Sustainable scenarios for the Southwest Delta based on Building with Nature strategies

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Client	Project	Reference	Pages
Ecoshape, Building with Nature	1202061-000	1202061-000-BGS-0002	118

Summary
The Building with Nature innovation programme aims to build hydraulic infrastructure utilizing the dynamics of the natural system. The Southwest Delta is one of the focus areas for the programme. The Dutch Southwest Delta is protected from storm surges by a series of ingenious engineering works: The Delta Works. Although keeping the Delta safe, the Delta Works have negative side effects. These include sand starvation in the Eastern Scheldt and ecological- and water quality issues in the former dammed estuaries. This situation is not sustainable.
Most Building with Nature measures are until now applied on a small scale: local ecological dike reinforcement, innovative nourishment strategies or a pilot for oyster reefs. In this report, we focus on the large-scale and long-term application of Building with Nature measures, i.e. on the scale of the Southwest Delta. For this purpose, three extreme scenarios are developed which illustrate outcomes of applying Building with Nature measures from a delta-wide perspective in the Southwest Delta. The natural scenario approaches the issues from a natural perspective (i.e. giving space to the estuarine processes), the Offensive Scenario approaches the issues from an offensive perspective (reshaping the entire Delta into a manageable but safe design) and the Defensive scenario approaches the issues from a defensive perspective (i.e. leaving the Delta as it is, but applying the currently used Building with Nature measures on the large scale).
The scenarios are assessed using a cost-benefit analysis. This analysis shows that, considering the costs, reshaping the Southwest Delta takes an investment, but is, even when applying these extreme scenarios, feasible. It also shows that continuing the present small scale approach also requires a big investment and leads to a less sustainable and less resilient Southwest Delta on the long term.
The considered scenarios are extremes, but within these extremes a wealth of more realistic opportunities for the Southwest Delta is possible. The document is meant to inspire policy makers and shows that Building with Nature techniques applied on the large scale opens promising pathways to the future

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Appendices

1 Introduction to this study

1.1 Background

Following a destructive flood in 1953, the Dutch Government decided to realize a series of closure dams to protect the Southwest Delta from the sea. These Delta Works made the Delta safer, increased mobility and created several freshwater lakes, which provided water for drinking and agriculture. Unfortunately, the Delta Works also resulted in a degradation of the water quality and in ecological problems. These ecological problems include the excessive growth of blue-green algae (cyanobacteria) in the freshwater Volkerak-Zoom lake (Verspagen et al., 2006), eutrophication of dammed estuaries such as the Markiezaatmeer and anoxic conditions in the Grevelingen (Lenkeek et al., 2007). Furthermore, in the Oosterschelde the Delta Works led to loss of intertidal habitats due to a decrease in tidal range (a process called “sand starvation”; Van Zanten en Adriaanse, 2008). In the Westerschelde, the impact of channel deepening and the associated compensation measures are a challenge. Climate change and associated sea-level rise will pose new challenges to the area. In order to deal with all the expected geomorphological and ecosystem changes and to make the Southwest Delta a sustainable (climate proof and safe), ecologically resilient and economically vital region, the current coastal-infrastructure and water-management practices have to be adapted. To address these issues, as well as future effects of climate change and sea-level rise, possibilities for restoring estuarine dynamics, salinity gradients and connectivity between water bodies are currently investigated by the Dutch government (Stuurgroep Zuidwestelijke Delta, 2010).

In general, the abovementioned problems are unwanted side effects of human measures taken in light of safety or economical development. In the coming century, effects of climate change, such as accelerating sea-level rise, increasing peak river discharges and increasing sea-water temperature, will exert a larger pressure on the system. This will influence the distribution and functioning of habitats and ecosystems of the Southwest Delta. These developments call for a coastal strategy that is more in line with functioning of the coastal ecosystem (Figure 1.1). *Building with Nature* is an innovation programme driven by cooperate enterprises (Ecoshape) that aims to build hydraulic infrastructure utilizing the dynamics of the natural system. Simultaneously, opportunities are created for enhancement of the ecological system, and for new functions and multifunctional use. Moreover, Building with Nature implies designing and constructing infrastructure while taking into account the values of nature.

The concept of Building with Nature can be applied on a range of spatial and temporal scales: from improving the ecological value of a stretch of dyke to influencing an entire delta, and from anticipating to unwanted side effects of hard structures on the scale of years, to a multi-decadal approach to dynamically reinforce the entire Dutch coast. The question therefore arose: would it be possible to design scenarios for the long-term future of the ZW Delta which make use of Building with Nature techniques on a large scale and what would this learn for possible pathways to a sustainable future?

Figure 1.1 A schematic overview of a delta: traditional (left) versus more sustainable (right) human use of a delta more aimed at conservation and smart utilization of natural processes (Reker et al., 2006).

1.2 Motive for this study

The concept of Building with Nature appears to generate interesting alternatives for the adaptation of the Netherlands to climate change and associated sea-level rise. Building with Nature solutions, such as oyster reefs to reduce coastal erosion, nourishments and rich revetments have been investigated on pilot scale. However, the advantages of applying Building with Nature have not been fully pursued. Therefore, in this project a comprehensive review is made from the costs and benefits of Building with Nature measures. In addition, to explore the advantages on the large scale and the long term, scenarios for the entire Southwest Delta guided by Building with Nature are explored and analysed using a cost benefit analysis. In the analysis, the performance of the scenarios under differing rates of climate change is also investigated.

1.3 Aim

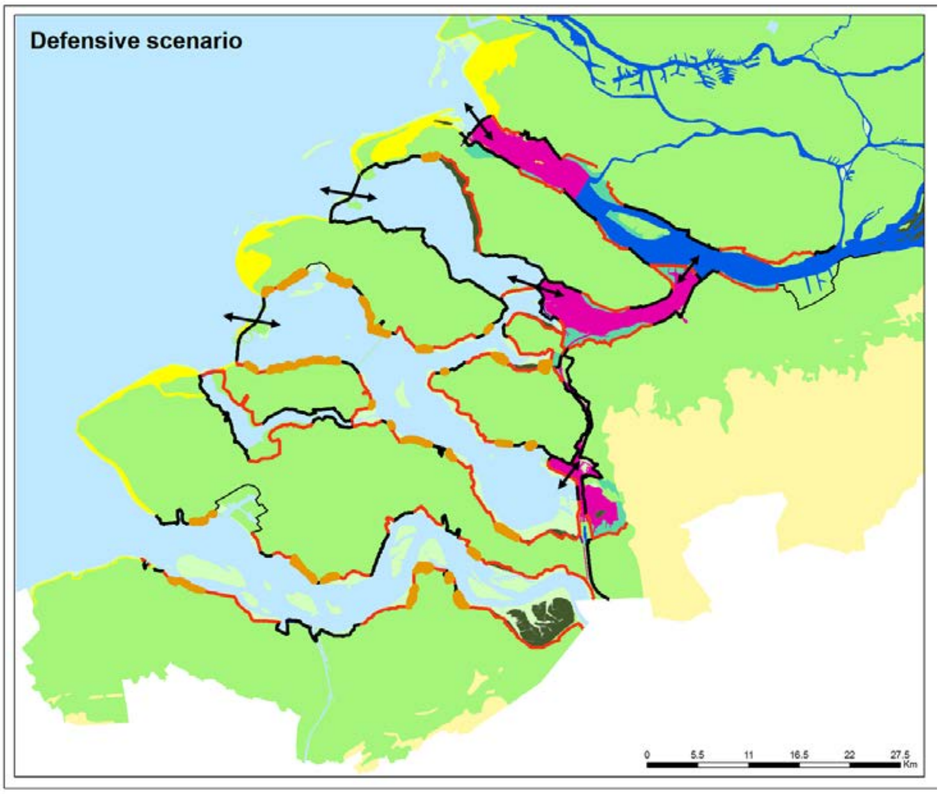
This report describes the outcome of a study on opportunities for long term (2100) sustainable scenarios based on Building with Nature solutions in the Southwest Delta of the Netherlands are investigated. The aim of this investigation is to inspire the public debate with strategies for system development in the entire Southwest Delta from a Building with Nature perspective. Building with Nature is explored by three “extreme” scenarios, each of which applies a distinctive set of Building with Nature solutions and measures over the course of one century. These scenarios are designed to explore boundaries of the feasible and the unfeasible. Subsequently, the scenarios are assessed using a cost-benefit analysis (CBA). This analysis will enable comparison between the scenarios and the Building with Nature solutions applied and will help to create insight in (cost)effective methods and strategies for a safe, economically vital and ecologically resilient South West Delta, as is pursued as long term goals by the Deltaprogramme for the Southwest Delta (Deltaprogramma Zuidwestelijke Delta, 2010).

1.4 Approach

The development of a long-term vision for the Southwest Delta, based on Building with Nature principles, was based on the following approach:
First, an inventory was made of the present day problems of the Southwest Delta, and the problems arising from autonomous trends like sea-level rise, surface subsidence and changing river discharge (Appendix A). Subsequently, for inspirational purposes and in order to get a feeling for the processes and dynamics acting on the long term, the paleogeography of the area was analysed and summarized (Appendix C). From these reconstructions general rules for Building with Nature on the long term and large scale were inferred. Subsequently, three extreme future scenarios were designed in which Building with Nature solutions are implemented on the large scale in the Southwest Delta, to address the problems identified in the previous stage. Each of these scenarios is based on a certain mind-set towards nature (enable nature, control of nature and conserve present values). The scenarios were chosen in such a way that together they span roughly all foreseeable policy and management possibilities for the coming century. Real policy and management scenarios will most likely be less extreme than the chosen scenarios and a first implication of their effects can be derived from this study, by linear interpolation between the scenarios discussed. The scenarios each consist of a selection of Building with Nature solutions implemented on the large scale and they contribute to a more sustainable delta on the long-term. The Building with Nature solutions, here used as Building Blocks as basis for the scenarios, were worked out in detail in Factsheets (Appendix B). These factsheets contain a review of the costs and benefits associated with the measures.

The extreme scenarios designed here are (Figure 1.2):

- Defensive scenario: continuation of current safety strategy and focus on preservation of current values (control scenario).
- Offensive scenario: focus on control of natural processes to maximize safety and human benefit.
- Natural scenario: focus on space and utilization of natural processes.


Defensive scenario
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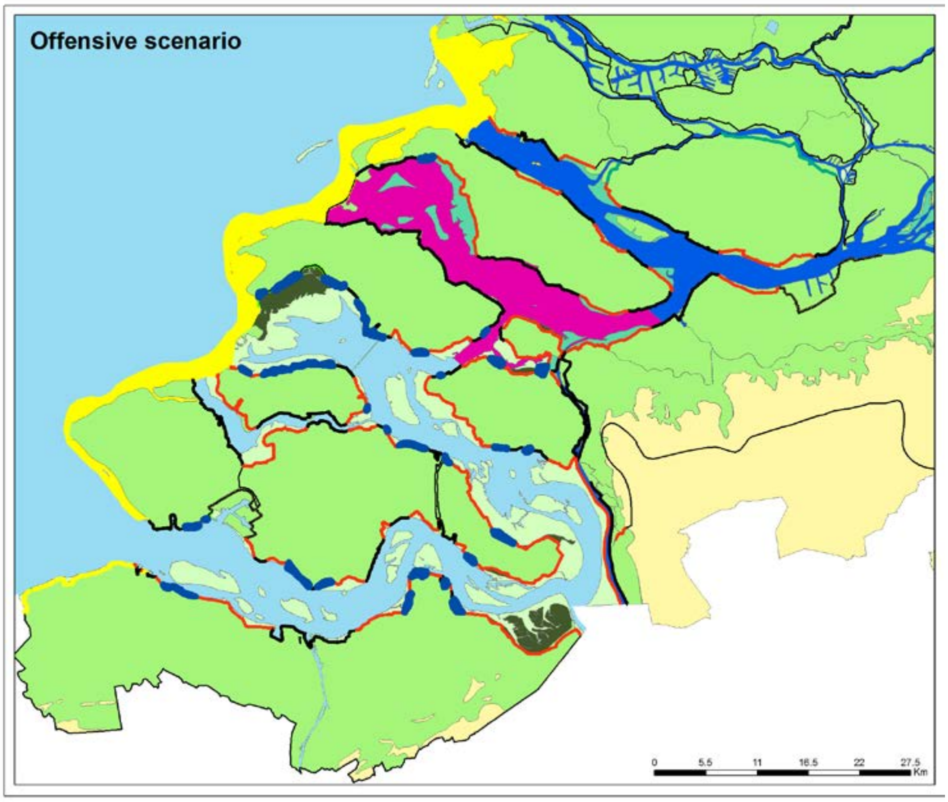
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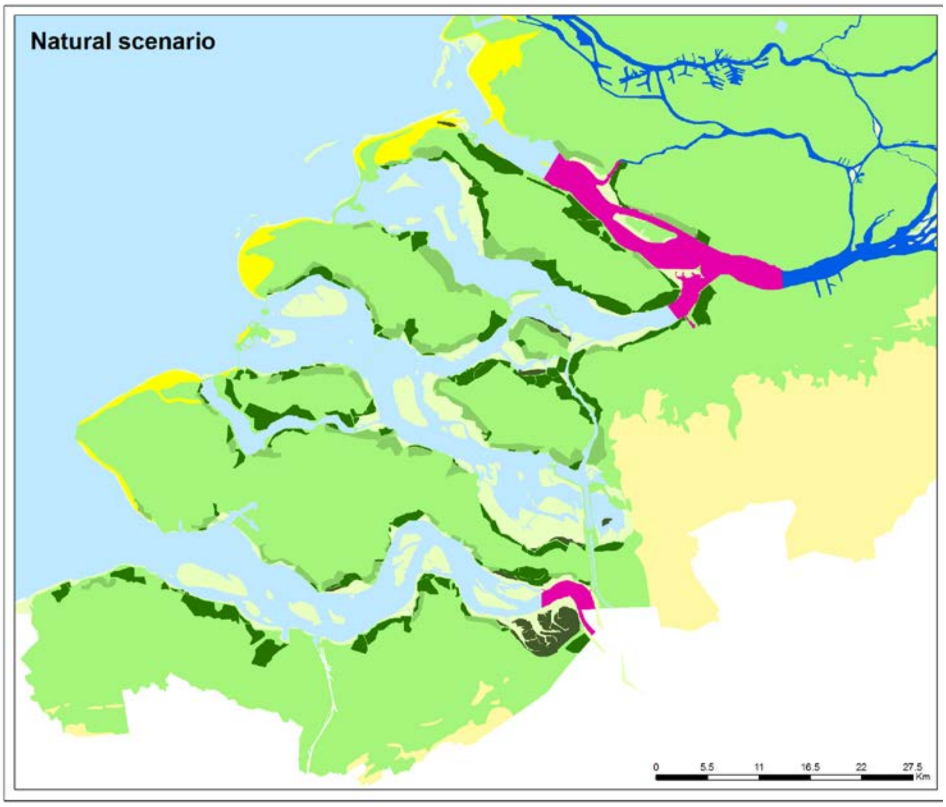


Figure 1.2 Overview of the three extreme scenarios: Defensive, Offensive and Natural scenario. Larger images of the scenarios including legends are provided in Chapter 4.

1.5 Cost Benefit Analysis

In a cost-benefit analysis financial impacts, environmental impacts and social impacts are considered. An attempt was made to express all the impacts in monetary terms (money). The advantage is that all impacts can be added so that it becomes clear if an investment has a positive or negative balance. When the balance of a project is positive, the investment is socio-economically sound. Because most impacts are expressed in monetary terms, different alternative projects can be compared with each other.

In the case of Building with Nature projects, a CBA can shed light on the advantages and the disadvantages, not only of the project alternatives but also of the individual Building with Nature solutions used within these alternatives. Some solutions may be cheaper or more durable because they make use of natural dynamics or materials. Others can be more expensive but can be favourable because they yield added values. And perhaps some solutions have to be discarded because the investments are larger than the added value they represent for society. This provides opportunities to customize BwN solutions and optimize the added value for the system as a whole.

1.6 Reading guide

As a starting point for this scenario study, we summarize present-day issues of the Southwest Delta (Chapter 2). Subsequently, to get insight into the processes acting in the natural system of the Southwest Delta and into the time scales at which changes can occur, in Chapter 3 the paleogeographical development is summarized. Chapter 4 describes the three extreme scenarios that the project team developed. In Chapter 5 we will discuss the implications of the cost-benefit analysis and compare the results for the scenarios and for the strategies. These results lead to a discussion (Chapter 5) for a sustainable Southwest Delta based on Building with Nature measures. Chapter 6 summarizes our findings and Chapter 7 contains the recommendations that we make on the basis of this study.

2 Present day issues and autonomous changes in the Southwest Delta

Except for increasing safety and connectivity of the Southwest Delta, the construction of the Delta works (Figure 2.1) led to a series of partially unanticipated side effects. In addition, the measures decreased the resilience to autonomous changes that are projected for the future. Here, we summarize the most important threats and problems.

Figure 2.1 The current situation of the Southwest Delta. The numbers indicate the Delta Works: 1. Grevelingendam, 2. Volkerakdam, 3. Haringvlietdam, 4.Brouwersdam, 5. Oesterdam, 6. Markiezaatkade, 7.Zandkreekdam, 8. Philipsdam, 9. Bathse Spuisluis, 10.Oosterscheldekering, 11. Veerse Gatdam.

2.1 Sand starvation

Since the Construction of the Oosterschelde storm surge barrier, less water can flow in and out of the Oosterschelde with the tides. The dimension of the tidal channels is still related to the water flowing through the Oosterschelde before the construction of the barrier. Therefore, they are oversized for the present volume of water flowing in and out. This implies that the water flows slower and sediment transport to the intertidal areas is reduced. However, wave action does erode the intertidal areas, the sediment of which is deposited in the channels. Here it stays. In other words: the eroding forces still work, but the building forces are reduced due to the barrier. The balance is disturbed, and erosion of intertidal areas dominates (ca. 50 Ha/yr). This process is known as “sand starvation” (Van Zanten and Adriaanse, 2008).

Also, along the Volkerak Zoommeer, Haringvliet and Grevelingen, the forelands deteriorate due to wave erosion in combination with sediment transport into the deep former tidal channels and surface subsidence.

2.2 Water quality issues

The construction of separate basins, some of which are fresh water and some of which are salt water, also resulted in side-effects. In the Haringvliet, the slow flow-rates resulted in sedimentation of polluted fine sediment coming from the river Rhine in the 1970s. Also, the valuable brackish water habitat has disappeared. The Grevelingen is a salt-water lake, and suffers from anoxic conditions on the lake bottom due to reduced estuarine dynamics. This leads to the extinction of bottom life and deterioration of water quality. Similarly, the Volkerak-Zoommeer suffers from algal blooms during dry warm summers caused by the lack of dynamics and accumulation of nutrients in the basin.

Most of these problems arose from a lack of dynamics and connectivity between the basins. Therefore, most solutions propose re-introducing dynamics into the Volkerak and Haringvliet by leaving the sluices slightly ajar. This would lead to a return of brackish conditions and increased dynamics and ventilation. An objection to this plan is that the brackish conditions have a negative effect on water availability for agriculture in the Southwest Delta, and new expensive infrastructure to bring fresh water to the Delta has to be build.

2.3 Sea-level rise

Due to the projected rise in temperatures as a result of the greenhouse effect, sea level is expected to rise. The causes for this process are the expansion of the warming sea water and the increase in meltwater from glaciers and ice-sheets. In 2006, the Royal Dutch Weather Service published scenarios for sea-level rise (KNMI, 2006; Figure 2.2), and predicted a rise in sea-level between 35 cm and 85 cm in 2100 (as compared to 1990).

