these areas there will be create an alternative. In the eastside of the lake there will be bird breeding islands. These islands need to be without disturbance by human and therefore need to be at least 300 meter away from human infrastructure (Wymenga & Zwarts L.I, 2013) (Spaans, 1996) . Furthermore the islands need to be dry in case of high water levels. An also the islands need to be within a range of ten kilometers of foraging area of the birds and the area need to be free off wind turbines (Alterra, sd). The pied avocet (*Recurvirostra avosetta*). Is a breeding bird at the saltmarsh. This bird knows an increase in breeding in the period between 1970 and 1990. But since 2000 there is a decrease in the numbers of successful breeding pairs. This decrease is mainly cost by succession in the saltmarsh (Sovon, 2015). The pied avocet will provide off the introducing of grazing cattle's .

3.3 ENERGY

One of the main causes of climate change is burning of fossil fuels. Unsustainable energy is a main emitter of carbon dioxide, which is the prime greenhouse gas. The mining and burning of fossil fuels also harms the environment and the health of the people (Wilkinson, Smith, Joffe, & Haines, 2007). In the year 1750 the atmospheric concentration of carbon dioxide was 280ppm. The last years the concentrations continually rises with 2ppm (Witt, Wild, Anthony, Uthclke, & Diaz-Pulido, 2011).

3.3.1 SUSTAINABLE ENERGY

Wind turbines, hydropower plants and solar energy are the most dominant forms of generating sustainable energy (milieucentraal.nl, 2016). The biggest downside of sustainable energy sources like solar panels and wind turbines is that they are not adaptable to energy demands, unlike hydropower plants. To make the region independent of fossil fuels, for generating electricity a natural battery to store excessive energy is necessary (Heijden, 2015). Hydro- pumped storage plants function as physical batteries, which are able to store excessive energy generated (IEC, 2011).

Hydro-storage plants use excessive energy generated during the night to pump water from a lake to a higher located water reservoir. During the day when the energy demand is high and the price for energy is higher this water flows back to the original source. The water flows through a generator that converts 85% of the kinetic energy the water holds into electricity (IEC, 2011). In Holwerd this process is reversible within the so called 'tidal basin´, using a reversed hydro-storage plant. The efficiency of pumped hydro storage is about 70%, but it allows countries to have a lower nominal generating power output than peak power. Additional energy produced at night is than no longer useful, but is usable when peak power is required (IEC, 2011).

The problem with conventional pumped hydro storage is, that it requires a lot of land and a difference in altitude. The Netherlands is one the most dense populated countries in Europe with 495 citizens per square kilometre in 2011 (Rijksinstituut voor volksgezondheid en milieu, 2014). To tackle this problem the energy storage lake could be placed into the saltwater lake, which will be realized in

Holwerd. A round dam will be placed inside the lake with a depth of 45 meters below N.A.P. this lake can be filled while the kinectic energy of water streaming through the pipe is converted into electrical energy using turbines. The inner lake can be emptied using pumps, when there is more energy available than the net needs. Inholland and teamwork technologies researched this construction for an application in the Markermeer and called it a valmeer, this article however will refer to it as a reversed hydro-pump storage system.. This study forms the basis for an application of such a construction in Holwerd. An artist impression of such a structure is shown in figure 16.

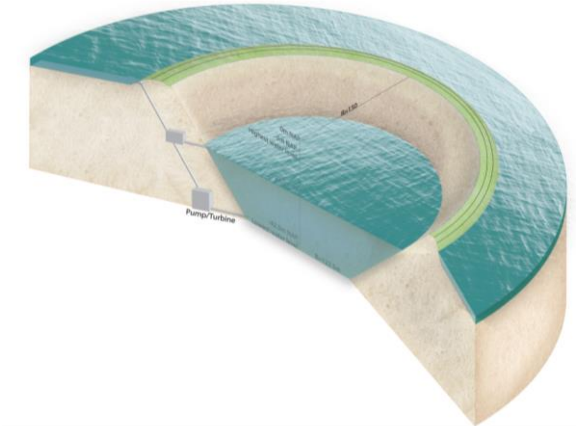

Figure 16 Artist impression reversed hydro pumped storage system

3.3.1 REVERSED HYDRO-PUMP STORAGE SYSTEM

The reversed hydro-pump storage system lets water from the tidal basin in during the day to generate energy. This water flows through turbines to generate energy. During this process the water level within the lake rises. During the night wind turbines provide energy for the pumps to pump this water out during the night. The water level drops so that the energy island can produce energy during the day (Teamwork technology & Hogeschool Inholland, 2015).

Holwerd offers space for a reversed hydro-pump storage system with a diameter of 300 meters, with a depth of 45 metres. To make sure the structure is stable the slope that starts from the bottom of the reversed hydro-pump storage system until NAP will have a ratio of 2:1. This means the bottom of the Reversed hydro-pump storage system has a diameter of 272.5 meter. The total volume of the reversed hydro-pump storage system is $\pi \times 126.25^2 + \pi \times 147.5^2 : 2 \times 30 = 2,207,137.5 m^3$.

A lower level difference means a lower flow, which ultimately lowers the number of possible generators. A kaplan turbine is the most suitable for generating power inside a valmeer, since it operates best if the construction has a low flow and low head. The turbine has an efficiency rate of 85% (Teamwork technology & Hogeschool Inholland, 2015). As is shown in figure 17.

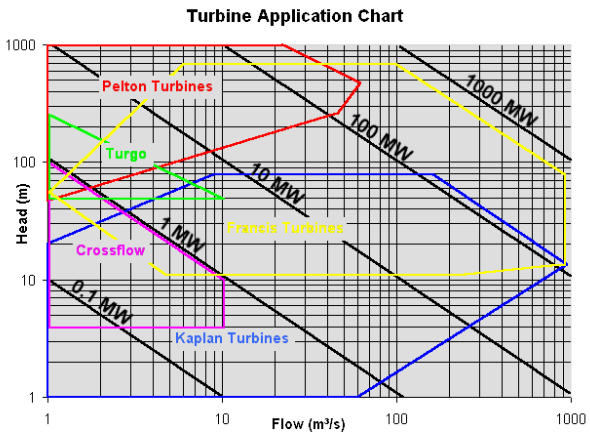

Figure 17 Turbine Apllication Chart

The reversed hydro-pump storage plant empties itself within 9 hours so the flow for the outgoing water needs to be 68,12m^3/s. The reversed hydro storage plant fills itself during the day when the energy demand is at its highest. Full capacity filling is possible between 7AM and 10AM, and from 3PM until 4PM. After that half capacity filling is used with a second turbine between 4PM and 9PM. The flow of the intake during 7AM and 10AM and 3PM and 4PM is 91.96m^3/s. During the other stated times the intake flow is 45.98m^3/s. Energy being delivered to the net, when the demand is high, is worth €11cnt/kw/h, while energy delivered to the net when the demand is low, is only worth €6cnt/kw/h (Teamwork technology & Hogeschool Inholland, 2015).

With this data the power of the pumps and the generators is calculated, using the formula $P* \eta=\phi * \rho*g*h$. This formula translates into flow x density x gravity x mean height. Using an efficiency of 85% for both the pumps and the generators (Muylaert, Inventarisatie Aquatische Biomassa, 2009).

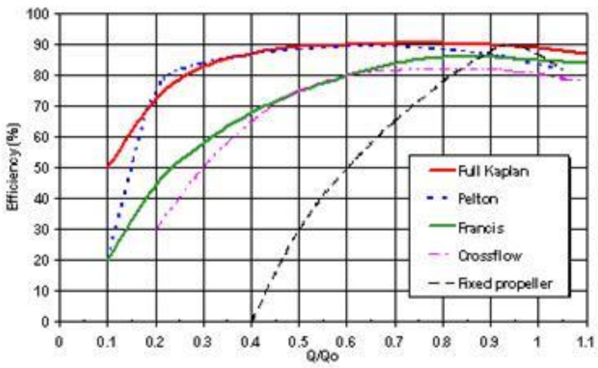

Figure 18 applicability and efficiency of multiple turbine designs

Using an 85% efficiency rate for the turbine gives the following results (91.96 x 1027 x 9.81 x 23.75) x 0.85 = 18.7MW during full capacity filling and (45.98 x 1027 x 9.81 x 23.75) x 0.85 = 9.35MW during half capacity filling (Muylaert, Inventarisatie Aquatische Biomassa, 2009).

On a daily basis, with custom made generators the Reversed hydro-pump storage system could generate 121.55 MW/H a day. Annually the Reversed hydro-pump storage system generates 44.365Mw/H. With an energy price of €0.11 per kw/h, (Muylaert, Inventarisatie Aquatische Biomassa, 2009) the total revenue of the reversed hydro-pump storage system is €4,880,233-. The power necessary to empty the Reversed hydro-pump storage system using pumps with 85% efficiency is bought for €0.06 per kw/h (Muylaert, Inventarisatie Aquatische Biomassa, 2009). The total energy costs for draining the Reversed hydro-pump storage system are 168.25 x 365 x 0.06 = €3,684,353-. Meaning the Reversed hydro-pump storage system will make €1.195.880- income.

Costs of the Reversed hydro-pump storage system

To realize a reversed hydro-pump storage system the mainland of Holwerd needs to be excavated, the ground is build up as followed. The area where the reversed hydro-pump storage system is supposed to be realised lies at 1.22 meters above NAP (ahn.nl, sd).

Depth (ground)[1]	Soil[1]	Volume	Costs m3[2]	Total costs
0 till -5m	Sandy clay	345.000m3	€2.25	€776.250
-5 till -5.5m	Peat`	35.000m3	€3	€115.000
-5.5 till -6m	Sandy clay	34.500m3	€2.25	€77.625
-6 till -6.5m	Peat	34.000m3	€3	€112.000
-6.5 till -46.22m	Sand	2190740m3	€2.25	€4,929,165
Total		2,2191,188		€ 6.010.040

Table 1 Ground layers and costs of removing (dinolket.nl, sd)1 (bodemrichtlijn.nl, sd)2

The ground also needs to be drained of groundwater using depth drainage with an underwater pump. Per 100 square meters a drainage filter is to be applied. This means there are 710 filters necessary to realize the reversed hydro-pump storage system. The costs of a single filter is €150/m, each filter needs to be 50 meters long, this means the cost of each drainage filter is €7.500. Each filter needs to be connected to an underwater pump that costs €4,000 each, but can be sold after the project is finished for about €2.000. The montage and removal costs for the pumps are about €1,000 per pump. The total costs for drainage is (7500 x707) + (3000x707) = 7,423,500 (bodemsanering.nl 2, sd).

The Reversed hydro-pump storage system needs to be non-water permeable; the costs of applying non-permeable foil to the ground are €5 per square meter. The slopes and bottom of the Reversed hydro-pump storage system have a surface area of 45.000m2 (300 x π x 47). The total costs of making the reversed hydro-pump storage system non-permeable are €225,000- (bodemrichtlijn.nl 3, sd).

The pump house will be placed inside the dam of the reversed hydro-pump storage system, this ensures the turbines and pumps are easy accessible. However, a hole and a waterproof staircase need to be made inside the dam to achieve this (Muylaert, Inventarisatie Aquatische Biomassa, 2009). The costs of building the waterproof staircase and rooms for the pump and turbines are estimated on €2.500.000. The costs for the turbine and pump house which are placed inside the same room and the north side of the reversed hydro-pump storage system (Muylaert, Inventarisatie Aquatische Biomassa, 2009). The costs for the turbines, pump, pipelines are based on the study of realizing a reversed hydro-pump storage system in the Markermeer by InHolland Alkmaar and teamwork technologies and are shown in table 2. The main activities to realize a reversed hydro-pump storage system and the total expenses are shown in table 3.