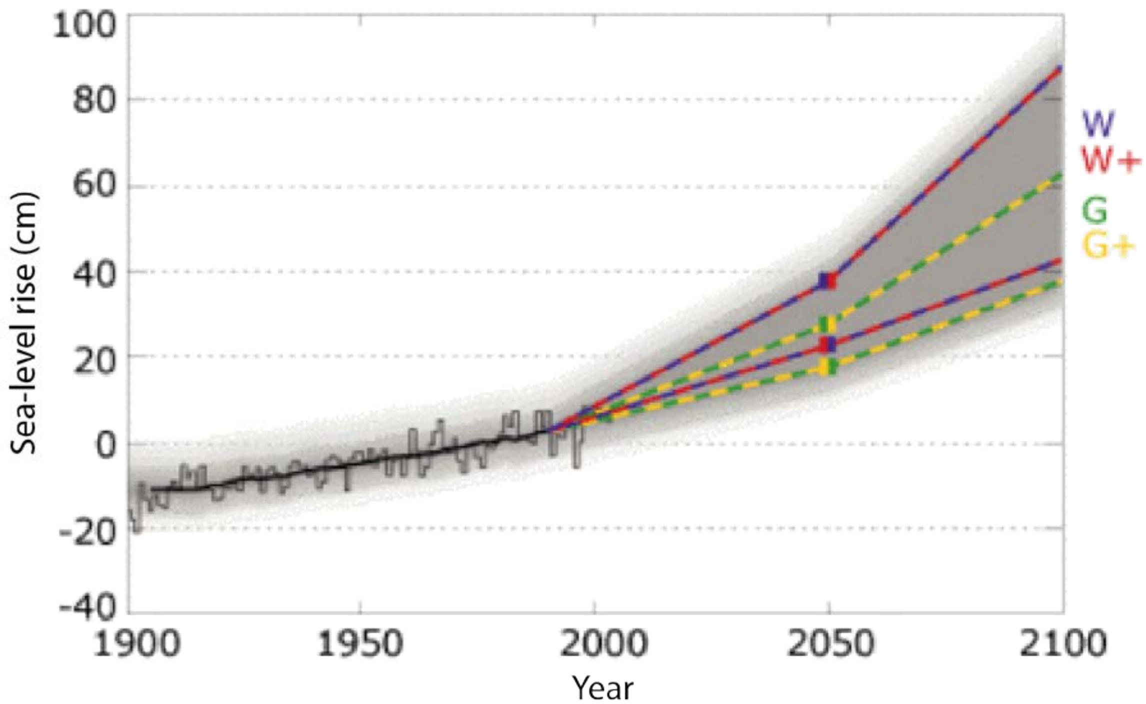


Figure 2.2 Scenarios for sea-level rise in the Netherlands. W, W+, G and G+ are the four different climate scenarios elaborated (source: www.knmi.nl).

The Delta Committee suggested that the Netherlands should take into account an even higher estimation of sea-level rise: they estimate use values of between 65 to 130 cm for 2100 (Delta Commissie, 2008). The difference in the scenarios comes forth from uncertainties regarding the exact contributions of the different factors influencing sea-level rise and the fact that the Delta Committee chose to use high end scenarios. The scenarios were subject to much debate. Finally the Delta Program chose a set of scenarios in which the KNMI scenarios were used to predict sea-level rise. In this report these are used to calculate the costs and benefits in our scenarios.

Except for the abovementioned absolute sea-level rise, the Southwest Delta also suffers from relative sea-level rise due to surface subsidence. This subsidence is the result of the oxidation of peat and the shrinking of clay due to dewatering. The surface subsidence is well reflected in the current land-surface elevation (Figure 2.3): The oldest polders have undergone most subsidence and all lie below sea-level. The anticipated land surface subsidence in the coming century varies from about 5 – 15 cm (pers.comm. Ger de Lange).

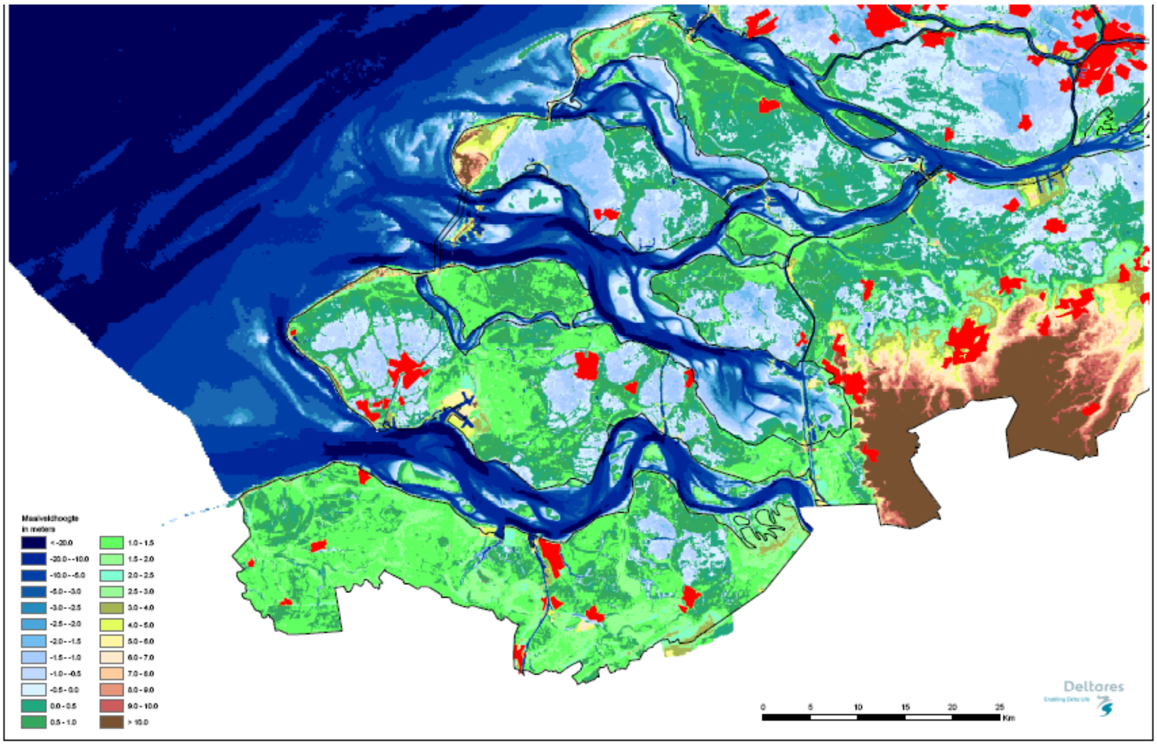


Figure 2.3 Digital elevation model of the Southwest Delta (source: Actueel Hoogtebestand Nederland 2: AHN2). The blue areas are below mean sea-level, and show the contours of the oldest polders.

2.4 Peak river discharges

An expected increase in winter precipitation will result in an increase in peak discharges in the coming century (KNMI, 2006). In the Alps, more precipitation will fall as rain instead of snow, which also increases winter discharge in the Rhine. Such peaks will have to be dealt with. If the levels of the connected basins (Hollandse Diep and Haringvliet) would increase this would increase this would increase the problems considerably, and cause problems in the densily populated area around the Nieuwe Waterweg.

In summer, the average precipitation is expected to decrease, and on the other hand, evaporation is expected to increase. In the Rhine and Meuse catchments, this implies lower discharges, and more often a water level affecting shipping. Lower river discharges in combination with higher temperatures also affect water quality and have a negative influence on the intake of cooling water of power plants. In combination with sea-level rise, lower discharges result in the intrusion of salt water from the sea.

2.5 Inland salinisation

The land elevation is below sea level and leads to seepage of salt water from the sea into the polders. This effect is strongest close to the dykes and in low-lying areas. Hydrological model runs suggest an increase in the salt load per hectare in many areas in the future (Van Baaren et al., 2010; Figure 2.4). Moreover, these model runs do not include sea-level rise and surface subsidence yet. The salt load will increase even more if these factors would be included. Salinisation due to salt seepage water results in a deterioration of agricultural yields. Part of this can be solved by adaptation of crops to the saltier conditions. However, eventually in many areas agriculture will not be profitable anymore.

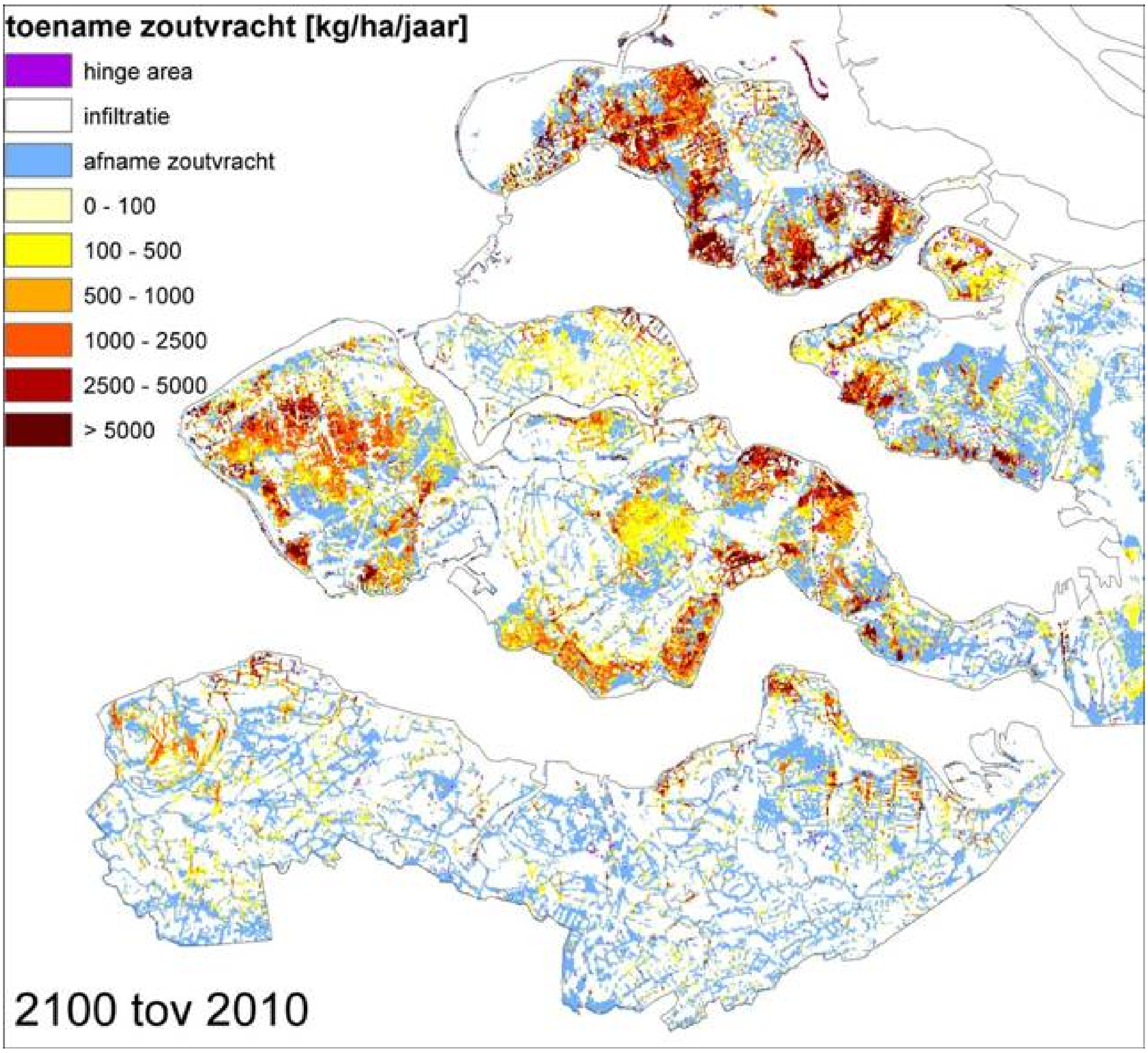


Figure 2.4 Model result of the expected increase in salt load in 2100 compared to 2010. Sea-level rise is not included in these model runs (Van Baaren et al., 2010).

3 Dynamics and development of the Southwest Delta (9000 years BP - present)

To get insight in the processes acting in the Southwest Delta and the timescales at which changes can occur, an analysis of the paleogeographic development was made. This analysis is mainly based on Vos et al., (2003) and Vos and Van Heeringen (1997; Figure 3.2). The full analysis including maps is attached to this document (Appendix C). Here we summarize the development and repeat the lessons learned.

The palaeographic development is constructed from information of soils found in boreholes. In the Southwest Delta, the subsurface consists mainly of peat, clay and sand. The formation of these soils was at the large scale controlled by the rise in sea level associated with the melting of large ice-sheets after the last ice-age. The rise in sea level was however not constant (Figure 3.1). At the beginning of the Holocene, the era after the last ice-age, up to 6000 years ago, sea-level rise was about 60 to 80 cm per century. In the periods thereafter, this rise gradually decreased to 15 cm per century at about 3000 years ago to 5 to 10 cm per century during the last 2000 years, with the exception of the last 150 year. In this period the sea-level rise at the Dutch coast appears to have accelerated to 18 cm/century.

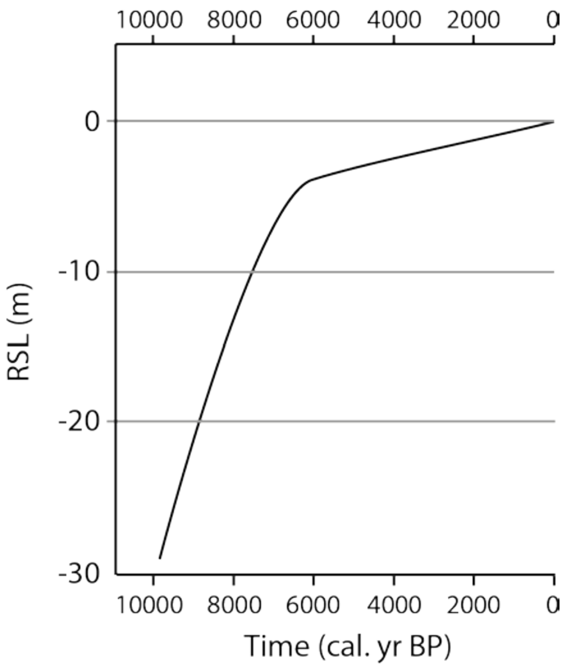


Figure 3.1 Reconstructed sea-level rise for the last 10.000 calendar years Before Present (modified after Vink et al, 2007 and Kiden, 1995).

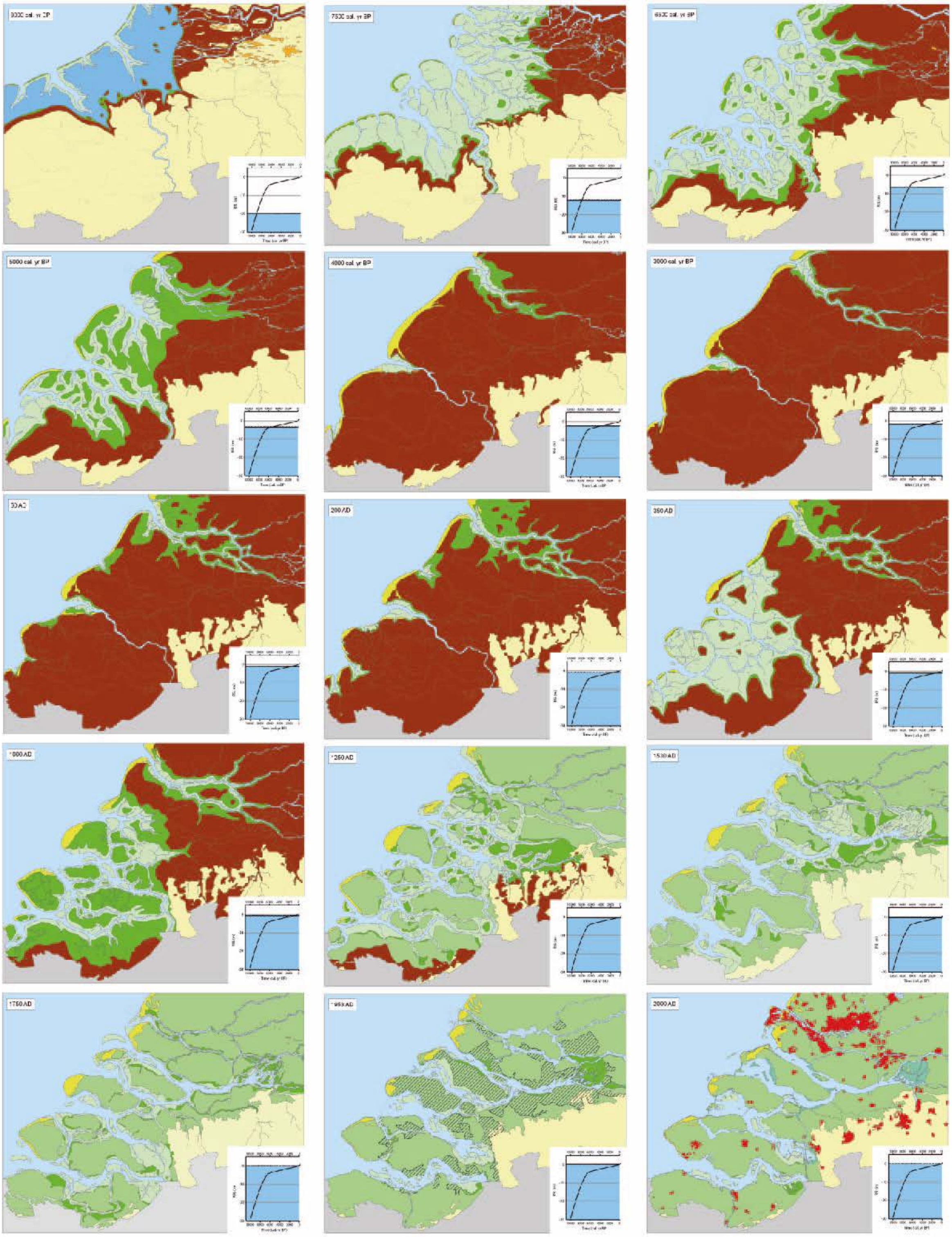


Figure 3.2 Overview of the paleogeographic development of the Southwest Delta Brown = peat; grey = intertidal flats; green = tidal marshes; yellow = dunes and beach; light green = land; shaded light green = flooded area; blue = sea; light yellow = higher Pleistocene landscape; dark blue = Lagoon (After Vos et al., 2002; Vos and Van Heeringen, 1997). Full-sized maps are provided in Appendix C.

During the first part of the Holoceen, the primary factors controlling the inundation history of are the fast rising relative sea level and the (Pleistocene) morphology of the land being

inundated. After about 5000 years, the rise in sea level decelerated and sedimentation and the formation of land prevailed. From that time onward, an extensive marshland was formed which was protected from the sea by beach ridge complexes forming an almost coastal barrier, only dissected by rivers.
After 500 BC the coastline breached, thereby inundating the extensive marsh area. The inundation history was different for different regions. In the Rhine-Meuse mouth the inundations was relatively small scale and it was mainly the river influence determining the coastal genesis. In the Southwest Delta, the inundation was more extensive took place later (post-Roman). The cause of the inundation was probably the sediment deficit that emerged along the coast leading to gaps in the coastal barrier in combination with the man-made large scale peat excavation inland. After 1000 AD, human influence became the dominant factor in coastal development, as large areas were systematically embanked. The embanking- and drainage activities led to a lowering of the groundwater level and an increase of the storm surge levels due to funnel effect. Herewith, man created conditions for catastrophic storm-surge disasters.

Important lessons that can be learned from the paleogeographic development are:

- The paleogeographical development of the area shows that the balance between sediment supply and sediment demand have controlled the build-up of the area. With a fast rising sea level, sediment supply could not keep up with the increasing sediment demand, and the area developed transgressively. When the sea-level rise started to diminish, the sediment supply surmounted the demand, and the area developed seaward.

- The transgressive (landward shift) and regressive (seaward shift) phases were accompanied by feedback cycles between accommodation space, tidal prism, tidal channel flow velocities and sediment availability. I.e.: During transgressions the sedimentation could not keep up with the increase in accommodation space and during regressions sedimentation exceeded the increase in accommodation space.

- Sediment accommodation space in fresh- and brackish water areas without sediment supply from coastal or fluvial processes was filled in by peat accumulation.

- Human interferences in the natural sedimentary system, especially ones increasing the accommodation space by digging away and draining peats, can result in catastrophic floods.

- The most valuable and largest natural areas (Biesbosch, Land van Saeftinghe) are former polders that were inundated.

4 Building with Nature solutions for the Southwest Delta

To explore opportunities for a sustainable future based on Building with Nature principles (see textbox), the project team designed three hypothetical extreme scenarios of a resilient and safe Southwest Delta over the course of the century (Appendix D). Each of the scenarios approached nature from a different mind-set (namely: enable nature, control of nature and conserve present values) and contains a selection of Building with Nature solutions applied on the large scale. Furthermore, also other innovative multifunctional elements, such as Delta Dykes and tidal energy polders have been applied.

The scenarios focus is on flood protection, estuarine processes and hydraulic infrastructure. Addressing the entire economical system on the scale of the Southwest Delta is beyond the scope of this document. This implies that important economical functions such as shipping or freshwater availability are not taken into account in this study.

The development of extreme scenarios allows us to investigate the separate Building with Nature solutions in spatial and temporal scale under different autonomous conditions. This makes it possible to evaluate the different scenarios and elements using a Cost Benefit Analysis.