Expense		Unit	Price in [€]
High turbine	Turbine	9 MW	1.000.000
	Pipeline	57 m	2.000
	Gearbox	9 MW	500.000
Low turbine	Turbine	19 MW	1.750.000
	Pipeline	57 m	2.000
	Gearbox	19 MW	1.000.000
Pump	Pomp	20 MW	1.750.000
	Pipeline	70 m	2.000
Valve	Valves	6st	12.000
	Total		6.018.000

Table 2 Costs turbines, pump, valves and pipelines (Muylaert, Inventarisatie Aquatische Biomassa, 2009).

Expense	Costs in €
Excavation	6,000,000
Drainage	7,750,000
Shielding	225,000
Pump house	2,500,000
Pipelines, turbines and pump	6,000,000
Research and other costs	2,525,000
Total	25,000,000

Table 3 Costs turbines, pump, valves and pipelines (Muylaert, Inventarisatie Aquatische Biomassa, 2009)

3.4 FOOD

In this paragraph will be explained how the food industry in the coastal area works and how to change this into a sustainable system.

3.4.1 FOOD IN COASTAL AREAS

A rising sea level means that river deltas and coastal areas will suffer from salt-water inclusion, which will make the cultivation of traditional crops harder (Nelson, et al., 2009). The worldwide climate is not only heating up, it is also destabilizing, meaning that seasons are shifting and patterns of precipitation are changing. This means that dry areas on our planets will become even drier resulting in droughts that will kill crops. Areas that receive more rain like Western Europe will suffer from more intense rainfall, which will flood land with crops (Nelson, et al., 2009). If areas do not adapt to these trends, the level of calorie availability in 2050 will have declined to pre-2000 levels (Nelson, et al., 2009).

Since 1950, the use of phosphor in agriculture has roughly quadrupled. In the next fifty years, phosphor usage will double due to the rising meat consumption and the increasing use of bio fuels. The known phosphor reserves lie in China, US, Morocco and Russia (de Boer & Curie, How the great phosphorus shortage could leave us all hungry, 2016). The phosphor peak production will likely occur in 2030 the year that production cannot keep up with demand. This result into increasing prices, also global reserves will be getting very scarce and increasingly more expensive with the projected increase in phosphor usage (Cordell, Drangert, & White, 2009). In 2015, 223 million tonnes of phosphor was mined and the U.S. Geological Survey, Mineral Commodity Summaries, expects that number to rise to 255 million tonnes in 2019. Companies use most phosphor to make fertilizers, but 43.7 million tonnes of phosphor are mined for chemical purposes, like cleaners and building materials (U.S. Geological Survey, 2016).

3.4.2 VISION ALTERNATIVE FOOD SUPPLY SYSTEM HOLWERD

The former two indentions conclude that Holwerd as a rural coastal region should invest into a food supply system that is circular. The supply system needs to be circular in a way that phosphor will be reused multiple times within the production cycle and will also be reused after the produced food is consumed, digested and has entered the waste stage of the life cycle assessment. Such a design is shown in figure 19.
Holwerd is going to create a saltwater lake by breaking down a part of the dam that separates Northeast Friesland from the Waddenzee and replacing that part by a regulated intake. This saltwater lake along with the climate change will cause the farmlands in Northeast Friesland to become saltier. This means regular cultivations will grow worse and a transition towards either silt cultivations or aquatic saltwater cultivations is necessary for the region. Seaweed, algae and mussels can be cultivated in the Netherlands and could provide a sustainable food supply (ECN), (Muylaert, Inventarisatie Aquatische Biomassa, 2009).

Valorizing waste streams in the region
Due to the extensive use of fertilizers today and even more so in the past, the Dutch soil, surface- and ground water in farmland contains enough phosphate to ensure exponential algae growth for decades. Usually this is seen as a huge problem for the water quality in the Netherlands (STOWA, 2011), (de Boer & Curie, How the great phosphorus shortage could leave us all hungry, 2016), even though it threatens nature reserves, it could very well form an element for seaweed, and mussel cultivation. The latter eats algae that consume phosphates out of the water.

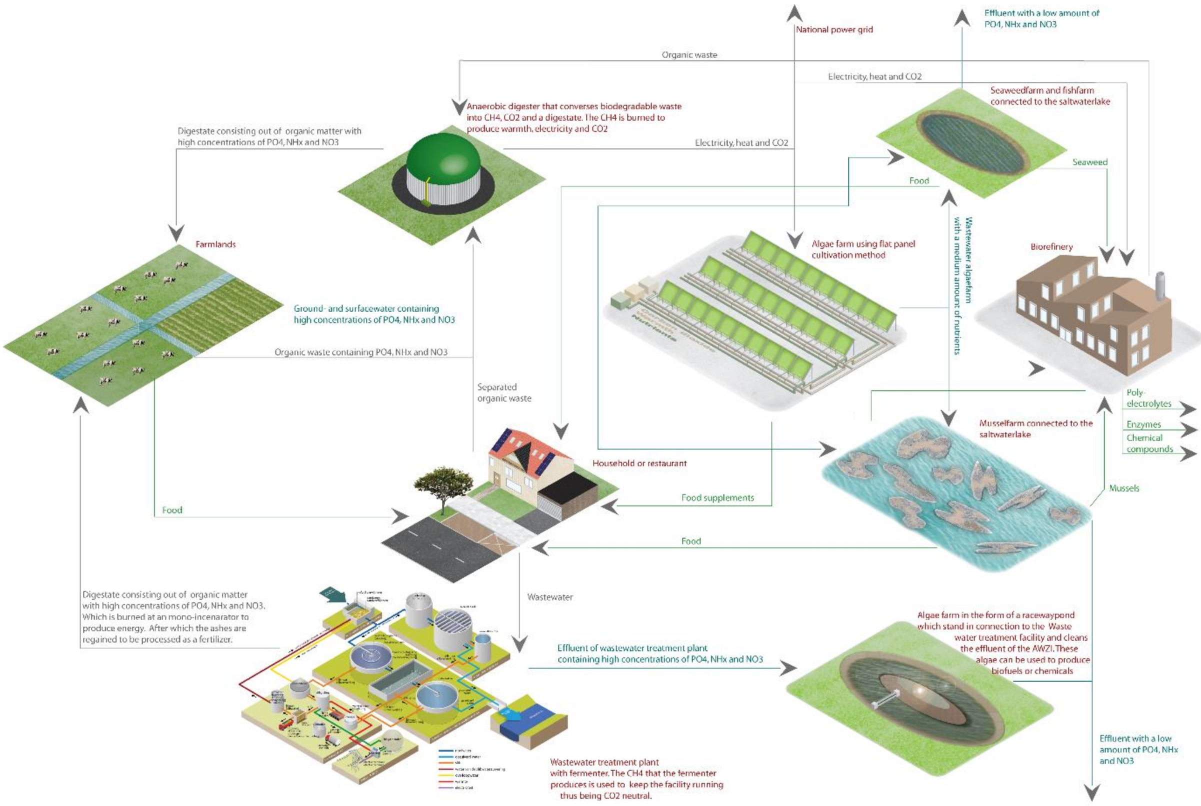

Figure 19 A flowchart of the redesign of the Holwerd food supply

Reusing the digestate of digesters as soil improver
Farmers and others use digesters in the Netherlands to harvest CH_4 out of organic waste using anaerobic bacteria. When a plant is digested by bacteria, the carbon hydrogen structures are broken down to H_2O and CH_4. The CH_4 escapes as gas into the air when farmers and others compost biodegradable waste. In digesters, that gas is won and burned to produce heat, energy and power or cleaned. The digestate contains many nutrients and is usable as a soil improver after a treatment (Agentschap NL, 2010).

Making use of a dry fermentation process a waste processor can break down biodegradable waste from households and biodegradable waste from the agricultural sector (Universiteit Gent, Vito, OWS nv, IGEAN, 2015). These products exist are drier than the feces and urine from livestock that is why the traditional wet fermentation process cannot be used. Until recently, this meant that to ferment biodegradable waste a processor had either to co-ferment this waste along with a livestock's feces and urine or add water to the process so that anaerobic bacteria keep themselves from overheating and killing themselves. In Gent however stands a biodegradable waste fermentation plant that does not use water (Universiteit Gent, Vito, OWS nv, IGEAN, 2015). A similar installation can be realized in Holwerd-On-Sea.

The wet part of the digestate can be processed towards liquid compost, which is valuable for the agricultural business. Meanwhile the dry part of the digestate can be sold as potting soil, which serves as nutrient rich soil improver. The reuse of the digestate prevents peat from being excavated and the additional mining of phosphor ore (Agentschap NL, 2010).

There are different manners to cultivate algae; you can use either a bioreactor or a raceway pond. Open-air cultivation is cheaper in purchase costs than using bioreactors, but bioreactors are more efficient. The most important bioreactors are the flat panel system, the stacked tubes system and the horizontal tubes system (Wolkers, Barbosa, Kleinegris, Bosma, & Wijffels, 2011). A recent study of the Wageningen University shows that the use of the vertical panel bioreactor is the most profitable in the Netherlands. Raceway ponds have the highest running costs per kilogram algae. In other parts of the world where the sun intensity and the temperature is higher the costs of running a raceway pond is considerably less (Wolkers, Barbosa, Kleinegris, Bosma, & Wijffels, 2011).

The cost to cultivate and dry a kilogram alga is €2.50 after harvesting the dry algae mass needs to be refined. Refinery costs for alga are usually €1- to €1.50 per kilogram dry algae mass (wageningenur.nl, sd). After that step, the right compounds that are useful for the food and feed industry need to be separated from the organic tissue. After that step, the food and feed industry can use these compounds in their products (wageningenur.nl, sd). To press the costs and promote symbiosis in Holwerd, the algae farm will be connected to the digester plant using pipelines, which provide CO2, heat and electricity. To provide the algae factory from nutrients it will take in the fresh surface waters that surround Friesland and chemically clean them if necessary.

3.4.3 SEAWEED

Seaweed is a crop that unlike traditional cultivations does not cost agricultural land or fresh water. Seaweed can be used for multiple bio refining steps, for example, a refinery can win the sugars in the cell wands as well as more recalcitrant structures like alginate (wageningenur.nl 2, sd).Within a natural ecosystem, and seaweeds have a yield of 11 metric tons per hectare. When fertilizers are carefully used to grow seaweed, this yield can rise to 45 metric tons per hectare (Muylaert, Inventarisatie Aquatische Biomassa, 2009, p. 41)

There are three classes of seaweed, divided by their pigment. There are brown seaweeds containing 1500 to 2000 different species, red seaweeds containing 4000-10.000 different species and green seaweeds, which count around 7.000 species. Wageningen UR studied the chances for seaweed cultivation in The Netherlands. They found out three species of seaweed would do well in the Dutch North Sea, which the Wadden Sea stands in direct connection with. The species that would do well in the North Sea are *Laminaria digitata* (Finger kelp; brown seaweed), *Palmaria palmata* (Dulse; red seaweed) and *Ulva lactuca* (Sea lettuce; green seaweed) (Muylaert, Inventarisatie Aquatische Biomassa, 2009).