Levels of Building with Nature
Building with Nature aims to build hydraulic infrastructure utilising the dynamics of the natural system, thereby simultaneously creating opportunities for nature. This can be achieved at different scales. The 8 levels on which Building with Nature can be applied.

1. **Modify** the configuration of a dynamic system to steer hydrodynamic conditions to enable desired functions (E.g. Natural channel deepening, decreasing tidal/storm surge amplitude, Harbour Terschelling)
2. **Employ** natural sedimentary and hydrodynamic processes into reinforcing coastal defense structures (e.g. modify the system so that tidal flats or marshes are formed in front of dykes)
3. **Facilitate** natural processes to reinforce coastal defense structures (e.g. Nourishments, or sediment catchments)
4. **Utilise** the potential of the ecological system to influence the environment (eco-engineers)
5. **Manage/maintain** sedimentary and ecological environments in such a way that they facilitate safety (salt marsh protection)
6. **Create environments** to reinforce natural defences (construct wetlands)
7. **Improve** infrastructure ecologically, thereby enriching the ecological system in the bordering basin (rich revetments)
8. **Minimize** damage to the environment during construction and mining resources (landscaping sand pits, predict and control dredging plumes)

4.1 Building with Nature Building Blocks

To facilitate the design of the extreme scenarios, a selection of Building with Nature solutions are defined, so called “Building Blocks”. Within these Building Blocks also other innovative hydraulic infrastructure elements are included. Here we provide a brief description of each Building Block that is used in this study. An exhaustive description is provided in factsheets

that are included as Appendix B in this report. These factsheets also contain an elaborate description of the costs and benefits of the elements.
The Building with Nature Building Blocks that we consider in this study are:

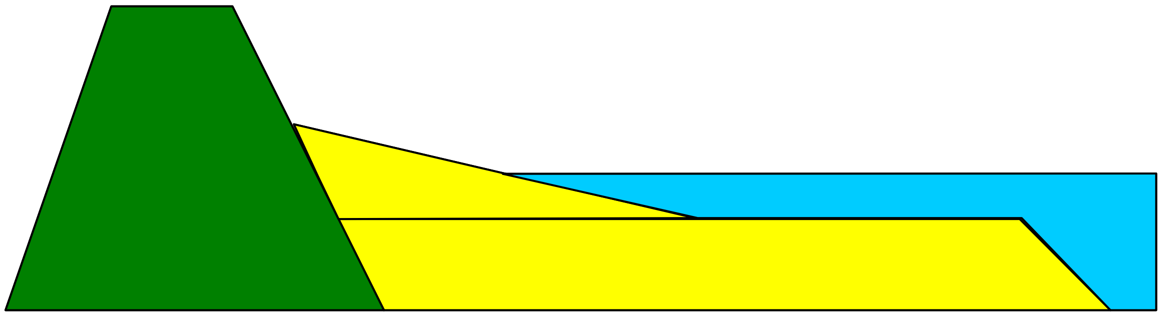
- Sand nourishments
- Coastal buffer zones
- Managed realignments
- Energy polder
- Rich revetments
- Delta dyke
- Eco-engineers
    - Oyster reefs
    - Salt marshes and reedland

Sand nourishments

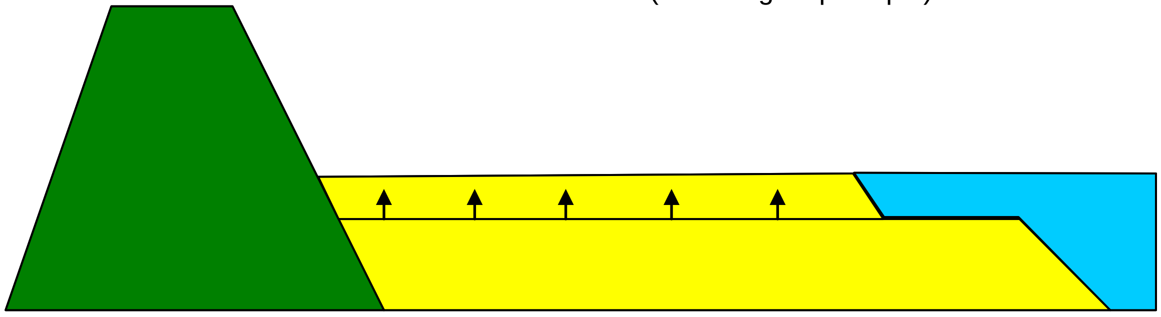
Coasts and tidal flats act as a buffer for safety by dissipating wave energy. If insufficient sedimentation takes place to keep up with sea-level rise such areas may become lower relative to sea level and may also become smaller in areal extent. Nourishments can be an effective measure to fulfill the sediment demand and maintain an equilibrium between erosion/drowning and sedimentation. Nourishment strategies to maintain tidal flats and beaches can reduce dyke reinforcement costs.

Nourishments can be applied in a number of ways:

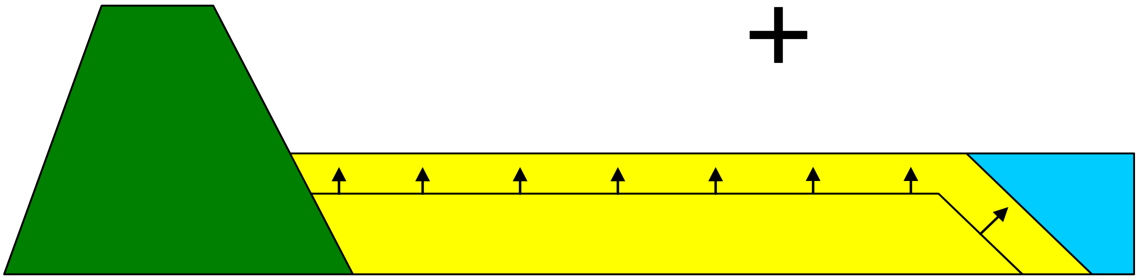
- Apply the necessary sand directly on the areas that need to be raised.



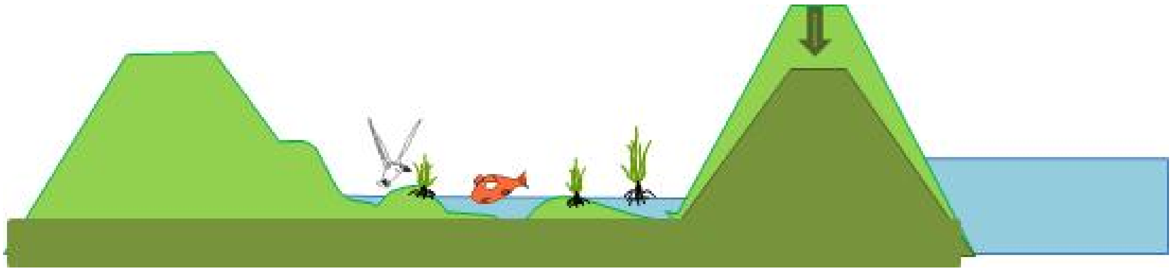
- Apply a surplus of sand at a strategic location and let natural processes distribute the sand over the area with a sediment demand (sand engine principle).



- Apply a surplus of sand pushing the balance between sedimentation and erosion into the direction of sedimentation

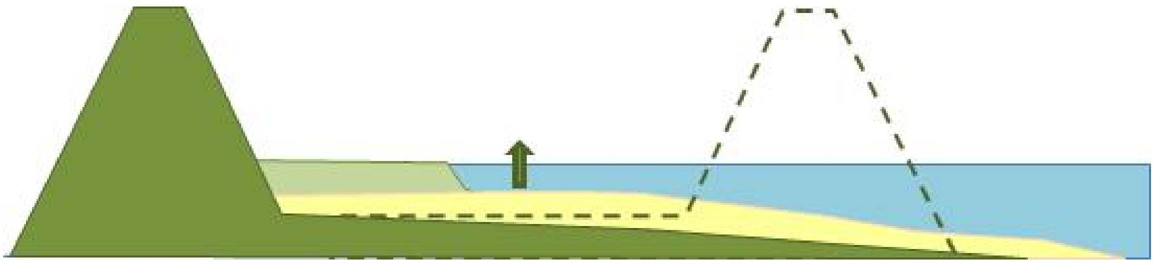


Coastal buffer zone



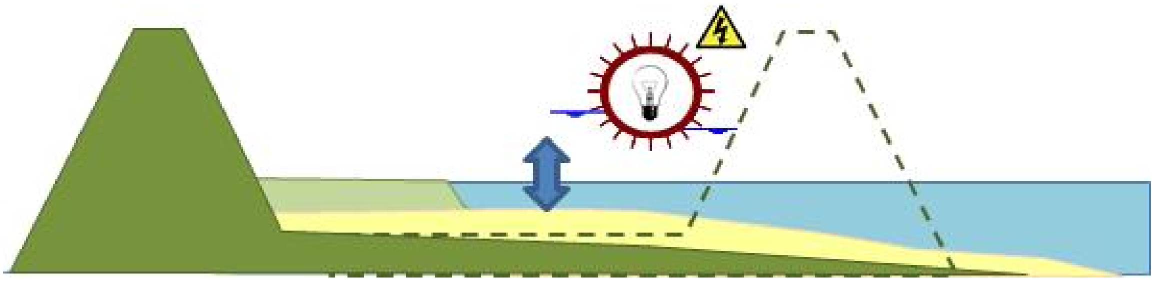
A coastal buffer zone is a predominantly salt/brackish zone along the coast between two dykes. Historically these areas, called “inlagen”, arose when people built a spare inner dyke parallel to the coastal defence when there was a threat of dyke failure. The principle of a coastal buffer zone is interesting from a coastal protection point of view and elaborated here. Because of the presence of a secondary dyke, the primary coastal defence can suffice with lower safety standards and may thus have a reduced height. Limited overflow during extreme high water conditions is acceptable because the secondary dyke will stop the water from inundating the land behind the secondary dyke. This is interesting from a cost and dyke maintenance point of view. The area between the dyke is not suitable for high quality land use as housing, but can serve as nature and recreation area and also has potential for aquaculture.

(Temporary) Managed realignment



Managed realignment involves a partial or complete dyke set back of the actively maintained defence to a new inland defence. A secondary parallel defence is constructed or a remnant dyke is used and enforced, then the sea defence is breached in order to let the tide flow freely in new intertidal area created between the two dykes. The goal is to create new intertidal habitat that will develop to salt marshes that enhance sedimentation resulting in a gradual increase of elevation with respect to sea level. After a while some of the polders may be repoldered again once their height is sufficient. This way of controlled inundation is an increasingly used method for coastal protection and anticipation to climate change (French 2006) and is also considered as a cost-effective and sustainable response to loss of biodiversity and sea-level rise (Garbutt 2008).

Energy polder

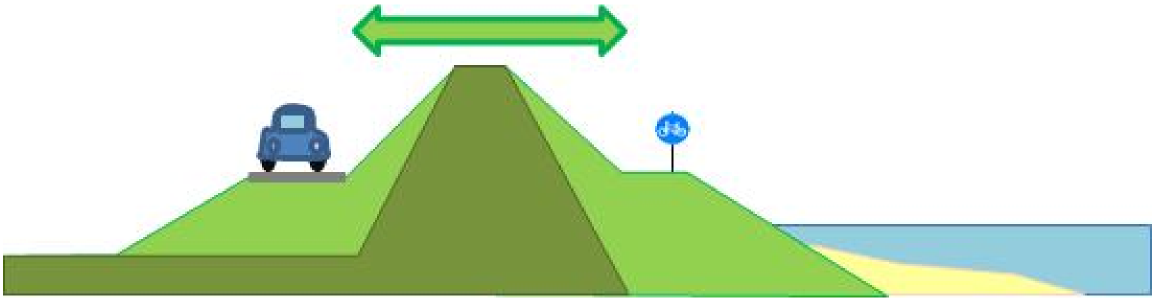


An energy polder is a new concept which is aimed at generating power from tidal movement in a controlled inundated area, for example a managed realigned area. Application of this concept has potential in polders that re-inundated and where tidal influence is (re)introduced. Tidal power can be generated by placing turbines in the breaches of the former dyke. This way the water will "push" through the turbines into the polder at high tide and generate power. An important prerequisite for this method to be cost-effective is a sufficient tidal range.

Rich revetments

The Southwest Delta coastal defence mostly consists of hundreds of kilometres of dykes and dams. These hard structures represent a potential habitat for flora and fauna that settle on hard substrates. These species (like seaweeds) are valuable because they provide shelter and feeding possibilities for other species. The Rich Revetment principle is aimed at optimizing ecological functioning of coastal works by creating a more heterogenous dyke substrate (ridges, pools, boulders etc). It enhances the establishment of flora and fauna (especially algae and macrobenthos). The results are more individuals and a higher diversity of species (Borsje, Van Wesenbeeck et al. 2011). Also see http://www.innovatielocaties.nl/veiligheid/rijke_dijk.

Delta dyke

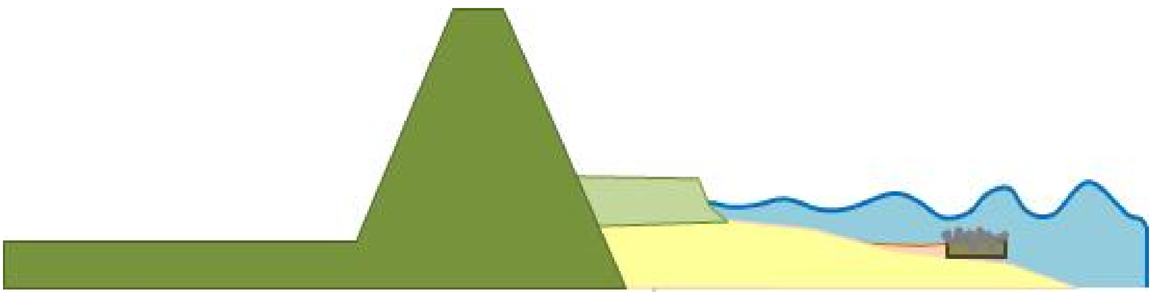


The “Delta dyke” concept aims to create a dyke with a design that is so robust that the chance of a dyke breach event is practically impossible even in case of overflow. The concept has several names like “Multidyke”, “Climatedyke” and “Superdyke”.

Ecosystem engineers

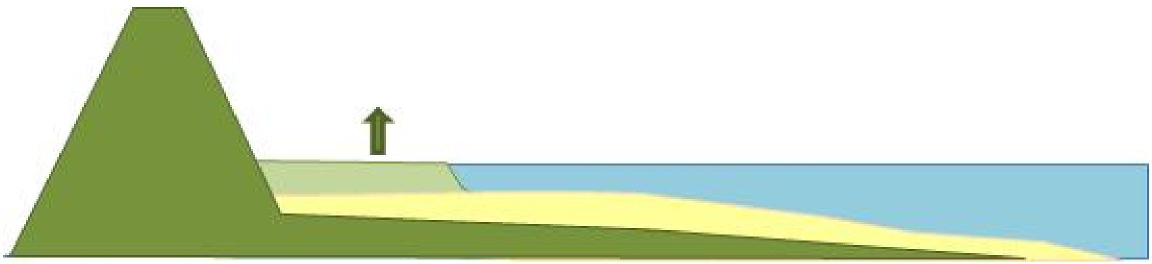
Ecosystem engineers are plants or animals that influence their environment with their presence or activities (Jones, Lawton et al. 1994). Many ecosystems are greatly affected by ecosystem engineering, such as coastal salt marshes, where macrophytes trap sediment (sand or clay particles) by reducing hydrodynamic energy (Bouma, De Vries et al. 2005). Other examples of ecosystem engineers in tidal environments are reed marshes, willow tidal forests, mangroves, sea grass beds, coral reefs and bivalve reefs. It is believed that the use of ecosystem engineers in coastal management can contribute to a more sustainable, cost-effective way of protecting our coasts, especially in the light of climate change and sea-level rise (Borsje, Van Wesenbeeck et al. 2011). Secondly, there is also a need for methods of coastal protection that incorporates the natural dynamics and processes of the ecosystem, allowing a more resilient and robust future coastline (Day, Psuty et al 2000). Three types of ecosystem engineers are investigated in this study: shellfish reefs, saltmarshes and reedlands.

Shellfish reefs



Shellfish reefs made of mussel and oyster is a promising ecosystem engineer to stabilise intertidal flats and saltmarshes in front of the dykes because they reduce hydrodynamic energy (waves and currents) and enhance sedimentation (de Vries, Bouma et al. 2007; Borsje, Van Wesenbeeck et al. 2011). These reefs can therefore perform similar functions as groynes and dams, but have additional advantages such as the creation of valuable habitat and the possibility to keep pace with sea-level rise.
Building with Nature investigates the application of reefs made of Pacific oyster (*Crassostrea gigas*) shells in the Oosterschelde. The goal is to investigate the role of artificial oyster reefs in erosion reduction and stabilisation of tidal flat edges. Pacific oyster was introduced in the Oosterschelde in 1964 and expanded quickly. It is a suitable ecosystem engineer because this oyster creates extensive reefs, formed by densely packed oysters growing upward and outward on top of each other. These reefs influence local ecology by creating shelter, increasing sedimentation and organic matter content through bio-deposition (Piazza, Banks et al. 2005) and enlarge biodiversity by creating new habitat (Borsje, Van Wesenbeeck et al. 2011).

Salt marshes and reedlands



Salt marshes are ecosystem engineers because they trap sediment, decrease erosion and attenuate wave energy. Möller et al. (2001) has determined on basis of field experiments that wave reduction on salt marshes is 50% higher than on bare tidal flats. Deliberately development or expansion of salt marshes is not so easy because salt marshes only develop if the right environmental conditions are present. Elevation, sediment load of the water, slope, hydrodynamic processes, geochemical conditions and development of creeks are important factors (Burd 1995; French 2006; French 2008; Borsje, Van Wesenbeeck et al. 2011).

Also in freshwater and brackish water environments bio-engineers can develop and used be for coastal protection. Under the right circumstances reed can develop quickly and form a dense vegetated area and are therefore interesting for their role in foreland protection.

4.2 Methodology and scenario design strategy

The design of the scenarios is based on a combination of Building with Nature strategies (described in Section 4.1) with the specific sets of Building Blocks (described in Section 3.2 and Appendix B). The considerations behind this scenario design are documented in a choice model for each scenario. With the help of experts and literature, the implications of the strategies for flood protection, estuarine processes and hydraulic infrastructure were determined. Some of these implications could be quantitatively calculated. Of other costs, only qualitative estimates could be reasoned. Perimeters and surface areas of all sedimentation areas, foreland and lengths of Delta dykes were calculated using GIS.

4.2.1 Defensive scenario

The **Defensive scenario** leaves the present configuration of the Southwest Delta largely intact. However, the delta is made more ecologically attractive and resilient by increasing the dynamics in basins, utilizing eco-engineers and facilitating sedimentary processes by supplying sediment. In addition, the hydraulic infrastructure is ecologically improved by creating environments such as rich revetments. Typical for this scenario is that the measures applied in this scenario are relatively small in scale.

Choice model

Key principle in the Defensive scenario is to maintain an effective wave breaking foreland for safety purposes (Figure 4.1). This effective wave breaking foreland is defined to be at least 80 m wide (Royal Haskoning, 2011). At places where secondary dykes are present, coastal buffer zones are developed. Dynamics are re-introduced by making openings in existing dams, comparable to current intends of introducing dynamics in the Haringvliet and Volkerak Zoommeer. Depending on the current function and processes acting, the effective foreland is maintained by nourishments and protected by ecosystem engineers.

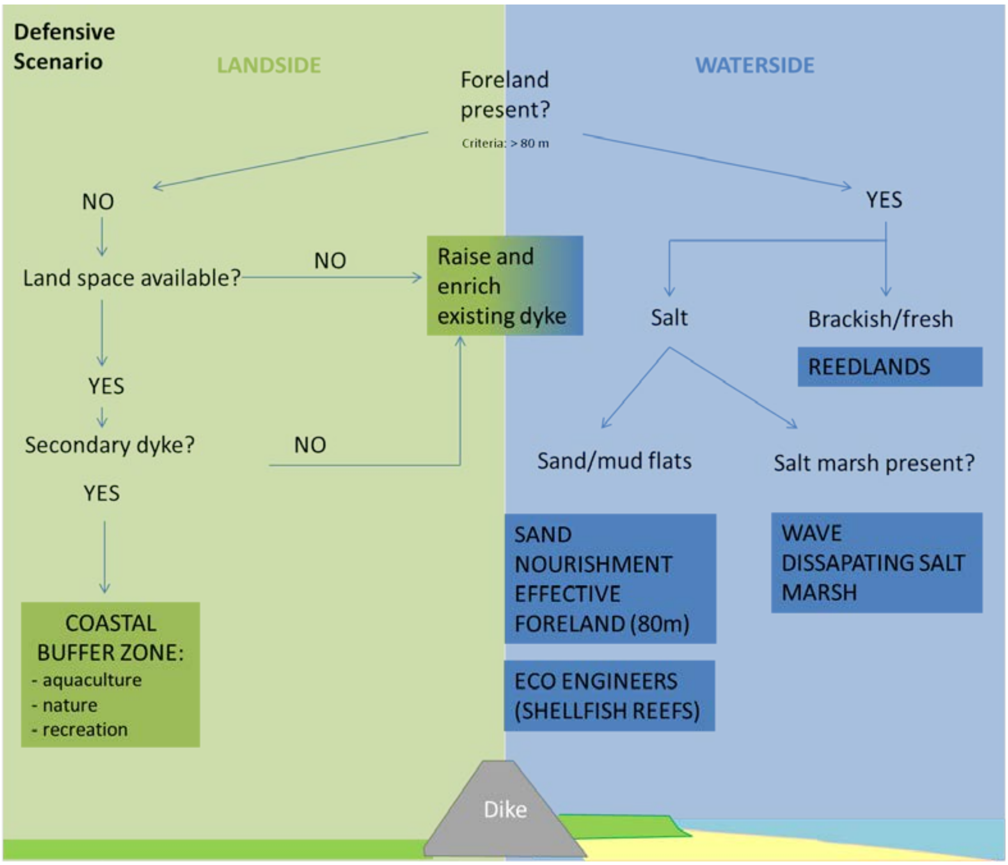


Figure 4.1 Choice model for implementation of Building with Nature measures in the Defensive scenario.

4.2.2 Offensive scenario

The **Offensive scenario** focus lies on modifying the configuration of the Southwest Delta in order to steer the hydrodynamic conditions to create a system that can grow along with autonomous changes. For this purpose, the coastline is reinforced and builds outward. The intertidal area is maintained by nourishing a surplus of sediment to grow along with the sea-level rise, while inland safety is guaranteed by innovative structures.

Choice model
The primary principle of this scenario is to reconfigure the Southwest Delta into a shape that is sustainable for the long term. To guarantee the inland safety, the following choice model is applied to reinforce hydraulic infrastructure (Figure 4.2):

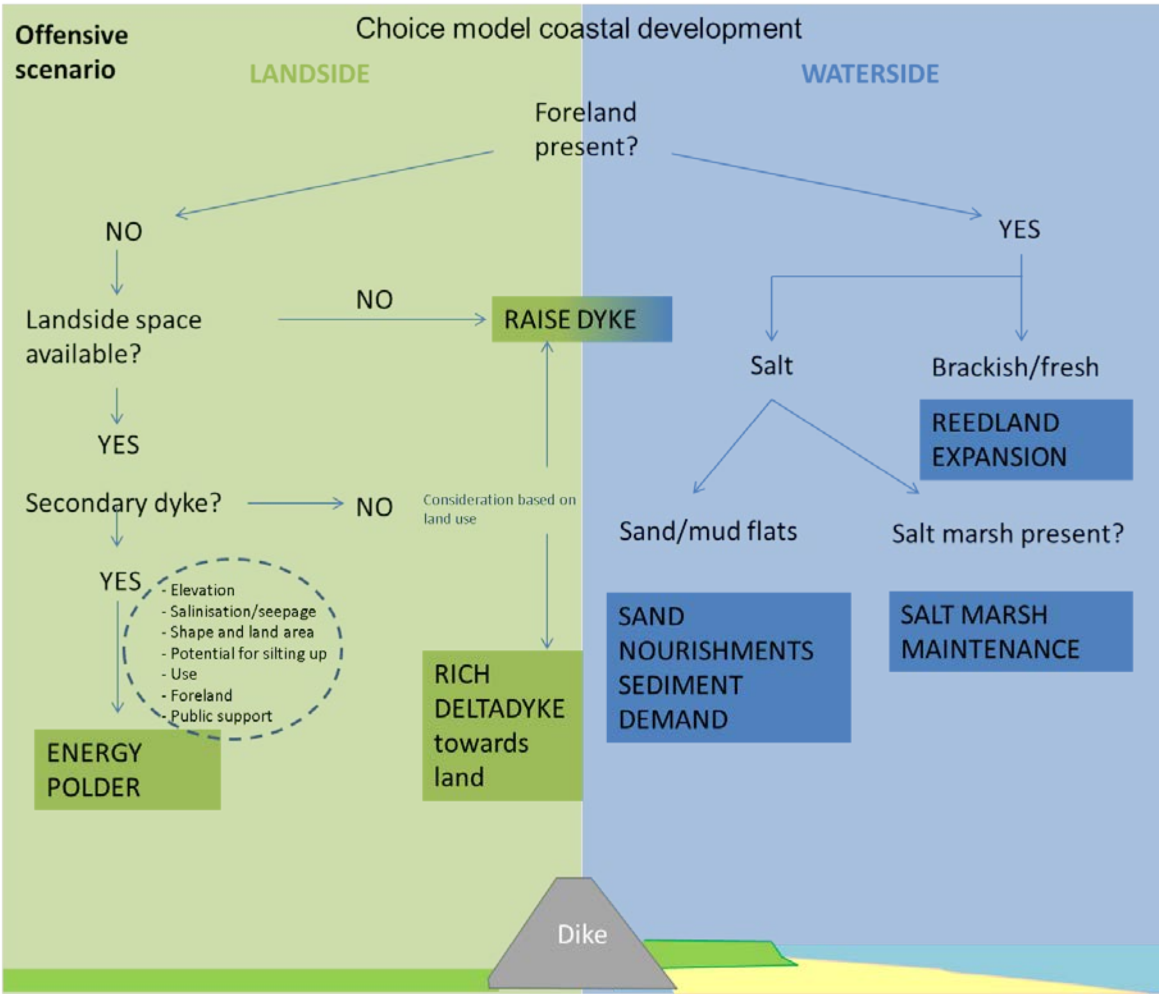


Figure 4.2 Choice model for implementation of Building with Nature measures in the Offensive scenario.

4.2.3 Natural scenario

The **Natural scenario** uses a combination of modifying the configuration, employing sedimentary and hydrodynamic processes to reinforce the coastal defences and manage and maintain environments. In other words, this scenario optimally employs natural forces to create a resilient system that is self-sustainable on the long term.

Choice model
The key principle of the Natural scenario is to regain estuarine dynamics by removing all Deltawork dams creating a fully open connection between the rivers Rhine, Meuse and Scheldt and the North Sea. Furthermore it is aimed at giving more space to natural processes and harness sediment dynamics to benefit a robust coastal zone. This can be done by widening the coastline in either sea- or landward direction (or a combination of both). As it is an “extreme” Natural scenario, the design aims to investigate the rather extreme limits of

estuarine recovery and coastal zone development. This exploration therefore goes beyond socio-economical limits and explores extreme boundaries of the possible or impossible.

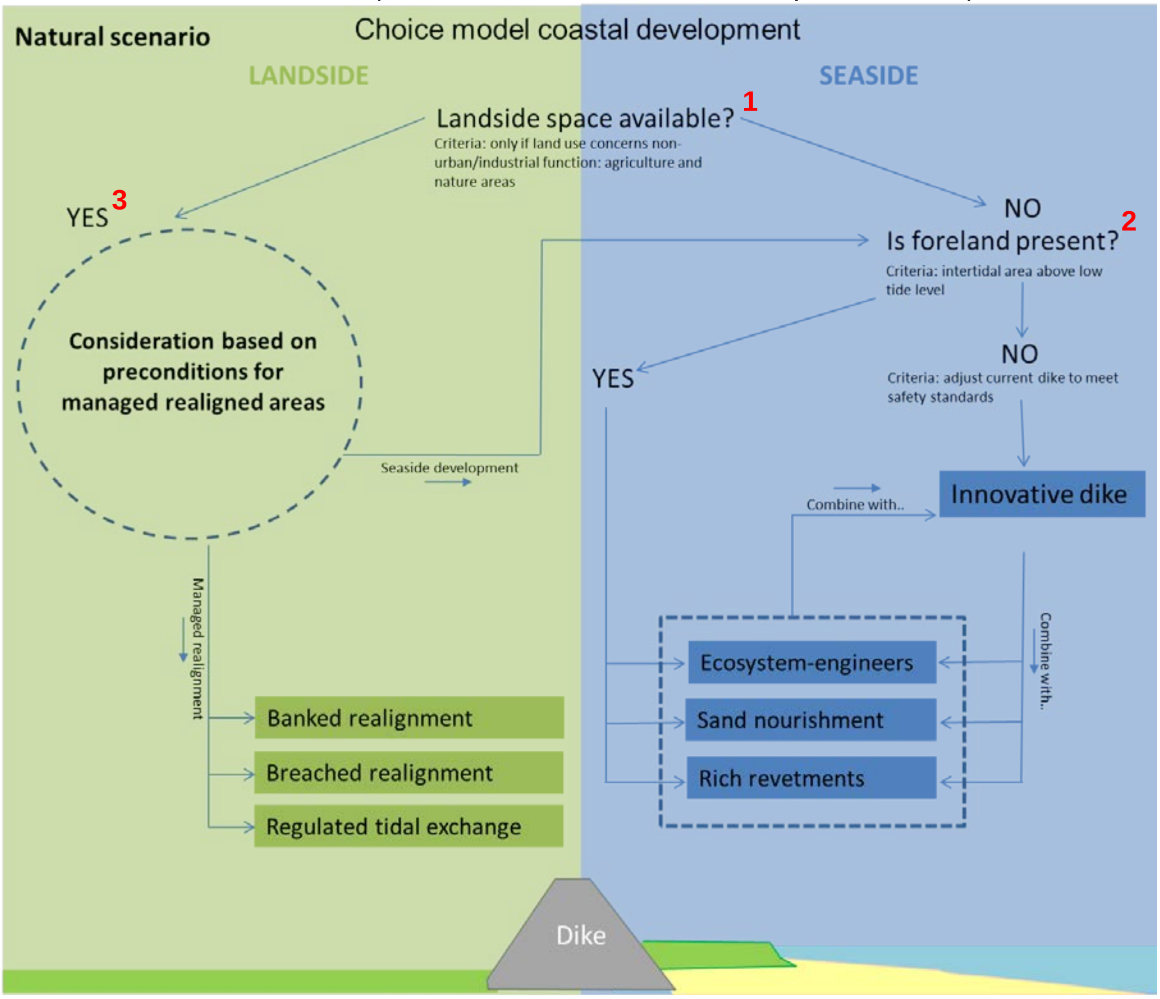


Figure 4.3 Choice model for implementation of Building with Nature measures in the Natural scenario. The red numbers correspond with the step by step explanation in the text.

The Building with Nature measures ("Building Blocks") as described before form a set of measures that can be used. The choice of measures is dependent of several factors (e.g. available space, appropriate abiotic conditions etc.). A choice model (Figure 4.3) was developed to motivate the considerations that formed the basis of the Natural scenario:

1) Land use often is a decisive factor in the choice of land- or seaward coastal zone extension. For example, if urban agglomerations (cities, villages, industries etc.) are located along the coast, landward development is not desirable.

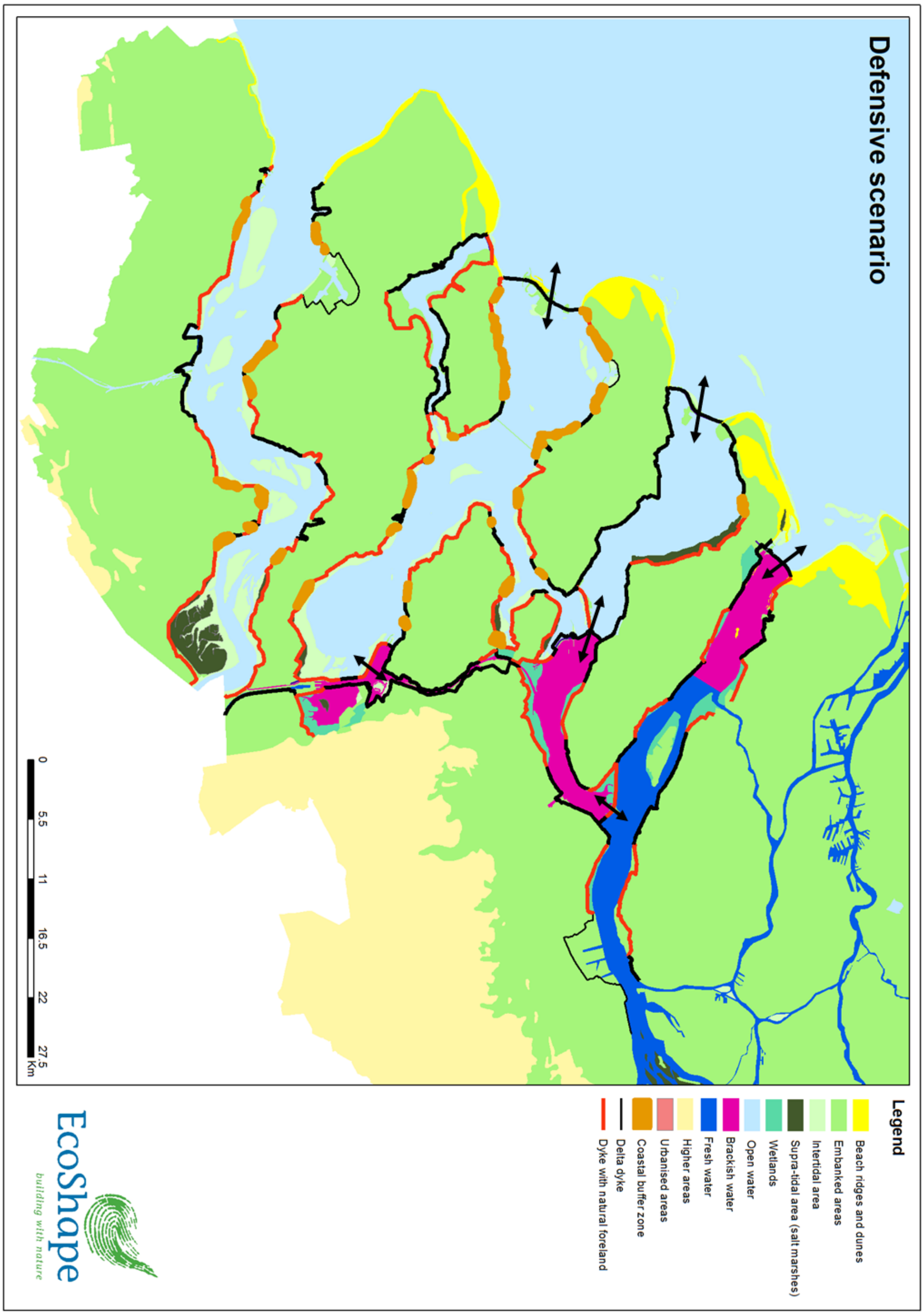
2) Seaside development: the presence and extent of intertidal area (foreland) in front of the coastal defence is guiding. Key principles are:

- Foreland creates a shallow coastal zone so that erosion and wave energy can be reduced.
- The presence of intertidal area above mean low tide level provides potential opportunities for application of ecosystem engineers and (strategic) sand nourishment. If necessary these measures can be combined with dyke development to achieve the desired safety protection level.

- When foreland is absent and the coastal water is deep and subject to currents the only option is dyke reinforcement and/or construction of an innovative dyke in combination with application of the rich revetment concept (as there is no space for landside development).

3) Landside development: when inland land use consists of agriculture or nature area behind the dyke, these areas are claimed for landside development that involves managed realignment. The potential of managed realignment measures are dependent on several boundary conditions. Some include elevation, sediment load of the water, soil characteristics etc. The Building with Nature wiki gives an elaborate analysis of success factors. In the Natural scenario, breached realignment is applied. Here the primary defence is breached but not totally removed. It enables natural processes and has proven to be more successful than banked realignment where the total primary defence is removed (Pontee 2007). To obtain more insight on the potential of breached realignment an expert workshop was organised (Appendix E). Experts stated that on overall enough sediment will be present to feed realigned areas when the Delta Works are removed. The Natural scenario describes overall potential but does not take specific boundary conditions (like elevation and soil characteristics) into account.

4.3 Defensive scenario



4.4 Introducing the Defensive scenario

Zeeland has done well in the past century when it comes to protection against the sea. As a reaction to the severe storm surge disaster of 1953 it has been protected by a large-scale Delta Works which protect the area for a repetition. Since, Zeeland has prospered. Therefore it is the logical choice of de Defensive scenario to follow that development.

The strategy leading to the Defensive scenario is in line with strategies that have been proposed in the last decades to stand up to the problems arising in the Southwest Delta. It is focused on treating the symptoms and not the source of unanticipated side-effects of the Delta Works, and employs Building with Nature measures. The present-day configuration of the Southwest Delta is left largely unchanged. To restore some of the dynamics, the basins are connected by small openings in the dams. Where they have a safety function, salt-marshes and sand flats are nourished and maintained. Otherwise, at places where there is no balance between sediment supply and hydrodynamic processes, these areas will gradually degrade.

4.5 Dynamics

To restore some of the dynamics in the basins, openings are made in the existing dams. This is in line with current proposals to introduce estuarine dynamics in the basins, such as the Volkerak Zoommeer and Haringvliet. It is expected that the improved dynamics and salt water will prevent algal blooms the Volkerak Zoommeer (Meijers et al., 2008) and reoxygenate the bottom of lake Grevelingen (Witteveen en Bos, 2009). In addition, the Haringvlietdam will be put slightly ajar to obtain a more gradual transition between the Haringvliet and North Sea, improving the ecological resilience of the area.
For the Grevelingen, a connection with the Oosterschelde is probably not enough, and therefore a connection with the North Sea through the Brouwersdam is required. A new sluice could introduce a tidal range of 50 cm, solve the anoxic condition for 90% and would convert the forelands into valuable intertidal areas. The costs of this sluice are estimated at 260M€ (Witteveen en Bos, 2009).
For the Volkerak, a connection will be made with the Grevelingen and Haringvliet through the Grevelingendam and Phillipsdam and with the Oosterschelde through the Oesterdam. In 2001, the total costs for these connections were estimated at 82 M€ (180 Mfl; Haas and Tosserams, 2001). These costs include a connection between the Volkerak-Zoommeer and Markiezaatsmeer.

Due to these measures, the current dry forelands are subjected to dynamics again, and are assumed to transform into intertidal areas or reed marshes in case of a brackish or fresh water environment.

4.6 Nourishment strategy

Nourishments in the basins aim at maintaining intertidal area in front of dykes solely to facilitate the safety. The nourishment volume therefore equals the effective wave breaking width of this intertidal area (80 m; e.g. Witteveen en Bos, 2007; Royal Haskoning, 2011) multiplied by the yearly sea-level rise. The downside of this measure is that erosion of the sand flats in semi-closed tidal systems such as the Oosterschelde will continue to take place. In the Oosterschelde yearly volumes of 1.5Mm^3 erode (Hesselink, 2003). This implies that in this scenario the tidal area of the Oosterschelde will decrease gradually from 11.000 ha in 1987AD to about 1500 ha in 2100AD (Kohsiek et al., 1987). An alternative would be to nourish to a higher level (for instance +3 m NAP) to: I) influence waves during storm surges and II) form a buffer for sand

The benefit of maintaining the intertidal area in front of stretches of dyke is that the maintenance costs will decrease as the dykes suffer less from wave impact (Witteveen en Bos, 2007).
To maintain the present balance in the Westerschelde and to prevent the North Sea coast from eroding, a volume equal to the active sediment demand of these systems is nourished every year (Table 4.1). This will take place in the form of Sand Engines (or feeder beaches) at strategic locations along the coast and in the Tidal Delta of the Westerschelde. This implies that for each mm of sea-level rise, a volume of 1.75 Mm^3 is nourished (Mulder and Van Heteren, 2009; Mulder et al., 2011).

Table 4.1: Overview of sand nourishment volumes for the Westerschelde and the North Sea coast.

Sea-level rise	Active sediment demand and Nourished Volume (Mm^3) 4.6.1
35 mm/year	6.1 4.6.2
50 mm/year	8.7
85 mm/year	14.9 4.6.3

4.6.1 Ecosystem engineers

4.6.1.1 Reed marshes

In the fresh- and brackish water environments, the forelands will convert into reed marshes when dynamics increase due to improved connectivity and as the water table rises due to climate change. These marshes can grow along with the rising water and require minimal maintenance. They are effective in dissipating wave energy, filtering water, retention of freshwater in times of drought and make valuable natural habitats (DHV, 2010). Periodical harvest for biomass can take place in these reed lands. The basins that are expected to host reed marshes in this scenario are the brackish Volkerak Zoommeer and Markiezaatmeer, and the Hollands Diep/Haringvliet.