The most promising source of income for seaweed cultivation is to isolate and win soy proteins out of seaweed. Soy is a main ingredient for feeding livestock and is found in the seaweed specie Palmaria palmata (OilWorld, 2010). A metric tonne Palmaria palmata contains enough soy proteins for a market value of €3.000- per metric tonne seaweed. In 2010, The Netherlands imported 2.765.000 tonnes of soy to feed their livestock (PDV, 2014).
To provide nutrients to the seaweed farm it will stand in a regulated connection with the surface water system surrounding Holwerd. It will also receive by the wastewaters of the algae factory and stands in connection with the tidal basin trough a diver.
.

3.4.4 MUSSELS

Mussels could be the most sustainable "meat" product available, especially when those mussels clean the hypertrophic waters of the Dutch farmlands, before they enter another water system. Mussels are very resistant against deceases; the shells of mussels contain mostly out of calcium carbonate, which means they absorb carbon dioxide (more than any other animal with a shell in fact). Insects contain many of the same quality as saltwater mussels. Where consumers accept mussels as food, insects are seen as filthy and scary. In that, respect mussels provide a much safer economic bet to provide as sustainable meat product (Levaux, 2014).

Mussels much like microalgae and seaweeds contain multiple compounds that are useful for industrial ends. Mussels contain polyelectrolyte and enzymes that can be used mainly in the chemical sector. For instance, enzymes are a necessary compound for detergents and pharmaceuticals. Polyelectrolytes are used for dewatering, which is necessary for the pre-treatment in the bio refinery. Dewatering is also one of the steps to make a useful digestate at a fermentation plant. The worldwide market for polyelectrolyte contains€$2x10^9$ revenue; the worldwide revenue for enzymes is €$5x10^9$ (Alpha Enzymes, 2015).

To provide nutrients and algae to the artificial mussel beds they will stand in a regulated connection with the surface water system surrounding Holwerd. It will also receive the wastewaters of the seaweed farm and stands in connection with the tidal basin trough a diver.

Wastewater treatment plant
Eventually food related products in Holwerd would be discarded via either the sewage or through the collecting of separated organic waste. With the latter, the products will be fermented. If these products reach the wastewater treatment plant, through the sewage the products will be processed there. Inside the wastewater treatment plant, the nutrients either will be stored in sewage or be broken down by bacteria. A mono incinerator will burn the sewage sludge from the wastewater treatment plant to produce energy. The ashes that come free during this process are reclaimable and can be converted into a fertilizer, which can be used in Holwerd and the region northeast Friesland to close the phosphor cycle (STOWA, 2011).

3.5 TOURISM AND LIVEABILITY

The development of nature area will increase the number of tourists. With floating walkways in the saltmarsh the tourist can walk through the nature in all seasons. The floating walkways make the wet salt marshes easy accessible for tourists. The floating walkways are already applied in other wetlands in the Netherlands (Natuurmonumenten, sd). In the new nature are will be a bird observatory (figure 20). The bird observatory offers tourists the opportunity to watch the breeding birds. These opportunity gets tourists nowadays only on sea. With the bird islands located close to the mainland this will b a unique spot to watch breeding birds.

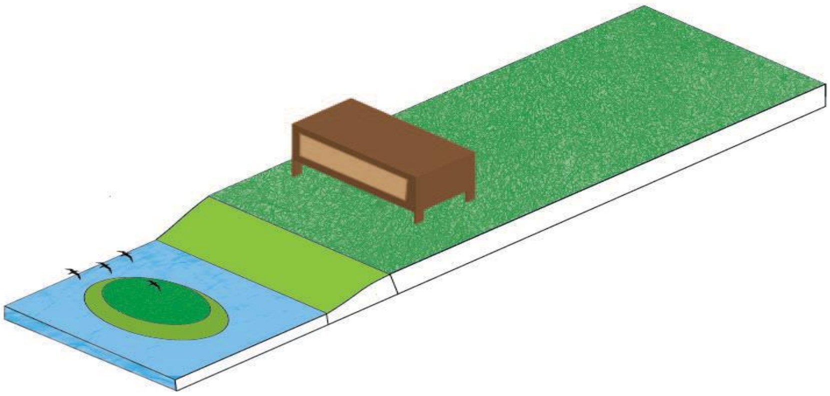

Figure 20 Sketch of the bird obsevatory in the new nature area

Besides nature tourism, Holwerd-on-Sea will be an important place for water tourism. Holwerd-on-Sea is the new connection between the lakes and channels of Friesland and the sea. In Germany are different examples of villages the profit from this kind of connections. Based on estimates made by experts from 'Holwerd On Sea" with 500 new possibilities for nights there will be an increase in the income for Holwerd-On-Sea from 5000000 euro (Holwerd Aan Zee, sd). The increase in numbers of tourists create opportunities for local entrepreneurs to start restaurants and shops. The old decayed village centre will be a great location for entrepreneurs to open restaurant, shops, hotels and bed and breakfast. Besides the old centre there will be a new "hotspot" for the village. This will be a new boulevard at the south side of the lake. This boulevard will be a good location for restaurants and shops. The boulevard will also serve as place to moor recreation ships. In figure 21 is a sketch of the boulevard visible.

Figure 21 Sketch of the boulevard between Holwerd and the lake

4 DESIGN

In this chapter the future of Holwerd is visualized in figure 22.

Figure 22 Integral design of Holwerd-On-Sea

The northern part of the area will be an important part of the UNESCO world heritage site. Important parts of the redesign are the new shell banks and the recovered salt marsh. At the east of the dam to the fair boat is the new channel visible. The created gap in the dike is been replaced with a sluice. Center part of the redesigned area is the newly created lake. The west-side of the lake will be the area for the new circulated food industry and the production of energy. At the eastside the new nature area with a salt marsh and the breeding islands is visible. At the Southside of the lake is Holwerd-On-Sea located with the new boulevard. At the eastside of Holwerd is the fish ladder and sluice visible that created the connection between the lakes and channels of Friesland.

5 CONCLUSION

A new integral design offers opportunities for Holwerd-On-Sea. Water safety is maintained using natural building stones in combination with the existing dyke and the new sluice. The existing dredging costs are lowered and fish migration between the Wadden Sea and the fresh waters of will be possible again, due to a fish ladder. Likewise recreational ships can travel between the Wadden Sea and the fresh surface water system of Friesland again.

The salt marsh will be recovered and the losses of area salt marsh and the endangered bird breeding areas in the Waddensea will compensate at Holwerd-On-Sea. The new design offers new opportunities for nature and water recreation, what will improve the local economy.

The area's cultivations and food supply system need to adapt to salt-water intrusion and climate change. Holwerd can do that by focussing on a circular food economy in which seemingly waste streams are valorised, towards a product or a nutrient or material.

Holwerd will store sustainable energy generated at night using a reversed hydro pumped storage. This system will ensure net stability. Ad a higher peak nominal output when required.

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REFERENCES

(2016, 10 04). Retrieved from Gabionsystems LCC: http://www.gabionsystems.com/oysterProducts.html

Agentschap NL. (2010). *Naar een betere toepassing van het digestaat.* Utrecht: Ministerie van economische zaken.

ahn.nl. (n.d.). Retrieved 09 17, 2016, from http://ahn.arcgisonline.nl/ahnviewer/

Alpha Enzymes. (2015). *MIT verslag: Mosselreststroom als grondstof. (voor enzymen en polyelectroliet).*

Alterra. (n.d.). *Natura2000*. Retrieved 7 27, 2016, from alterra.nl: http://www.synbiosys.alterra.nl/natura2000/

Asplund, T. R. (2000). *The Effects of Motorized Watercraft on Aquatic Ecosystems.* Madison, US: Wisconsin Department of Natural Resources.

Bakker, J. P. (2012). *Restoration of salt marshes.* Blackwell Publishing.

Bakker, J. P., Esselink, P., Van Der Weal, R., & Dijkema, K. S. (1997). Options for restoration and management of coastal salt marshes in Europe. *Restoration Ecology and Sustainable Development*, 268-318.

Bakker, J., De Leeuw, J., K.S, D., P.C, L., Prins, H., Rozema, & J. (1993). Salt marshes along the coast of The Netherlands. *Hydrobiologia*.

bodemrichtlijn.nl. (n.d.). Retrieved 09 17, 2016, from http://www.bodemrichtlijn.nl/Bibliotheek/bodemsaneringstechnieken/c-grondverzet/c2-open-ontgraven/open-ontgraven-kosten-verwijderen-grond

bodemrichtlijn.nl 3. (n.d.). Retrieved 09 17, 2016, from http://www.bodemrichtlijn.nl/Bibliotheek/bodemsaneringstechnieken/f-isolatie/f2-methode-bovenafdichting/factsheet-bovenafdichting-met-kunststoffolie

bodemsanering.nl 2. (n.d.). Retrieved `09 17, 2016, from http://www.bodemrichtlijn.nl/Bibliotheek/bodemsaneringstechnieken/c-grondverzet/c2-open-ontgraven/open-ontgraven-kosten-bemaling

Cordell, D., Drangert, J.-O., & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global environmental change, 19*(2), 292-305.

de Boer, M., & Curie, M. (2016, 02 11). How the great phosphorus shortage could leave us all hungry. *The conversation*.

de Boer, M., & Curie, M. (2016, 02 11). *How the great phosphorus shortage could leave us all hungry*. Retrieved from theconversation.com: http://theconversation.com/how-the-great-phosphorus-shortage-could-leave-us-all-hungry-54432

De Groot, A. V., Van Wesenbeeck, B. K., & Van Loon-Steensma, J. M. (2013). *Stuurbaarheid van kwelders.* Wageningen: IMARES Wageningen UR.

(2015). *Deltaprogramma.* Den Haag: Ministerie van Infrastructuur en Milieu, Ministerie van Economische Zaken.

Dijkema, K., & Van Duin, W. (2007). 50 jaar monitoring van kwelderwerken. *De Levende Natuur*, 118-122.

Dijkman, R. (2013). *Vaargeul Holwerd-Ameland, aanpakken of blijven aanmodderen.* Leeuwarden: Rijkswaterstaat, Ministerie nvan Verkeer en Waterstaat.

dinolket.nl. (n.d.). Retrieved 09 17, 2016, from https://www.dinoloket.nl/ondergrondmodellen

Doornbos, A. (2012). *Kwelders als golfslagbreker.* Leeuwarden: Provincie Groningen.

ECN. (n.d.). *Fotobioreactor-technologie voor algenteelt.* Retrieved 11 07, 2016, from https://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publicaties06.pdf

Ecomare. (n.d.). *Zeespiegelstijging*. Retrieved 11 7, 2016, from ecomare.nl: http://www.ecomare.nl/ecomare-encyclopedie/natuurlijk-milieu/waterhuishouding/zeespiegelstijging/

Esselink, P., Zijlstra, W., Dijkema, K., & Van Diggelen, R. (2000). The effects of decreased management on plant-species distribution patterns in a salt marsh nature reserve in the Wadden Sea. *Biological Conservation*, 61-76.

European Commison. (2013). *Interpration manuel of European habitats.* European Commison.