4.6.1.2 Shellfish reefs

Shellfish reefs are applied to protect the nourished sand from erosion by currents and waves. The idea is that the reefs can stabilize eroding (intertidal) coastal areas, and at the same time can grow with sea-level rise. The shellfish filter material from the water column and deposit it in the form of faecal pellets. Hence, sediment is trapped between the shells. The reefs enhance bed roughness, thus influencing near-bed water flow and wave action. This in turn influences sediment transport, sedimentation, consolidation and stabilization processes. Besides this dynamic interaction with the physical environment, the reefs provide a complex habitat for many other species, can provide economic benefits and contribute to a healthier ecosystem functioning.

To build a sustainable shellfish reef, certain conditions should be met. For instance, the reefs should be placed at relatively low energy areas, and they must fall dry at least 60% of the time.

Since research on shellfish reefs is still in a fundamental stage, no quantitative estimates on the costs and benefits could yet be made. In this study we assume that the reefs can stabilize intertidal areas in combination with the nourishments. No further costs or benefits are calculated.

4.6.1.3 *Salt marsh management / maintenance*

Observations of salt marshes in the Oosterschelde show a decrease in surface height and area. For 2060, a model study predicts a decrease in area of 40-60% of the smaller salt-marshes, the larger and more protected salt marshes have decreased in size by 10- 20% by 2060 (Jacobse et al., 2006).

Salt marshes are an important factor in dyke safety, as they dissipate wave energy. In this scenario, only the salt marshes that are important for dyke safety are maintained. They will be protected by artificial walls. Where necessary, they will be managed, for example by the introduction of *Spartina anglica*, a robust invasive salt marsh plant. This strategy results in a decrease in dyke maintenance cost. The prize that has to be paid for this selective maintenance is the disappearance of a large area of salt marshes, here assumed to be about 50%. In the Westerschelde, the salt marsh area is assumed to remain equal to the current area since no deterioration has been observed here yet.
Due to the increased dynamics in the Grevelingen, the current vegetated forelands will be subjected to tides again. It is assumed that these areas will develop into a combination of sand/mud flats and salt marshes that will have a wave dissipating function.

4.6.2 Coastal buffer zones

As a remnant of the historical development of the area, many secondary dykes are still present in the landscape parallel to the primary dyke. This leads to the presence of a series of miniature polders that are surrounded by the primary and secondary dyke. Due to salt-water intrusion in these polders, they are unsuitable for agriculture and often used as nature reserve area. In this scenario, these so called coastal buffer zones are set up as a mixture of nature reserve areas, recreational areas and aquacultural areas. The primary dyke is lowered so it can be overtopped, and the secondary dyke is reinforced. This way, an innovative flood protection zone is created, with benefits for safety, nature, recreation and aquaculture.
Most of the coastal buffer zones are situated along the Oosterschelde and Westerschelde. They comprise a total of 70 km dyke.

4.6.3 Rich revetments

Many tens of kilometers of dykes and dams consisting of hard substrate remain that could not be protected partly by Building with Nature measures. These constructions are a potential substrate for marine life. To optimize the ecological functions of these artificial constructions, the structures are made more attractive by creating puddles, ridges, cracks and varying the substrate (wood, stone; Figure 4.4). These enriched hydraulic infrastructural elements make up “rich revetments”.

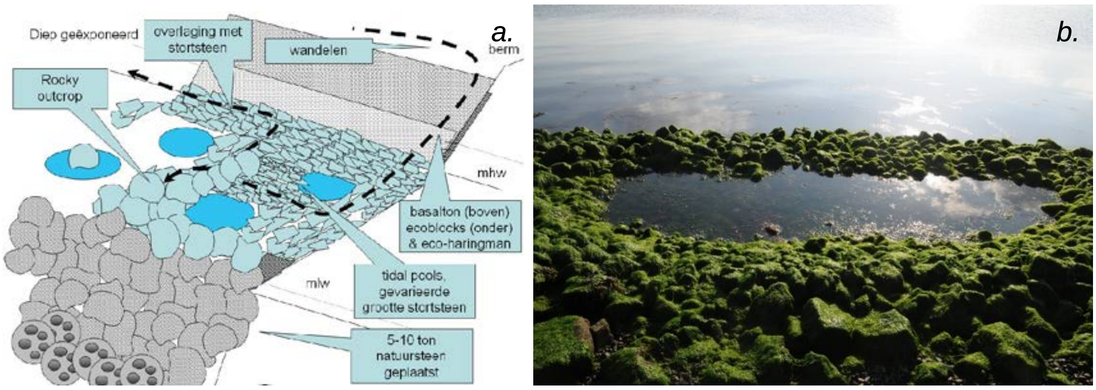
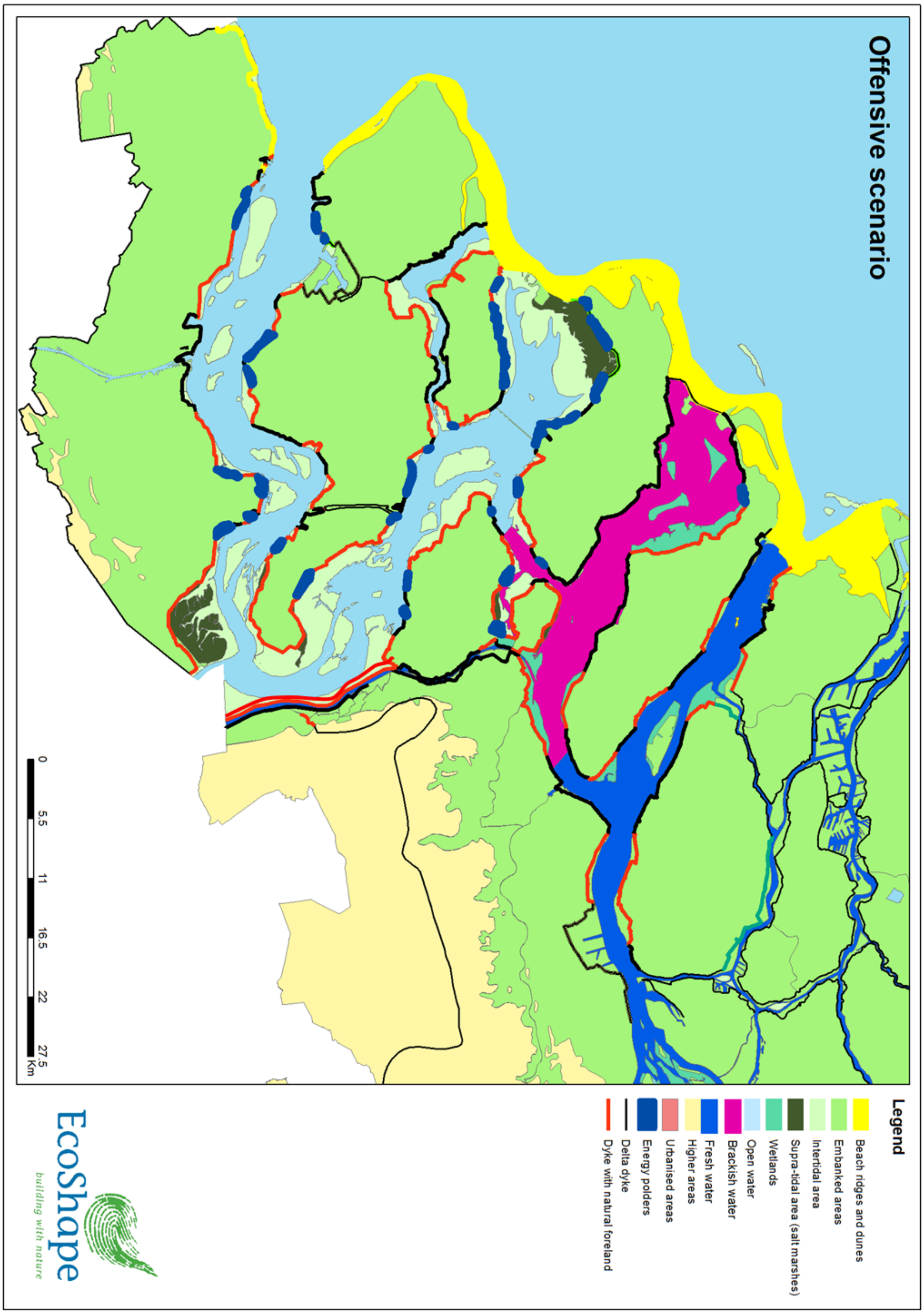


Figure 4.4 impression of a rich revetments (www.innoverenmetwater.nl). b. Example of a rich revetment at Koude- en Kaarspolder near Yerseke where a puddle is created in the fore shore (www.ecoshape.nl).

4.7 Offensive scenario



4.7.1 Introducing the Offensive scenario

Sea level is expected to rise, whereas the former sea arms of Zeeland deteriorate in quality and problems with freshwater supply gradually increase. And perhaps this is not **the** solution for 2100, but it might well be for 2250 as sea-levels have risen even further. The offensive approach to shape the Southwest Delta implies here that the configuration of the delta is modified in such a way that it tames the hydraulic conditions. At the same time it is able to cope with changing autonomous conditions such as sea-level rise and changes in river runoff. In this scenario, the delta basins serve as one long and broad estuary in which all water flowing through the Hollandsch Diep drains into Westerschelde. In this configuration, the entire delta is a gradual salt – fresh water transition.

To achieve this final configuration, the coastline is largely closed off, with the exception of the Westerschelde. Closure will be realized by nourishing the coastline with a surplus of sand. In this way, a broad and safe coastline will develop with twice the present area of dunes. It should be borne in mind that perhaps this does not require extensive extra nourishments because the ebb-tidal delta's in front of the coastline will be worked to the coasts by waves once tidal action (Oosterschelde) or outflow of freshwater (former sea arms north of the Oosterschelde) ceases. At the moment this process is already occurring N of the Oosterschelde area. When this sand encloses the Delta works the larger part of the coastal stretch will become sandy without additional nourishments. In addition to this closure, a connection between the Oosterschelde and Westerschelde is realized: the Overschelde.

The connection between the Westerschelde and Oosterschelde leads to an increase in tidal prism of the Westerschelde: more water will flow through the Westerschelde with the tides. Nevertheless, the tidal range will probably decrease as a result of the reduced funnelling effect. The new configuration dissipates the tidal wave, as well as storm surges. To the north, this dissipation continues. The connected basins also offer a large buffering capacity during periods with high river discharge, without rising the water to extreme heights. In the estuary, a resilient ecosystem will gradually develop that is accustomed to going from Westerschelde to Haringvliet brackish or fresh conditions in a very gradual gradient which minimizes ecological damage of high river discharge periods and/or a storm surges. Upstream, influence of salt-water intrusion associated with a rising sea-level will be less dramatic because the river mouth is extended by over one hundred kilometres.

Storm surges will be able to further invade the delta, thereby testing the dykes. The dykes have to be dimensioned to this peak load. However, the new configuration leads to relatively lower normative water levels than before the Delta Works. Although the extended and reconfigured estuary will dissipate the surge, a combination of peak river discharge and storm surge may lead to extreme water levels downstream in the rivers (Hollandsch Diep). This can be prevented by placing a storm surge barrier comparable to the Maeslant barrier in the Zijpe, the narrowest part of the Oosterschelde. Assuming comparable costs to the Maeslant barrier, the Zijpe barrier would cost about 450 M€. In the scenario that the barrier closes, the northern basins act as a buffer for high river discharges, while at the same time the southern basins dissipate a storm surge.

To maintain a tide-free shipping route between Rotterdam and Antwerp, the former Schelde Rhine Canal is diverted along the eastern shore of the Westerschelde, Overschelde and Oosterschelde.

4.7.2 Removal of dams

To adjust the configuration of the Southwest Delta, most the dams that were constructed for the Delta Works are removed (Oesterdam, Zandkreekdam, Philipsdam, Grevelingendam, Volkerakdam) in this scenario, while the Haringvlietdam, Brouwersdam and Oosterschelde storm surge barrier will be gradually covered by dunes formed by nourishing the shore. The removal will imply costs, but on the other hand high maintenance costs are avoided. With the construction of the Overschelde of about 4 km x 4 km, a large volume of sediment comes available that can be used for the construction of Delta Dykes or for nourishments. Assuming an average depth of the Overschelde of 5 meters, a volume of 80 Mm^3 is available for these purposes.

4.7.3 Nourishment strategy

To create the robust coastline along the North Sea, large scale nourishment takes place. The sediment surplus that is created causes a progradation of the coast, leading to a broad dune area. To reach this goal, sand will be nourished as “feeder beaches” along the coast. This concept involves concentrating the preferred volume of sand on one location, and let natural processes distribute the sand along the coast. An example is the Sand Motor on the Holland coast.

The active sediment demand of the coastal fundament (near-shore area between 0 and -20m MSL) including the Westerschelde is between 3 and 4 Mm3 with the current sea-level rise (2mm/year; Mulder and Van Heteren, 2009; Mulder et al., 2011). Derived from these volumes, in the Offensive scenario we assume an active sediment demand of 1.75 Mm3 per mm sea-level rise per year. Compensating this sediment demand would result in a dynamically stable coastline. However, the Offensive scenario aims to build the coast outward. To achieve this goal and build a robust broad coastline, twice the volume of sand necessary to balance the sediment demand is nourished (Table 4.2).

Table 4.2 Overview of sand nourishment volumes for the Westerschelde and the North Sea coast.

Sea-level rise	Active sediment demand (Mm^3)	Nourished volume (Mm^3)
35 mm/year	6.1	12.2
50 mm/year	8.7	17.4
85 mm/year	14.9	29.8

This approach leads to increased safety, but the dune area will also attract recreants and can accommodate luxurious living. Other benefits include maintaining the infrastructural connections with the mainland and on the long term, a fresh-water body will develop under the dunes. This process can be accelerated by infiltrating fresh water from the rivers.

Within the basins, the current status-quo between sea-level rise and morphodynamics will be maintained by nourishing an amount of sediment equal to the yearly sediment demand caused by sea-level rise. This comes down to a volume of sand equal to the area of the basins multiplied by the yearly sea-level rise. By nourishing an amount of sand into the system equal to the sediment demand, on the long term degradation and associated costs will be avoided.
The Oosterschelde is currently suffering from sand starvation (Van Zanten en Adriaanse, 2008). This sand starvation consists of erosion of the intertidal areas due to reduced tidal prism in the basin after the construction of the storm-surge barrier. The volume of sediment eroded from the intertidal areas was estimated by Hesselink et al., 2003 to be about 1.5 Mm^3

per year. To maintain the current intertidal area, this sand starvation and the yearly sediment demand caused by sea-level rise have to be compensated (Mulder et al., 2011). Because these figures were available for the Oosterschelde, in this basin the sand starvation (1.5 Mm3) and amount of sea-level rise on top of the intertidal areas is nourished. In the other basins, we assume that compensation for the sediment demand of the entire basin caused by sea-level rise results in a stable intertidal area.
The large volumes of sand applied in this scenario can be applied anywhere in the basin where necessary to keep or reinforce the desired functions on a comparable level. For instance, sand flats in front of a dyke can be nourished to well above the present level, thereby facilitating the dyke-safety, and on the longer term covering them with sand dunes. In the same way, salt-marshes can be maintained or their growth can be facilitated. Which type of nourishment is desired depends on the location, the moment and the goal.
Estimated costs for Nourishments vary widely, mainly depending on the source of the sand. Sand from the North Sea is more expensive, but by using sand from the Oosterschelde, the sediment deficit is not compensated and the system deteriorates gradually. In Witteveen + Bos (2010) different nourishment strategies were thoroughly explored. The estimated prices for a cubic metre of sand varied from €5.20 for sand from the Oosterschelde to €13.70 for sand from the North Sea. For the sand to have effect for the long-term sediment balance, in the Offensive scenario it has to be mined in the North Sea. Therefore, in the cost-benefit analysis a price of 13,70/ m^3 (Witteveen+Bos, 2010) is used.

4.7.4 Flood protection

To guarantee safety in this scenario, the dykes have to be reinforced. A concept that fits the Offensive scenario is the application of Delta Dykes (also Climate Dykes or Super dykes; Vellinga, 2008). A Delta Dyke is a dyke that is dimensioned in such a way that breaching is almost excluded. During extreme water levels, the dyke does not fail, but will only be overtopped which results in much less damage then when a regular dyke would breach (Figure 4.5).

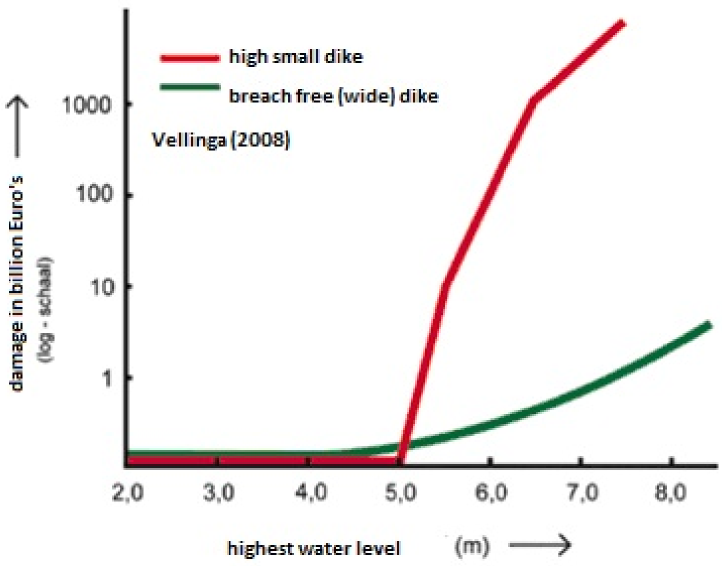


Figure 4.5 Tentative damage curve for narrow and wide dyke (Vellinga, 2008).

Except for safety, due to their dimensions a Delta Dyke can also host a range of other functions such as living, pastures and recreation (Figure 4.6). The concept is however difficult to apply in densely populated areas. In a study for the WNF (Van Winden, Tangelder et al., 2010) to a possible long-term development of the Haringvliet, three concepts of Delta Dykes have been worked out for application in various areas (Figure 4.6):

- Delta Dyke in suburban areas: broad dyke of 190 meters wide which creates space for fields and pastures, infrastructure and sub-urban living.
- Delta Dyke in urban areas: relatively narrow dyke of 90 meters wide which makes it applicable in densely populated areas. The dyke can be set up for urban living and infrastructure.
- Delta Dyke in rural areas: broad dyke of 200 m wide. Terraces on the sea side enable growing of salt tolerant vegetables and/or nature/recreation and infrastructure. The widest part of the dyke is suitable for recreational living, nature areas and small pastures.

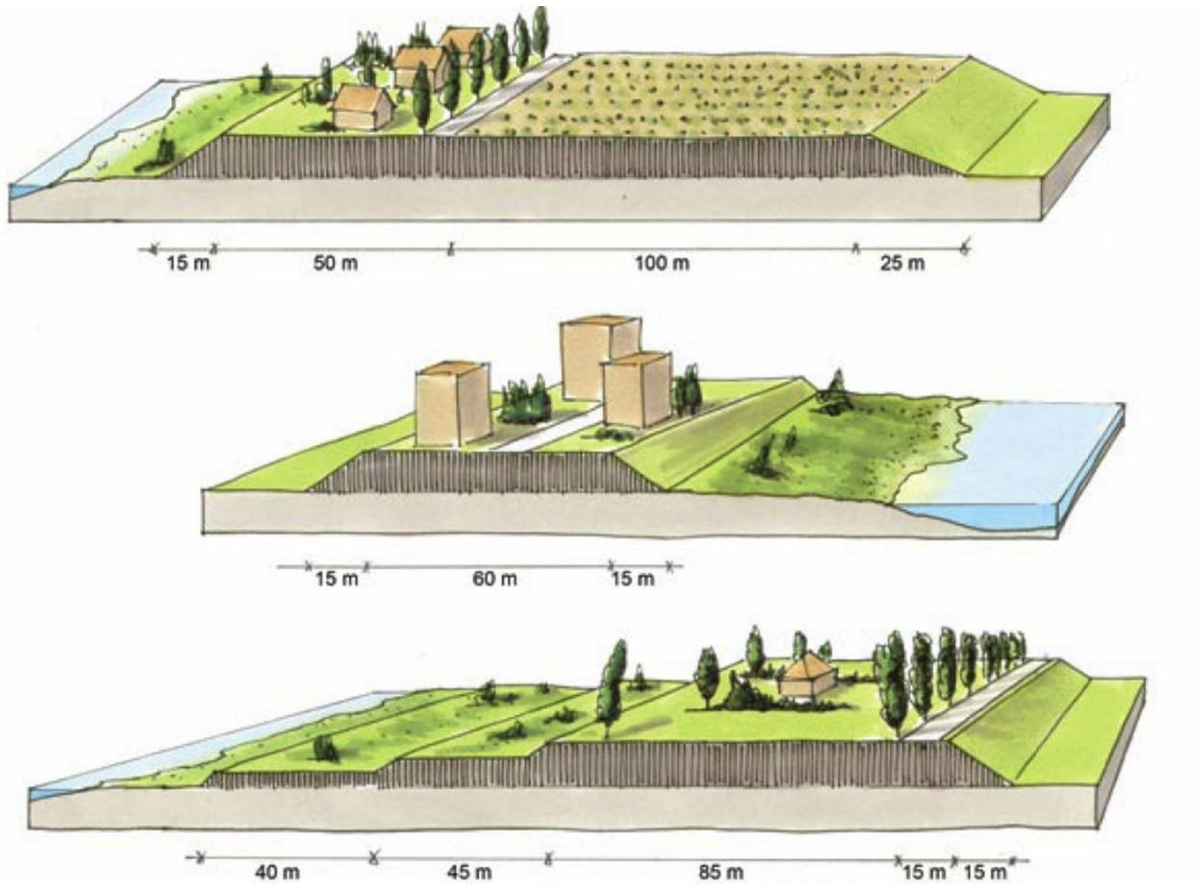


Figure 4.6 Three possible designs for the application of Delta Dykes (Van Winden, Tangelder et al., 2010).Upper panel: sub-urban Delta Dyke; Middle panel: Urban Delta Dyke and lower panel: Rural Delta Dyke.