Google. (n.d.). *maps.google.com*. Retrieved from maps.google.com: https://www.google.nl/maps/place/Holwerd/@53.3633274,5.8624711,8213m/data=!3m1!1e3!4m5!3m4!1s0x47c9070c43666e4b:0x1a20c28c7a4d4990!8m2!3d53.3683775!4d5.9005378

Griendhout producten. (2016, 11 05). Retrieved from Van Aalsburg Griendhouthandel: http://www.griendhouthandel.nl/nl/griendhout-producten/kraagstukken/

H. Vereecken, P. P. (2008). *Waterbeheer in Oost- en West Vlaanderen.* Antwerpen: Waterbouwkundig Laboratorium.

(2008). *Habitatrichtlijn.* Ministerie van LNV.

Heijden, R. v. (2015, 07 15). *Stop meer energie in energieopslag*. Retrieved from Kennislink: http://www.nemokennislink.nl/publicaties/stop-meer-energie-in-energieopslag

Holwerd Aan Zee. (n.d.). *Toerisme en recreatie*. Retrieved 11 7, 2016, from holwerdaanzee.nl: https://www.holwerdaanzee.nl/nld/over-haz/project/pijler-4-recreatie-en-toerisme

IEC. (2011). *Electrical Energy Storage .*

Innovatie Estafette. (2016, 11 10). Retrieved from Innovation Expo Sustainable Urban Delta: http://www.innovatie-estafette.nl/article/10185/Opvallende-waterinnovaties-scheidingssysteem-zoet-en-zout-water-en-tijdelijke-waterkeringen

IPC Groene Ruimte. (2009). *Cursus Grofwildbeheer.* Arnhem: IPC Groene Ruimte.

IPC Groene Ruimte. (2016). *Grofwildbeheer.* Schaarsbergen: IPC Grone Ruimte.

Kahn, B. (2016, 06 15). *climatecentral.org*. Retrieved from climatecentral.org: http://www.climatecentral.org/news/antarctica-co2-400-ppm-million-years-20451

Kauwen, L. v. (2010). *Verkenning naar de gevolgen van klimaatverandering en klimaatadaptatiemaatregelen op KRW en Natura 2000 maatregelen en doelen.* Deltares.

Kosten-batenanalyse sluizencomplex Kornwerderzand. (2016, 11 10). Retrieved from Bis, Zwolle: http://bis.zwolle.nl/cms/Bis.nsf/F65091717A464163C1257C910055DFD7/$File/02_%20Sluizencomplex%20Kornwerderzand%20casus.pdf

Kranenbarg, J. (2005). *Quick-scan hydromorfolgische herstelmaatregelen voor vis in overgangswateren.* Delft: WL Delft Hydrauclis.

Levaux, A. (2014, 10 24). *alternet.org*. Retrieved from http://www.alternet.org/food/mussels-may-be-worlds-most-sustainable-meat-so-be-smart-and-buy-fresh-ones

Mandema, F. S. (2014). *Grazing as a nature management tool.* Groningen: Rijksuniversiteit Groningen.

milieucentraal.nl. (2016, 09 02). Retrieved from https://www.milieucentraal.nl/klimaat-en-aarde/energiebronnen/

Ministerie van de Vlaamse Gemeenschap. AMINAL, A. W. (2005). *Vismigratie ,een handboek voor herstel in Vlaanderen en Nederland .* Brussel: Heirma, Jean-Pierre.

Ministerie van Economische Zaken. (2016, 10 02). Retrieved from sybiosys.alterra.nl: http://www.synbiosys.alterra.nl/natura2000/documenten/profielen/habitattypen/Profiel_habitattype_1140.pdf

Muylaert, K. (2009). Inventarisatie Aquatische Biomassa. *AcuaticBiology*.

Muylaert, K. (2009). Inventarisatie Aquatische Biomassa. *AcuaticBiology*.

Natuurkennis.nl. (n.d.). *Kwelder & schol*. Retrieved 7 27, 2016, from natuurkennis.nl: http://www.natuurkennis.nl/index.php?hoofdgroep=2&niveau=4&subgroep=108&subsubgr

Natuurmonumenten. (n.d.). *Vlonderpad De Wieden*. Retrieved 11 2016, 7, from natuurmonumenten.nl: https://www.natuurmonumenten.nl/natuurgebied/nationaal-park-weerribben-wieden/route/vlonderpad-bij-bezoekerscentrum-de-wieden

Nelson, G. C., Rosegrant, M. W., Jawoo, K., Robertson, R., Sulser, T., Zhu, T., . . . Lee, D. (2009). *Climate change, Impact on Agriculture and Costs of Adaptation.* Washington DC: International food policy research instiitute.

Netwerk Ecologische Monitoring. (2014). *Vogels per Gebied, Natura 2000 gebied Waddenzee*. Retrieved 7 27, 2016, from Sovon.nl: https://www.sovon.nl/nl/gebieden

OilWorld. (2010). Major meals, World summary balances. *Oil World Weekly, 55*(3), p. 45.

OysterProducts. (2016, 10 04). Retrieved from Gabionsystems LCC: http://www.gabionsystems.com/oysterProducts.html

PDV. (2014). *pdv.nl*. Retrieved 09 03, 2014, from www.pdv.nl

Prins, M. (2013, 11 01). Tilburg krijgt grootste composiet sluisdeuren ter wereld. *Brabants Dagblad*, p. 1.

Rijksinstituut voor volksgezondheid en milieu. (2014). *Bevolking: Zijn er verschillen tussen Nederland en andere landen?*

Rijksoverheid. (2015). *Nationaal Waterplan.* Den Haag: Ministerie van Infrastructuur en Milieu, Ministerie van Economische Zaken.

Rijkswaterstaat. (2011). *Natura 2000 doelen in de Waddenzee.* Noord Nederland: Rijkswaterstaat.

Rijkswaterstaat. (2011). *Natura 2000-doelen in de Waddenzee.* Noord Nederland: Rijkswaterstaat.