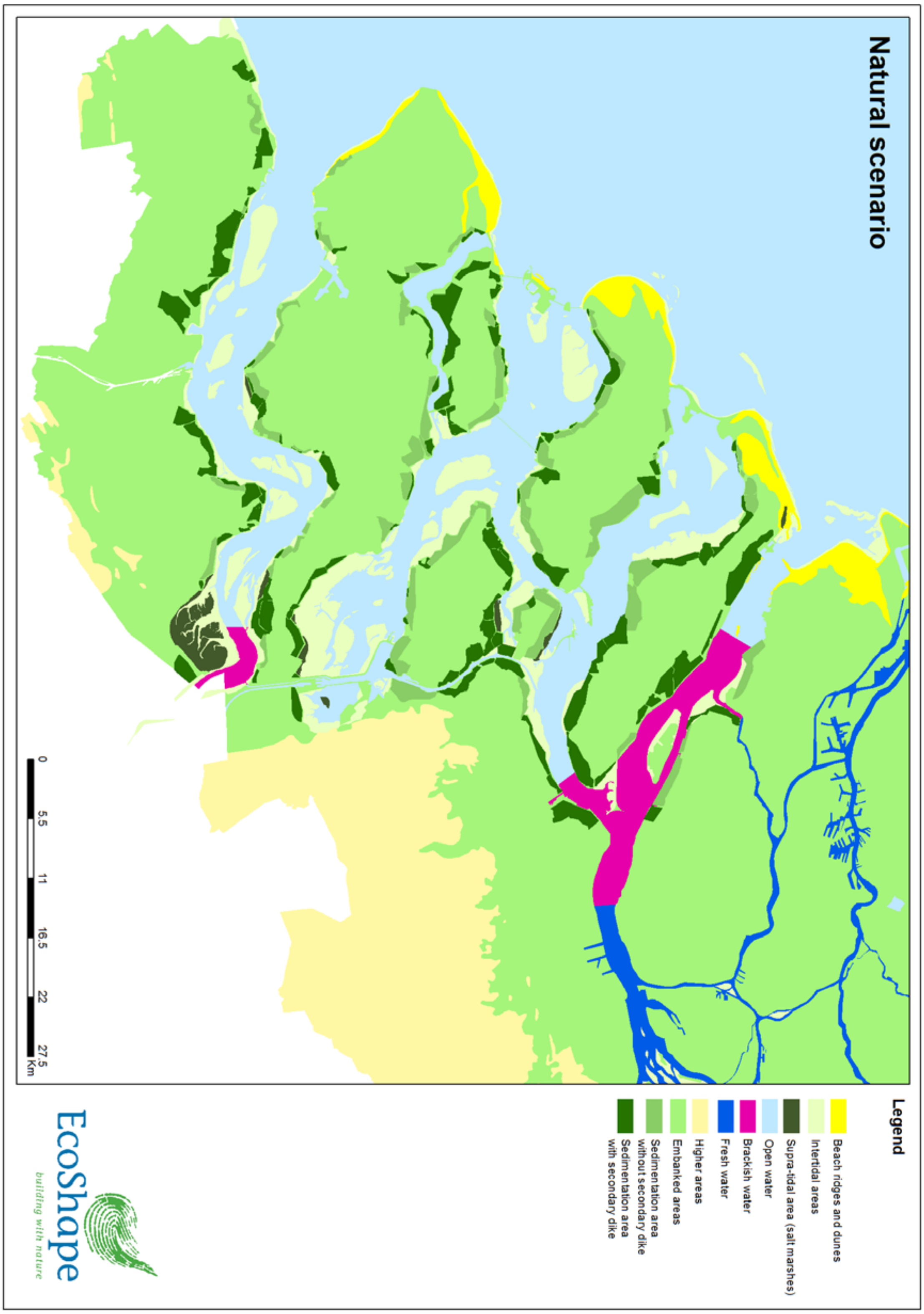
In the Offensive scenario, Delta dykes will only be applied in areas where the dyke is not protected by a foreland (sand flat, salt marsh or wetland) or when the dyke is backed up by a secondary dyke. In this scenario, Delta Dykes will only be constructed at a few locations along the Eastern- and Western Scheldt. The dykes are assumed to be constructed one time,

no matter what the sea-level rise will do in the coming century. The cost benefit analysis for this scenario calculated with the concept of an unbreachable dyke. Hence, the dimension is the minimal version of a Delta Dyke.
Locations where the dykes are backed up by an older secondary dyke, will be organized as an energy polder (Figure 4.7). In Energy Polders, energy from the tides that flows in and out the polder through turbines is converted into electricity. Energy Polders are especially favourable in areas with a high tidal range. To construct an Energy Polder, the secondary dyke has to be strengthened, and an inlet has to be build in the miniature-polder.

Figure 4.7 Artist impression of an energy polder at the Prosper Polder and Hertogin Hedwigepolder before (left) and after (right) construction (Haskoning, 2009).

Since the secondary dykes only have to be reinforced and the primary dyke has no function for safety, investments associated with the construction of an energy polder can be minimized. Areas in the Offensive scenario that are most suitable for energy polders are the small polders along the Westerschelde and Oosterschelde, because the tidal range is high enough.

4.8 Natural scenario



4.8.1 Introducing the Natural Scenario

Another extreme scenario which might be challenging for policy makers is a return to the " old situation". The Natural scenario would be more or less the situation we would have had without the Delta Plan. In the Natural scenario of the SW-Delta focus lies on recovery of estuarine dynamics and utilization of natural processes to benefit a more robust coastal zone (*Building with Nature*) and create opportunities for new land use practices (e.g. aquaculture, saline crops and recreation).

Focus

The Delta Works have greatly diminished estuarine dynamics. Furthermore, on-going land reclamation has reduced intertidal areas and shallow waters that are now embanked by dykes. The key principle of the Natural scenario is to regain estuarine dynamics and natural processes and also benefit human use. This can be done by widening the coastline in either sea- or landward direction (or a combination of both) depending on boundary conditions and local circumstances. As it is an "extreme" Natural scenario, the design aims to investigate the rather extreme limits of estuarine recovery and coastal zone development.

The main principles for this scenario therefore are:

- Enhance estuarine dynamics by complete removal of all Deltawork dams
- Move from coastline to a robust coastal zone
- "Grow with the sea"
- Create new land-use opportunities

Figure 4.8 illustrates the Natural scenario with open sea arms and broad coastal zones.

4.8.2 Goal

To investigate the potential of *Building with Nature* measures to benefit a robust and safe coastal zone with land use opportunities when realizing large scale estuarine recovery and broad sea defence zones.

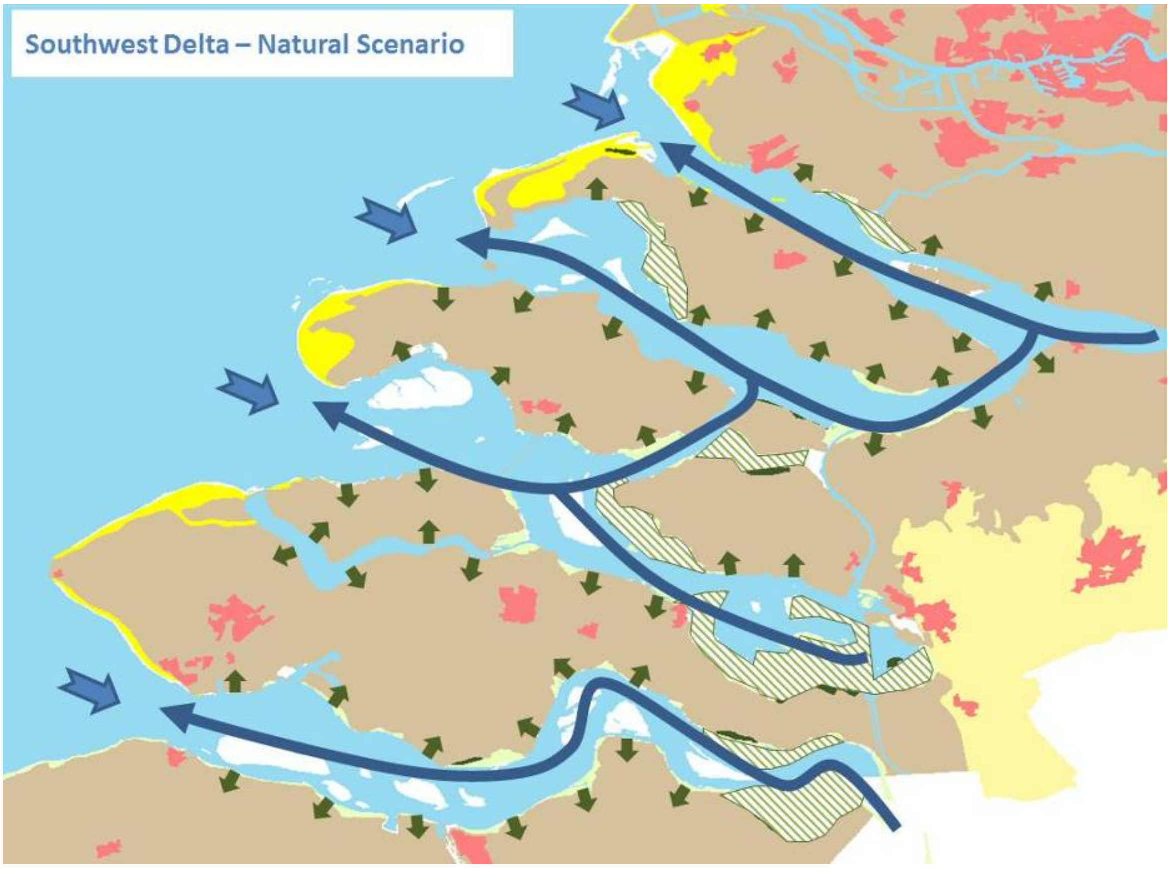


Figure 4.8 General overview of the Natural scenario principles: open connection between river and sea, broadening of the coastline by protecting forelands or managed realignment in landward direction.

4.8.3 Building Blocks Natural scenario

In the Natural scenario, applications of several Building with Nature measures or concepts are explored and listed below:

Managed realignment – sedimentation areas
In the Natural scenario application of managed realignment is explored for two reasons. The main reason is to investigate potential for salt marsh recovery as sedimentation fields that gradually increase in elevation to form a broad barrier in front of the new inland defence and attenuate wave energy. This is done for every basin in the SW Delta The second reason is to explore more generally the options for (new) land use (aquaculture, aquatecture, saline crops, recreation) in the realigned areas and how these benefits weigh up to loss of pre-realigned land use functions (cropland, fields etc.). We will refer to managed realigned area as “sedimentation areas”, as the goal is to obtain elevation rise by sedimentation. A sufficient sediment load of the water is a prerequisite for elevation rise. To explore the potential of managed realigned areas in relation to sediment loads, a “sediment workshop” with experts helped to gain more insight. A summary of this workshop is included in Appendix E.

Ecosystem engineers: oysterreefs
In the Natural scenario we investigate the application of reefs made of Pacific oyster (*Crassostrea gigas*) shells. The Pacific oyster may be a suitable ecosystem engineer because it creates extensive reefs, formed by densely packed individual oysters growing upward and

outward on top of each other. These reefs influence local ecology by creating shelter, increasing sedimentation and organic matter content through bio-deposition. (Piazza, Banks et al. 2005) and enlarge biodiversity by creating new habitat (Borsje, Van Wesenbeeck et al. 2011).

Innovative dyke concept: Delta dykes and Rich revetment

In the Natural scenario several Building with Nature coastal defence strategies are investigated that strive for maximising system potential. However, these strategies cannot be applied along the entire coastline in the SW Delta due to unfit boundary conditions or social-economical aspects. In some places landward expansion of the coastline is not possible (because of an urban agglomeration or industry for example) and conditions for seaward expansion are unsuitable (high currents, absence of intertidal area etc.). In these areas there is no other option than using dykes. However it is possible to “upgrade” traditional dykes to benefit land-use and ecology. Where Building with Nature measures cannot be applied, innovative dykes will ensure safety. In the Natural scenario all dykes that remain are adjusted with inclusion of the Rich Revetments concept. This creates extra ecological potential in places where hard coastal defence (dykes) has to be sustained.

4.8.4 Overview

Table 4.3 shows detailed information on sizes of several components. All information of measures, salinity, elevation and accretion rates is included in Appendix F. For the sedimentation areas a division was made in areas with and without an inland secondary dyke. These dykes are remnants of the reclamation works and once served as coastal defense. Now tides are re-introduced into the polder they serve as protection of the hinterland once again. This subdivision between areas with and without secondary dykes is made because there is a substantial difference in construction costs.

Type	**Area/length**
Sedimentation area (with secondary dyke)	18.978 ha
Sedimentation area (without secondary dyke)	12.042 ha
Foreland	27.672 ha
Delta dykes	146 km

Table 4.3 details Natural scenario

4.8.4.1 Fresh to salt gradient

In the Natural scenario the original open connection between rivers and the North Sea will be restored, which means there will develop a gradual gradient from fresh to salt. Based on a study by Wolff (1973) salt concentrations before the Delta Works were reconstructed (Figure 4.9). With these data is determined which managed realigned areas will become fresh, brackish and salt water marshes (Figure 4.10). The salt concentration of the water determines to a large extent the vegetation types that will develop in the managed realigned areas (Figure 4.11).

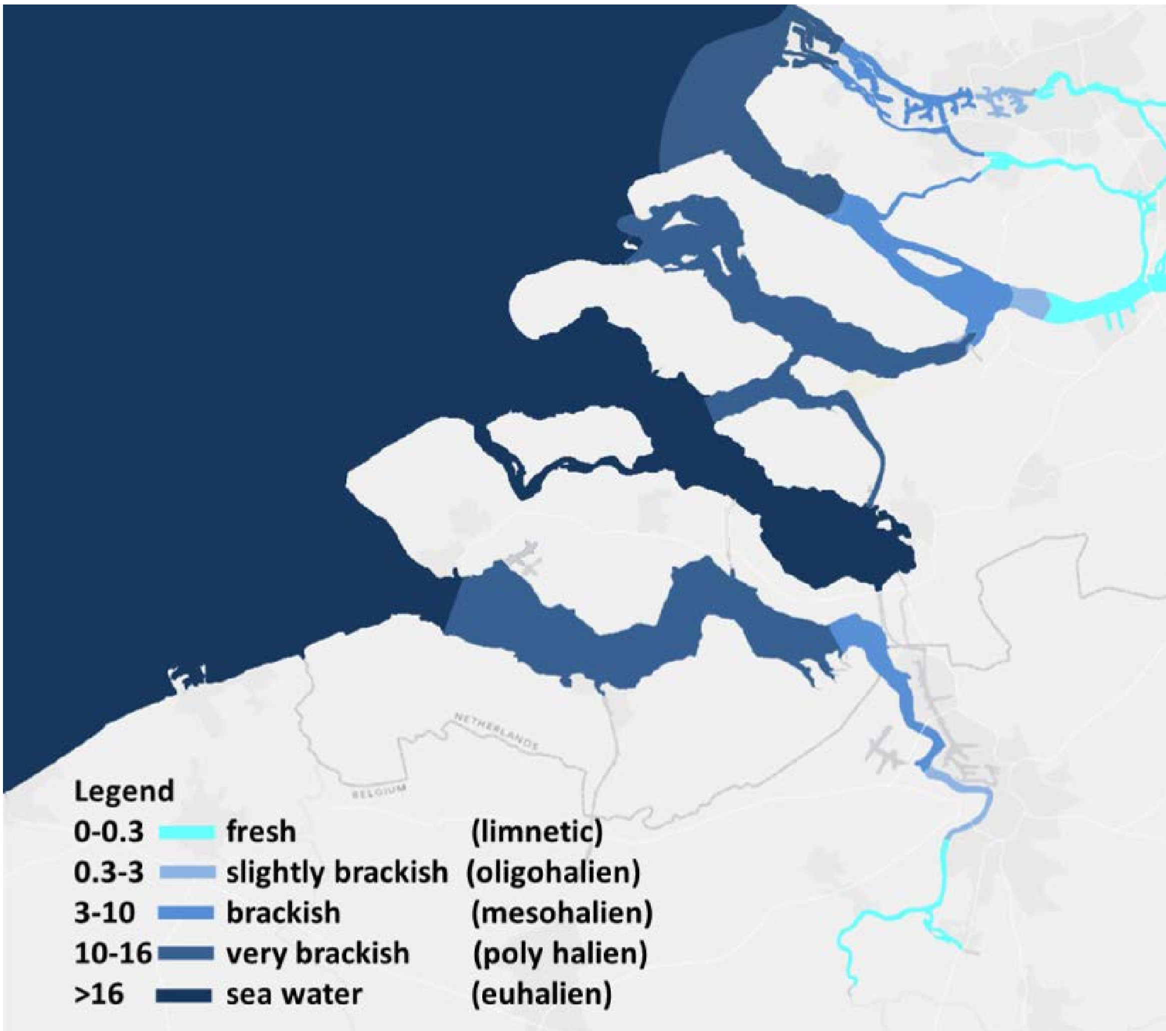


Figure 4.9 salinity of the bottom water of the Delta area at high tide during an average river discharge reproduced from Wolff (1973) and expressed in CL‰.

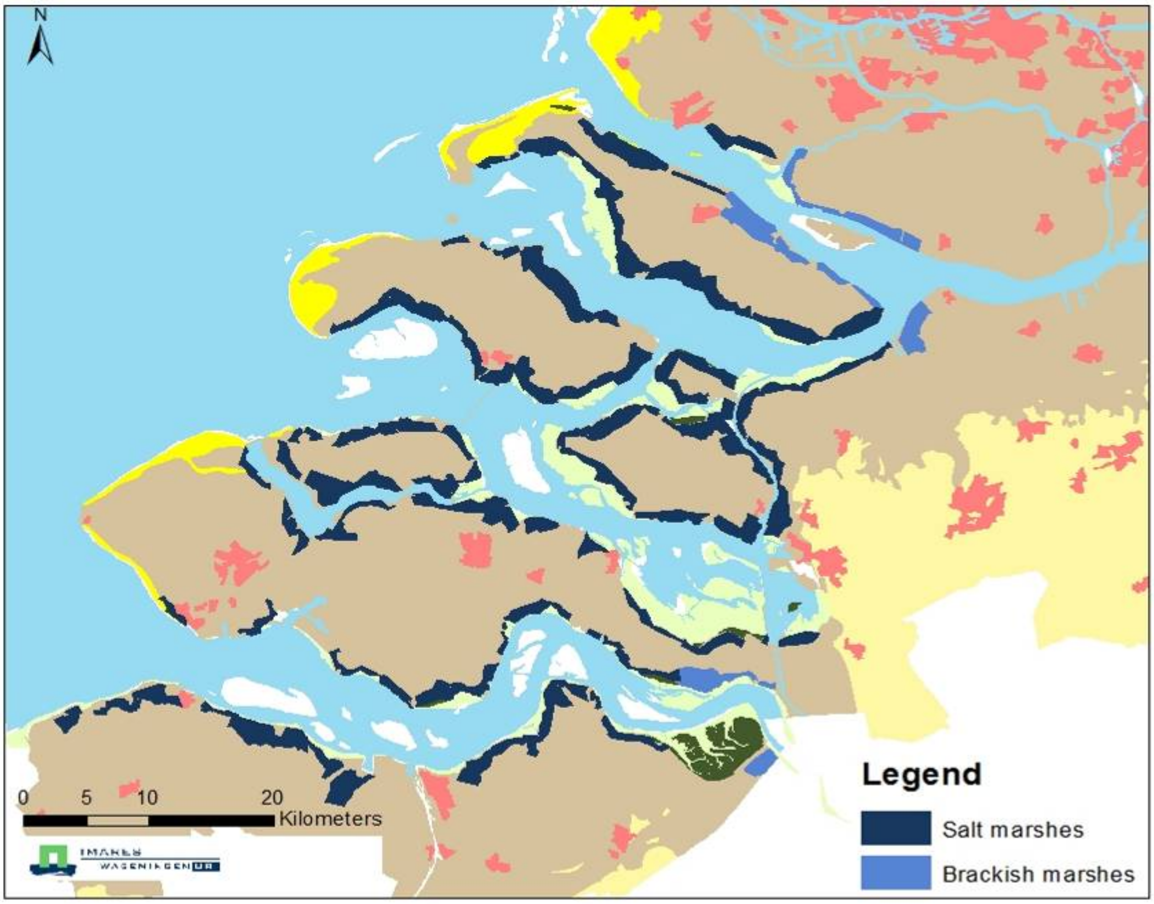


Figure 4.10 location of salt and brackish water marshes of the realigned areas in the Natural scenario. Salt marshes >10 CL‰ and brackish marshes 3-10 CL‰.