Rijn, L. v. (2016). *FLUID MUD FORMATION.*

Schaminee, J., Sykora, K. S., & Horsthuis, M. (2010). *Veldgids plantengemeenschappen van Nederland.* Zeist: KNNV.

Soortenbank. (n.d.). *Driedoornige stekelbaars*. Retrieved 9 26, 2016, from soortenbank.nl: http://www.soortenbank.nl/soorten.php?soortengroep=zoetwatervissen&id=61&menuentry=soorten

Soortenbank. (n.d.). *Fint*. Retrieved 9 26, 2016, from Soortenbank.nl: http://www.soortenbank.nl/soorten.php?soortengroep=zoetwatervissen&id=25&menuentry=soorten

Soortenbank. (n.d.). *Paling*. Retrieved 9 26, 2016, from Soortenbank.nl: http://www.soortenbank.nl/soorten.php?soortengroep=duikgids&id=72&menuentry=soorten

Soortenbank. (n.d.). *Spiering*. Retrieved 9 26, 2016, from Soortenbank.nl: http://www.soortenbank.nl/soorten.php?soortengroep=zoetwatervissen&id=63&menuentry=soorten

Sovon. (2015). *Kluut*. Retrieved 7 27, 2016, from sovon.nl: https://www.sovon.nl/nl/soort/4560

Spaans. (1996). *Effecten van verstoring door mensen op wadvogels in de Oosterschelde.* Texel.

Sportvisserij Nederland. (n.d.). *Zeebaars*. Retrieved 9 26, 2016, from Sportvisserij Nederland: http://www.sportvisserijnederland.nl/vis-water/vissoorten/140/zeebaars.html

STOWA. (2011). *Fosfaatterugwinning in communale afvalwaterzuiveringsinstallaties.* Stowa.

Teamwork technology & Hogeschool Inholland. (2015). *Project valmeer.* Alkmaar.

thameswater.co.uk. (2013, 11 6). Retrieved from http://www.thameswater.co.uk/media/press-releases/17393.htm

U.S. Geological Survey, M. C. (2016). *Mineral Commodity Summaries.*

UNESCO. (n.d.). *Wadden Sea*. Retrieved 11 7, 2016, from whc.unesco.org: http://whc.unesco.org/en/list/1314

Unesco werelderfgoed. (2016, 11 05). Retrieved from Wadden.nl: http://www.wadden.nl/wadden/unesco-werelderfgoed

Universiteit Gent, Vito, OWS nv, IGEAN. (2015). *DROGE ANAEROBE VERGISTING VAN BERMGRAS, IN COMBINATIE MET GFT +.*

Van Der Eijk, A., & Esselink, P. (2014). *10 jaar kwelderherstel in Noord-Fryslan Butendyks.* Heerenveen: SMG Groep.

Van Der Eijk, A., & P, E. (2014). *10 jaar kwelderherstel in Noord-Fryslan Butendyks.* Heerenveen: SMG Groep.

Van Duin, W., & Dijkema, K. B. (2007). *Cyclisch beheer kwelderwerken Friesland.* Leeuwarden: Rijkswaterstaat.

Van Duin, W., Esselink, P., Bos, D., Klaver, R., Verweij, G., & Leeuwen, V. (2007). *Proefverkweldering Noard-Fryslân Bûtendyks.* Wageningen: IMARES WAGENINGEN UR.

van Loon-Steensma, J. (2015). Salt marshes to adapt the flood defences along the Dutch Wadden Sea coast. *Mitigation and Adaption Strategies for Global Change*.

Veilinga, H. e. (2015). *Kennistafel 'Spoelmeer Holwerd aan Zee'.* Leeuwarden: Provincie Leeuwarden.

wageningenur.nl. (n.d.). Retrieved 05 25, 2016, from http://www.wageningenur.nl/nl/Expertises-Dienstverlening/Leerstoelgroepen/Agrotechnologie-en-Voedselwetenschappen/Bioprocestechnologie/Profielwerkstuk/Algemene-informatie.htm

wageningenur.nl. (n.d.). Retrieved 05 25, 2016, from http://www.wageningenur.nl/en/Expertise-Services/Facilities/AlgaePARC/News/Show/Costeffective-algae-production-within-reach.htm

wageningenur.nl 2. (n.d.). Retrieved 05 25, 2016, from http://www.wageningenur.nl/en/Expertise-Services/Facilities/AlgaePARC/News/Show/Costeffective-algae-production-within-reach.htm

wageningenur.nl 2. (n.d.). Retrieved 08 2016, 30, from https://www.wageningenur.nl/en/article/Promising-seaweed-biorefinery.htm

Waterman, R. (2010). *Integrated Coastal Policy via Building with Nature.* Delft: Technische Universiteit Delft.

wfp.org. (n.d.). Retrieved 08 22, 2016, from https://www.wfp.org/climate-change/climate-impacts

Wilkinson, P., Smith, K. R., Joffe, M., & Haines, A. (2007). A global perspective on energy: health effects and injustices. *The Lancet, 370*(9591), 965-978.

Witt, V., Wild, C., Anthony, R. N., Uthclke, S., & Diaz-Pulido, G. (2011). Effects of ocean acidification on microbial community composition of, and oxygen fluxes through, biofilms from the Great Barrier Reef. *Environmental microbiology, 13*(11), 2976–2989.

Wolkers, H., Barbosa, M., Kleinegris, D. M., Bosma, R., & Wijffels, R. ,. (2011). *Microalgen: het groene goud van de toekomst?* Wageningen: Wageningen UR Food & Biobased Research.

Wymenga, E., & Zwarts L.I. (2013). *Mogelijke effecten op vogels van openstelling van de binnenkant van de Balgzanddijk.* Feanwalden: Altenburg & Wymenga ecologisch onderzoek.