4.8.4.2 *Accretion of sediment areas*

Marsh development

Sediment areas will start to capture sediment once the tide is re-introduced in these areas. Development of marshes is an important prerequisite for sedimentation and gradual elevation of the area. The position of the area in the tidal frame determines whether tidal flat or marsh will develop (French 2006). Marsh development takes place above Mean High Water Neaptide level (MHWN) (Vandenbussche et al. 2002).

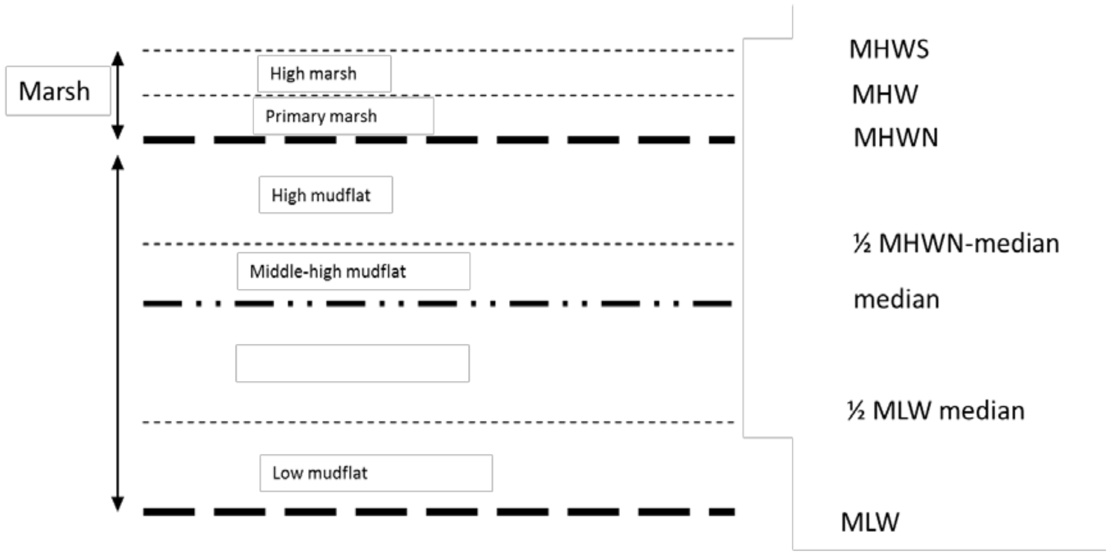


Figure 4.11 An overview of the position of intertidal habitat types with respect to sea level (median). MLW=Mean Low Water, MHW= Mean High Water, MHWN= Mean High Water Neaptide, MHWS=Mean High Water Springtide (Soresma 2009)(translated).

Tidal frame

Historic tidal data were (Table 4.4) used to determine the MHWN threshold for marsh development (Table 4.4 and Figure 4.12). Tidal amplitude can differ considerably from east to west. Therefore the delta was subdivided into nine sections for which tidal data were determined.

*Table 4.4, Mean Low Water (MWL), Mean High Water (MHW) and tidal amplitude levels in basins of the SW Delta before the execution of the Delta Works based on historic data in cm +/- NAP. Mean High Water Neap tide (MHWN) is based on the assumption MHW – 20% = MWHN. *Estimated mean tide levels with assumed symmetrical tides. In reality these levels could deviate 10-20 cm.*

Basin names and sections	**historic data**	**MLW**	**MHW**	**MHWN**	**ampli tude**	**reference**
Hollandsch Diep	Willemstad Moerdijk Mean	-85 -75 -70	+85* +75* +70*	+56	140	(Haring 1947; Haring 1947)
Haringvliet		-100*	+100*	+80	200	(Tönis, Stam et al. 2002)
Krammer Volkerak	265+242	-129*	+129*	+103	258	(Vroon 1994)
Grevelingen East	303	-152*	+152*	+122	303	(Vroon 1994)
Grevelingen West	234	-117*	+117*	+94	234	(Vroon 1994)
Oosterschelde East	340+378	-180*	+180*	+144	359	(Vroon 1994)
Oosterschelde West	293+279	-143*	+143*	+114	286	(Vroon 1994)
Westerschelde East	Saeftinghe 1940	30	+475	+380	445	(Van Braeckel, Piesschaert et al. 2006)
Westerschelde West	Vlissingen 1940	47	+415	+332	383	(Van Braeckel, Piesschaert et al. 2006)

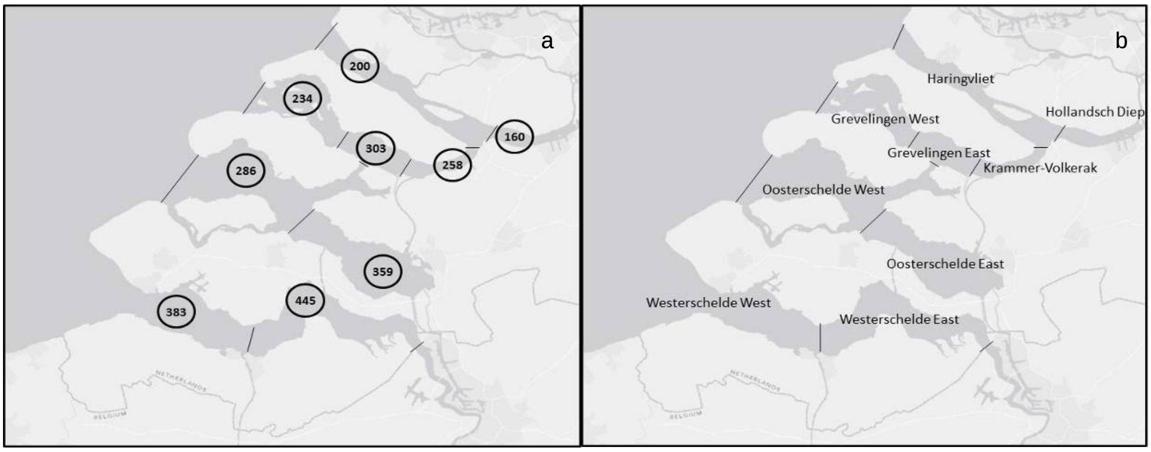


Figure 4.12 Tidal amplitudes before the Delta Works a: tidal amplitude, b: basin names and sections.

Elevation

Mean current elevation of the sediment areas was determined (Appendix F) using elevation data (www.ahn.nl; Figure 4.13). With these elevation data could be determined which areas would develop to tidal flats and marshes at the time of construction. The sedimentation rate and degree of sea-level rise determines their development over time.

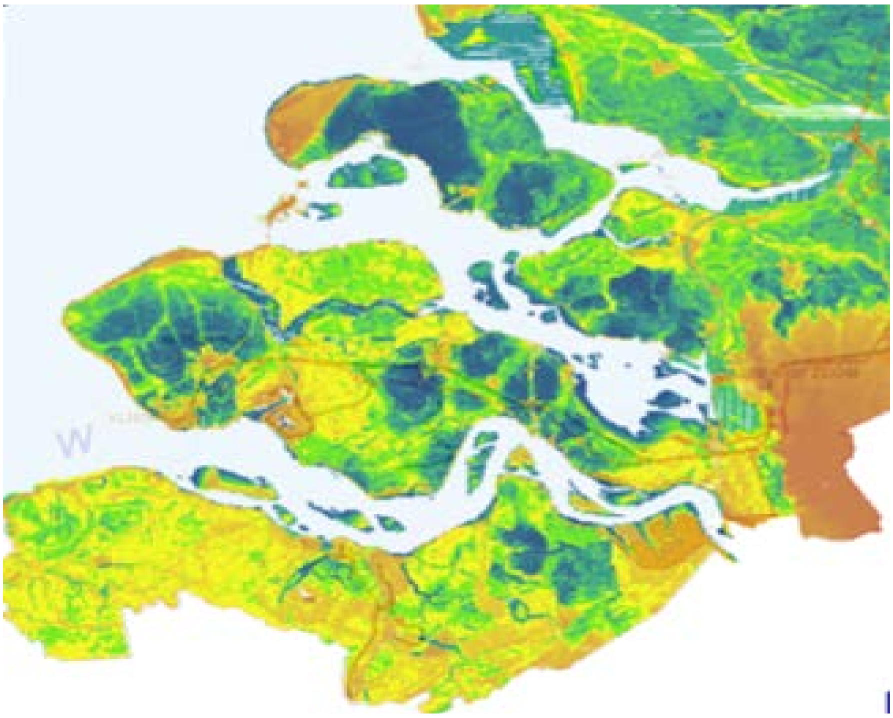


Figure 4.13 Elevation of the Southwest Delta: red is high and blue is below sea level.

Accretion rates and sea-level rise

In an open estuary sediment from the North sea and the rivers can freely access the basins. Sediment load is expected to be 20mg/l up to 100mg/l on the shallow shoreline (expert workshop). In the Westerschelde concentrations lie around 25-100 mg/l with a maximum on the Dutch-Belgian border with mean concentrations around 100-200 mg/l based on monitoring data 1996-2001 (Van Damme, De Winder et al. 2001). Based on a study by (Temmerman, Govers et al. 2004) accretion rates of young marshes in the Westerschelde

(1931-1955) was 1.6-3.2 cm and 0.4-18cm/y of older marshes (1955-2002) with an average of 1.5 cm/year. Based on expert judgement the average accretion rate in the other basins is expected to be 1cm/year (expert workshop).

Between 2000-2100 sea-level will rise 35 to 85 cm with a mean of 50 cm. This is expected to rise further to 100-250 cm in 2300 (KNMI 2006). Sea-level rise will influence the position of the sedimentation areas in the tidal frame. The height above which marsh development will be possible will thus increase.

Figure 4.14 shows development of tidal flats into marshes in the managed realigned areas over time at 50cm sea-level rise.

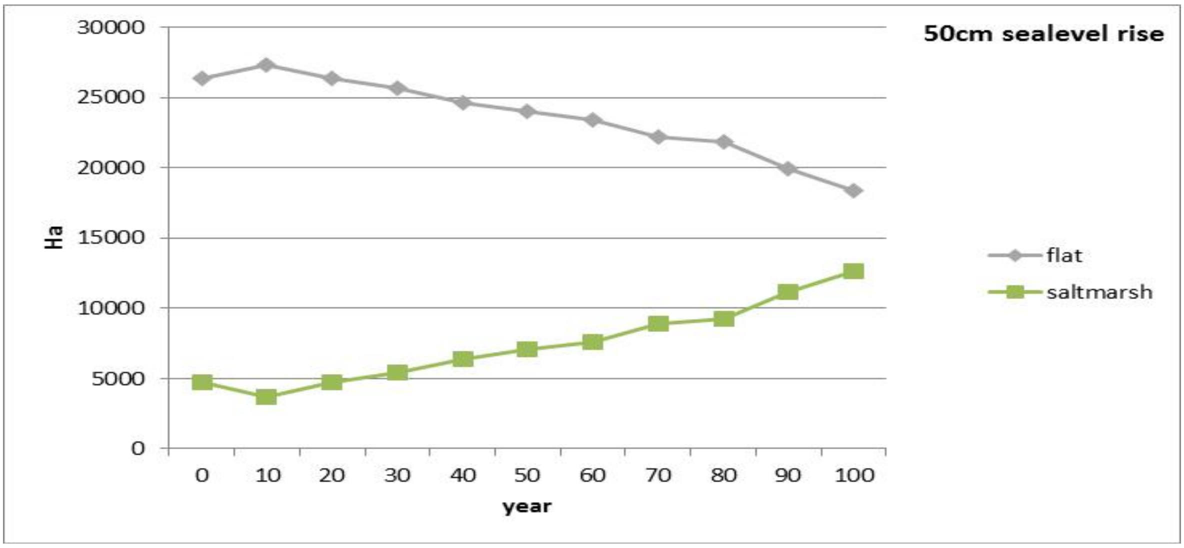


Figure 4.14 Development of tidal flats into marshes in the managed realigned areas over time at 50cm sea-level rise.

Aquaculture

A study by De Mesel et al. (2012 (in preparation)) describes several forms of aquaculture and cultivation of saline crops that are possible in a re-inundated saltwater tidal area. As the main goal of a realigned area is elevation increase by sedimentation, land use forms should be extensive without hampering the sedimentation process. Table 4.5 describes several forms saline land use with a potentially high market value, based on De Mesel et al.(2012 (in preparation)) and related studies .

Table 4.5: Aquaculture and saline crop yield in an managed realignment area based on a study by De Mesel et al. (2012 (in preparation)) and related studies.

Type	Species	Method	Yield	Reference
Shellfish	Blue mussel –*Mytilus edulus*	Mussel growth on poles (“Bouchot”) in the intertidal zone	41920€/ha/year	www.fao.org
	Pacific Oyster – *Crassostrea gigas*	Oyster growth on “tables” in the intertidal zone	25000€/ha/year	www.fao.org
	European flat Oyster – *Ostrea edulis*	Oyster growth on “tables” in the intertidal zone	20900€/ha/year	(Van der Hiele, Heringa et al. 2008) and related references
Worms	Ragworms - *Nereis virens*	Extensive digging for rag worms at low tide		
Sea weeds	Tough Laver - *Porphyra umbilicalis*	Marcoalgae attached to floating devices	651	(Lobban and Wyne 1981)
	Hudson - *Gracilaria verrucosa*	Marcoalgae attached to floating devices	435	(Xin 1989)
Plants	Common glasswort – *Salicornia europaea* (Salt marsh)	Saline crop field	84000€/ha/year	(Van de Voort, Dekking et al. 2005) and related references
	Sea aster – *Aster tripolium* (Salt marsh)	Saline crop field	35000€/ha/year	(Goosen 1999)
	Common reed-*Phragmites australis* (Brackish marsh)		2€/ha/year	(Ruijgrok, Smale et al. 2006)

5 Cost benefit analysis

5.1 Introduction

In this chapter the socio-economic cost-benefit analysis for the three scenarios in the Southwest Delta is described. It starts with an explanation of the method, including the working steps of the analysis. In paragraph 5. the results are presented and interpreted. In the following paragraph (5.4) the robustness of the outcome is tested in a sensitivity analysis. The data and experience numbers that are used to calculate the costs and benefits are documented in the appendices. Most of the experience numbers are documented in the factsheets of the building blocks (Appendix B). The scenario specific numbers and data are described in appendix G.

5.2 Socio-economic cost-benefit analysis

In the public decision making process, it is becoming less and less acceptable to spend tax payers' money on projects that do not clearly have significant socio-economic benefits. That is why in the year 2000, the Dutch Government decided that socio-economic Cost Benefit Analyses (CBA) should be conducted prior to investment decisions. Socio-economic cost-benefit analysis is a method to assess all positive and negative impacts of an investment (project) to society as a whole. In the cost-benefit analysis financial impacts, environmental impacts and social impacts are considered. All these impacts are expressed in monetary terms (money). The advantage is that all impacts can be added so that it becomes clear if an investment has a positive or negative balance. When the balance of a project is positive, the investment is socio-economically sound. Because all impacts are expressed in monetary terms, different alternative projects can be easily compared with each other. So, socio-economic cost-benefit analysis is a decision support tool, which is used for large investments.

One of the special features of a social cost-benefit, as opposed to a 'normal cost 'benefit analysis is that it takes into account not only those effects which have an impact on the direct financial costs and benefits of a project, but all effects that have an impact on human welfare. So, a CBA will also look at the value of nature or at social values. For example the value we address on leaving cultural historical items to the generations after us. Even if it has no direct market price, things like this can be important to us in our lives and provide us welfare.
A socio-economic cost benefit analysis is therefore an assessment method that encompasses a trade off between all present and future effects of a project which affect our welfare. In a CBA the advantages, i.e. benefits and disadvantages, for not just one person, company or sector are looked at, but benefits and costs of all stakeholders are integrated. If the benefits of the winners outweigh the costs of the losers, a project is considered to be a sound investment, as it generates a net welfare gain to society.

To perform a CBA the following steps have to be taken (from: Witteveen+Bos, 2008):

1. Describing baseline.
2. Describing project alternatives.
3. Cost calculation of every alternative.
4. Identification and assessment of physical impacts for every alternative.
5. Identification, quantification and monetisation of welfare impacts for every alternative.
6. Discounting and making up the balance.
7. Sensitivity analysis.
8. Conclusions and recommendations.

If the balance is negative, the design of one or more a project alternatives could be improved. By doing this several times (iteration) the alternatives can be optimized. Figure 5.1shows this iterative process.

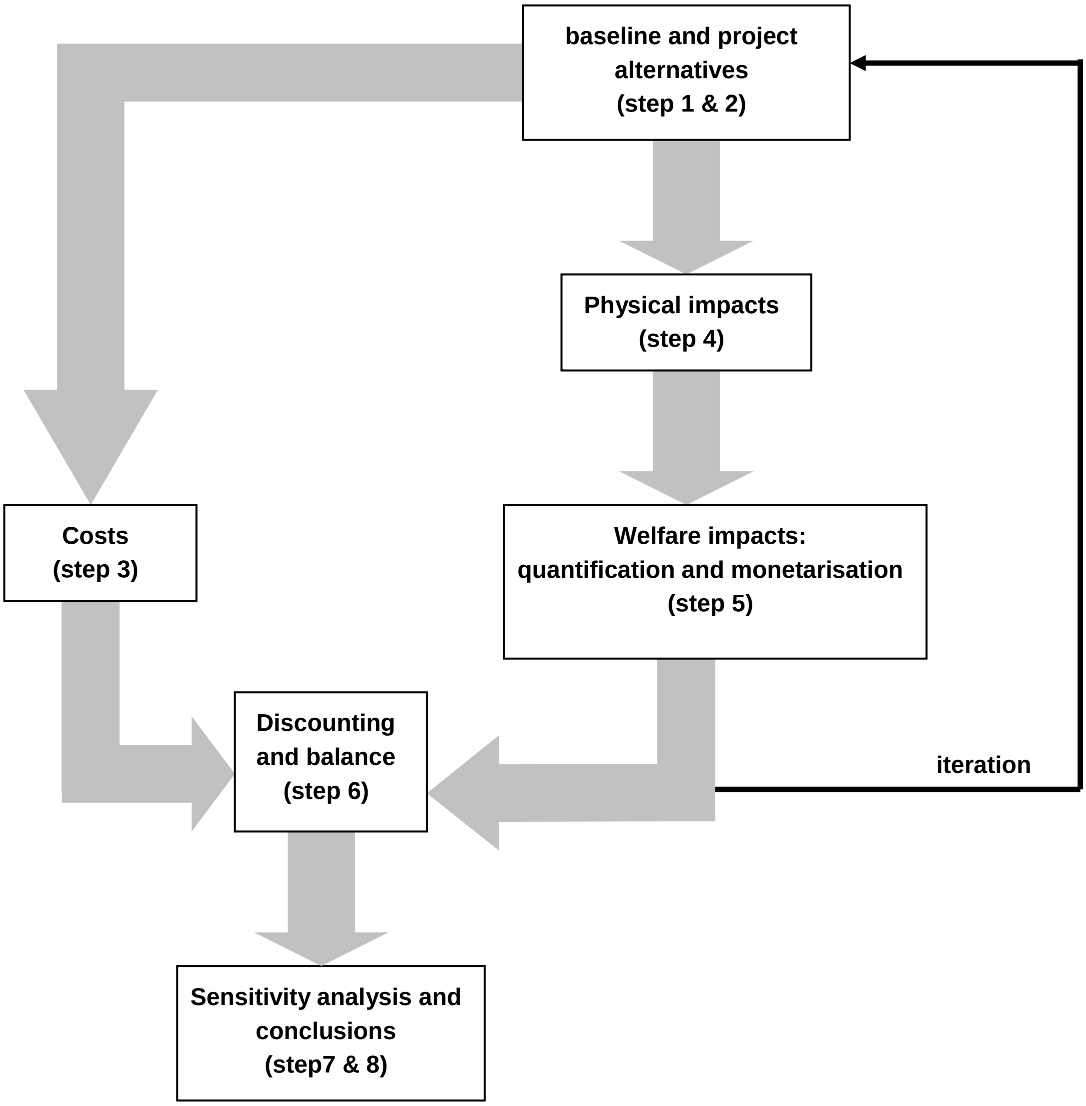


Figure 5.1 Working steps of a socio-economic cost benefit analysis.

Step 1 & 2) The CBA of the Southwest Delta is somewhat different. There is no baseline. Instead, we compare the three scenarios because we are interested in the differences between the used concepts in the scenarios. So this CBA describes these three scenarios and treats them as they were project alternatives. The concepts used in the scenarios, for example managed realignment, delta dykes and energy polders are described as are their impacts on the surroundings. Using different kinds of modelling and GIS-analyses it is calculated how many kilometres of dykes, hectares' of coastal buffer zones, reed marshes, intertidal flats etcetera there are in the three scenarios and how this evolves over time (the next 100 years).This is done for the three climate scenarios.

The scenarios focus on the application of Building with Nature in the entire Southwest Delta on the long term (100 years). On such long time and large spatial scales it is impossible to capture the entire complex system of economy, ecology, demography and hydraulic processes in a Cost Benefit Analysis within this project. Therefore the focus is on matters of flood protection, estuarine processes and hydraulic infrastructure.

Step 3) Per scenario the costs are calculated. The costs of the scenarios comprise:
- Investment costs (Euros);
- Cost of operation and maintenance (Euros per year).

Usually the investment costs are made at the start of the project and are made just once. In the Southwest Delta CBA there are also investment costs to be made annually. Costs of operation and maintenance are made during the lifetime of the project on regular intervals. All costs (and benefits) are expressed as net present value (with a standard discount rate of 5,5%).

Step 4 & 5) Every benefit is a quantity times a price. The quantity depends on local conditions and its estimation is always tailor made. In order to make the tailor made estimates easier one can use models (e.g. to estimate travel time reductions in case of a road construction project) or one can use standard numbers (e.g. a standard number for the yearly amount of nitrogen that a reed land can remove from the water).
In a CBA all welfare effects are expressed in monetary terms. Some effects are logical to express in monetary terms. Take for example the Natural scenario. In this scenario mussels and pacific oysters are being harvested. It is easy to understand that when sold the mussels and oysters generate money and so the benefits are clear. On the other hand is it much harder to understand how the growing area of salt marshes in the same scenario contributes to welfare and especially hard to think of a figure in Euro's which represent the benefits of the salt marshes.

This is just one example of effects that are hard to express in Euro's. The same goes for effects like air pollution, noise and depletion of natural resources. These are common goods without a market price. Moreover these effects are mere physical impacts on the environment. It is not yet clear how they affect human welfare. That is why physical impacts must be translated into welfare impacts before they can be socio-economically valued. To give an example, in the Natural scenario the area of salt marshes grows. Salt marshes can uptake heavy metals and by doing that contribute to a decrease in pollution. The welfare effect of this decrease in pollution is a contribution to the health of (local) people that use the water. The prices for effects in a CBA can be obtained from standard pricelists or by consulting experts. In the Netherlands a special handbook has been made containing standard numbers for quantification and standard price tags for the valuation of impacts on nature, water, soil and landscape. This serves as a tool to make the computation of non-market impacts quicker and easier.

Step 6) After quantification and monetisation of the various costs and benefits, they are put on a time line. Some of the costs and benefits are unique (they occur only once). Other costs and benefits are recurring, such as costs of operation and maintenance. As said the costs and the benefits should be made comparable by discounting. The discount rate used for socio-economic cots benefit analysis of the Southwest Delta is 5,5% and the time horizon is infinite. All discounted cost and benefits of the natural, offensive and Defensive scenario are summed per climate change scenario. The result is the net present value of each of the scenarios. Based on the net present value, the three scenarios can be compared to each other and statements can be made about the influence of climate change on the costs and the benefits.

Step 7) In the CBA of the Southwest Delta there are uncertainties. A lot of input data is the result of models. These models are simplified reproductions of reality. Because of that the outcomes are never certain. Also sometimes, to calculate the costs and benefits, assumptions are made or experts are asked to make an educated guess. These assumptions or guesses can lead to over- or underestimations of the effects. Therefore a sensitivity analysis is highly recommended. Insight in the robustness of the ranking of the project alternatives is important. For example, it is known that the choice of discount rate has influence on the net present value. Therefore the computations of the CBA should be made with varying discount rates. If the ranking of the project alternatives does not change for different discount rates, the result of the CBA is robust. On the other hand, if the ranking is highly sensitive for changing discount rates, one should be careful drawing far-reaching conclusions.

The cost-benefit analysis provides insight into which costs and benefits are particularly relevant for the outcome of the analyses. If these important costs and benefits are based on uncertain data the analysis may not be very robust. So, a second part of the sensitivity analysis is to investigate whether the ranking of project alternatives is sensitive to variations in uncertain data. This analysis can be carried out by repeating the computations with altered data. Finally the outcomes of the CBA are presented in a report. In this case, the outcomes of the Southwest Delta scenarios are presented and discussed in chapter 6.

5.3 Comparison of scenarios

In this chapter the results of the socio-economic cost benefit analyses are presented. The most important benefit - coastal protection - is not expressed in monetary terms (only included as a pro memory aspect). This is a difficult aspect to calculate and does not differ between the three scenarios. All three scenarios generate the same protection level - so calculation is of minor importance.

Normally a cost-benefit ratio of < 1 indicates a negative advice on the project/ scenario. That is not the case in this study as the coastal protection has to be guaranteed. This study generates information in which *way* coastal protection can be generated and the costs and benefits that are linked to these different strategies. The results should be interpreted as a comparison between the scenarios. Table 5.5.1 shows the overall results in terms of costs and benefits of the three scenarios.

Table 5.5.1 Socio-economic costs and benefits of the three scenarios (in M€, interest 5,5%, 50 cm climate scenario).

	Defensive scenario	Offensive scenario	Natural scenario
costs	3,801	8,034	14,258
benefits	906	2,948	5,786
balance (benefits-costs)	-2,896	-5,086	-8,472
ratio (benefits-costs)	0.24	0.37	0.41

Table 5.1 shows the results for the average climate scenario (50 cm sea-level rise). The Defensive scenario has the best (least negative) balance. This indicates that the Defensive strategy is the most efficient strategy. In figure 5.2 and 5.3 the balance and ratio are presented over the different climate scenarios.

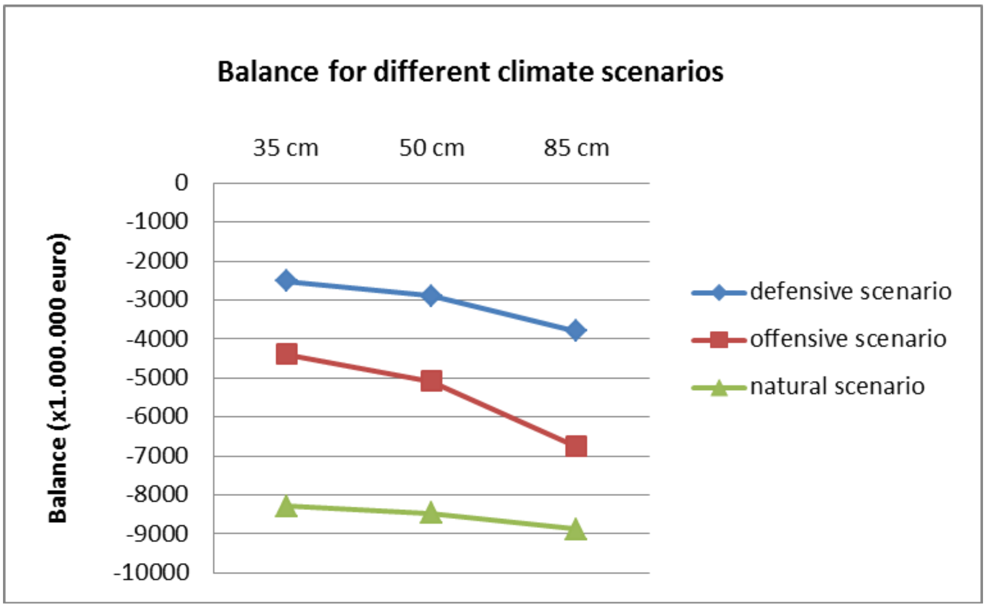


Figure 5.2 Balance for different climate scenarios.

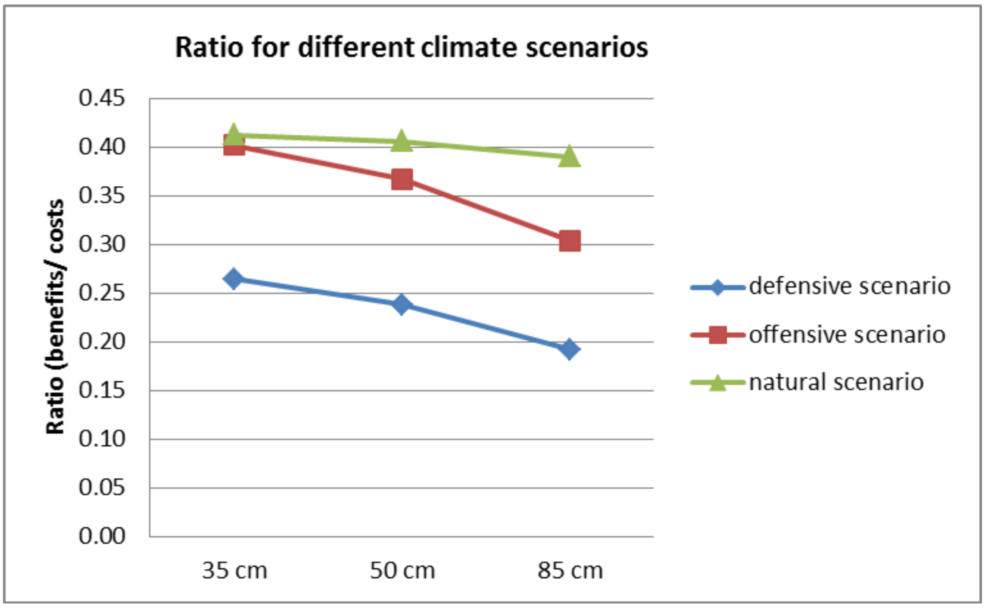


Figure 5.3 Ratio for different climate scenarios.

Figure 5.2 shows that the Defensive scenario stays the most efficient strategy, even when the climate change gets more serious. The Natural scenario gets more effective when the climate change gets more extreme. Costs and benefits remain more or less the same, while the costs of the other scenarios rise significantly.
The ratio of benefits and costs (Figure 5.3) of the Defensive scenario however is smallest, meaning that per invested euro this scenario returns the least benefits.

5.3.1 Defensive scenario

In Table 5.5.2 the results of the Defensive scenario are presented.

Table 5.5.2 Socio-economic costs and benefits of the Defensive scenario (in M€, interest 5,5%)

climate scenario	35 cm	50 cm	85 cm
Costs			
Sand nourishment Delta total	612	873	1,494
Regular dyke enforcement	279	398	677
Construction rich levees	18	18	18
Construction overtopping resistant dyke	280	280	280
Construction opening Brouwersdam	260	260	260
Construction opening Grevelingendam	82	82	82
Maintenance costs civil engineering works	1,439	1,439	1,439
Maintenance costs additional adaptations	451	451	451
Costs total	3,421	3,801	4,702
Benefits			
Coastal protection	+ p.m.	+ p.m.	+ p.m.
Production aquaculture	483	483	483
Clean surface water	726	726	726
Protection against climate change	7	7	7
Saved costs dyke reinforcement			
Non-use value nature	-98	-98	-98
Recreational expenditures	0	0	0
Recreational perception value	-212	-212	-212
Benefits total	906	906	906
Balance	-2,515	-2,896	-3,796
Ratio (benefits/costs)	0.26	0.24	0.19

The Defensive scenario can be seen as the most effective strategy. The success of this scenario is mainly the minimisation of the costs. The strategy connects best to our current strategy, so no large investment costs have to be made. Furthermore cost saving concepts like overtopping dykes and specific sand nourishment are part of this scenario.

The benefits are significantly lower than the other scenarios. Although some ecosystem services are generated (like for example production and clean surface water), they are lower than the other scenarios. The Defensive scenario leads to a loss of biodiversity (mainly because of sand starvation) and therefore has ‘negative benefits’ on the non-use value of nature and the recreational perception value.

The Defensive scenario shows a vulnerability to the process of climate change. When the climate change gets more extreme the costs are rising significantly (and the benefits remain the same). This indicates that the strategy of minimising costs is more effective when the climate change is small. The effectiveness reduces when climate change gets bigger.

5.3.2 Offensive scenario

In
Table 5.5.3 the results of the Offensive scenario are presented.

Table 5.5.3 Socio-economic costs and benefits of the Offensive scenario (in M€, interest 5,5%)

climate scenario	35 cm	50 cm	85 cm
Costs			
Removal civil engineering works	1.097	1.097	1.097
Creation Overschelde	1.772	1.772	1.772
Creation storm surge barrier Zijpe	450	450	450
Construction Energy Polder	159	159	159
Sand nourishment	1.617	2.318	3.987
Construction Delta Dykes	1.159	1.159	1.159
Maintenance costs	1.078	1.078	1.078
Costs total	7.333	8.034	9.704
Benefits			
Coastal protection	+ p.m.	+ p.m.	+ p.m.
Saved costs dyke reinforcement	+ p.m.	+ p.m.	+ p.m.
Saved maintenance costs civil engineering works	1.439	1.439	1.439
Production aquaculture	200	200	200
Clean surface water	754	754	754
Protection against climate change	7	7	7
Generation of tidal energy	170	170	170
Non-use value nature	101	101	101
Recreational expenditures	261	261	261
Recreational perception value	16	16	16
Benefits total	2.948	2.948	2.948
Balance	-4.385	-5.086	-6.755
Ratio (benefits/costs)	0,40	0,37	0,30

The costs for the Offensive scenario are relatively high (compared to the Defensive scenario). Large investments are necessary to generate the Overschelde by-pass, the storm surge barrier at Zijpe, the Delta Dykes and the energy polders. Also the sand nourishment contributes significantly to the total costs, especially when the climate scenario gets more extreme.

The main benefits of this scenario are the coastal protection, energy production, non-use value of nature and recreation. The sand nourishment contributes to the creation of extra dunes and intertidal area, especially in the coastal area and significantly reduces the maintenance costs of civil engineering works such as the Oosterschelde storm surge barrier This might well be an economically interesting part of the scenario which could be carried out as a stand-alone in this or the next century, provided that the blockade of the waterways is compensated by another way to bring fresh water to the sea. The coastal area is where most of the tourists are, so furthermore a high benefit in recreational expenditures is calculated. The benefits in recreational perception value is more on the recreational valuation of nature/ biodiversity. The Offensive scenario generates nature values, but to a smaller extent than the Natural scenario.

5.3.3 Natural scenario

In Table 5.5.4 the results of the Natural scenario are presented.

Table 5.5.4 Socio-economic costs and benefits of the Natural scenario (in M€, interest 5,5%)

Natural scenario	**35 cm**	**50 cm**	**85 cm**
Costs			
Removal of civil engineering works	2.854	2.854	2.854
Construction of Managed Realignment	6.847	6.847	6.847
Regular dyke enforcement	279	398	677
Sand nourishment Voordelta	32	45	77
Maintenance costs	1.971	1.971	1.971
Loss of agriculture	2.143	2.143	2.143
Costs total	14.125	14.258	14.569
Benefits			
Coastal protection	+ p.m.	+ p.m.	+ p.m.
Saved costs dyke reinforcement	+ p.m.	+ p.m.	+ p.m.
Saved maintenance costs civil engineering works	1.439	1.439	1.439
Production aquaculture	880	858	810
Clean surface water	925	903	854
Protection against climate change	13	13	13
Non-use value nature	2.251	2.251	2.251
Recreational expenditures	110	110	110
Recreational perception value	212	212	212
Benefits total	5.830	5.786	5.688
Balance	-8.296	-8.472	-8.881
Ratio (benefits/costs)	0,41	0,41	0,39

In case of a 35cm climate scenario the investment costs of the Natural scenario are about 14.125 M€. That is significantly higher than the Offensive scenario (7.300 M€) and the Defensive scenario (3.400 M€). The construction costs for the managed realignment are the main part of the costs. Also the loss of agricultural production and the costs for removal of the dams do contribute to the high investment costs.

The Natural scenario also shows the highest benefits, mostly because of the several ecosystem services that are generated in this scenario: food production, clean surface water, protection against climate change, recreational perception value, recreational expenditures and non-use value of nature. Also the saved maintenance costs for civil engineering works (after their removal) are significant. Although the benefits are high as well, the overall balance is the lowest of the three scenarios.

The Natural scenario shows a cost benefit ratio of 0,41 - 0,39 indicating that the costs exceed the benefits to a large extent. This can partly be explained by the high investment costs that are necessary in order to create natural dynamics (the removal costs of several dams). The applicability of a coastal protection strategy as it is worked out in the Natural scenario is lowered by the choices that are made in the past (that lead to less natural dynamics). For (other) areas with a less controlled starting situation the natural strategy can get better results in terms of costs and benefits.

The costs and benefits of the Natural scenario are relatively stable in the perspective of climate change. This makes sense as the strategy is designed to deal with climate change in the long-term perspective. The concept of managed realignment can keep up with sea-level rise for this century without large extra investments. However, the next century sea-level rise velocities may increase so strongly that the marshes cannot silt up fast enough and the natural values and protection might be lost. The same counts for the calculated ecosystem services form the benefits of this scenario. Table 5.4 shows a slightly diminishing cost-benefit ratio when the climate change gets more extreme. Note that the other scenarios show decreasing ratios when the climate change gets more extreme.

5.4 Sensitivity analysis

A sensitivity analysis determines in what way the results change when the discount rate is varied. In Table 5.5 the original results with a standard discount rate of 5,5% are presented. Table 5.6 shows the results with a discount rate of 2,5%. A discount rate of 2,5% is more likely to use when you are more certain on (future) effects to happen the way you expect (less uncertainty). A discount rate of 7,5% (table 5.7) handles with more uncertainty in long-term perspective.

Table 5.5 Socio-economic costs and benefits of the three scenarios (in M€, interest 5,5%, 50 cm climate scenario)

Discount 5,5%	Defensive scenario	Offensive scenario	Natural scenario
costs	3,801	8,034	14,258
benefits	906	2,948	5,786
balance (benefits-costs)	-2,896	-5,086	-8,472
ratio (benefits-costs)	0.24	0.37	0.41

Table 5.6 Socio-economic costs and benefits of the three scenarios (in M€, interest 2,5%, 50 cm climate scenario)

Discount 2,5%	Defensive scenario	Offensive scenario	Natural scenario
costs	5,390	12,548	18,536
benefits	1,703	6,184	12,491
balance (benefits-costs)	-3,687	-6,364	-6,044
ratio (benefits-costs)	0.32	0.49	0.67

Table 5.7 Socio-economic costs and benefits of the three scenarios (in M€, interest 7,5%, 50 cm climate scenario)

Discount 7,5%	Defensive scenario	Offensive scenario	Natural scenario
costs	3,451	7,056	13,308
benefits	690	2,206	4,300
balance (benefits-costs)	-2,761	-4,849	-9,007
ratio (benefits-costs)	0.20	0.31	0.32

Tables 5.5 to table 5.7 show that the order of the scenarios does not change when the discount rate is varied. This indicates that the results are robust. The Natural scenario profits from a low discount rate. This is logic as this scenario has high short term investment costs and high long term benefits. If it is assumed more certain that these long term effects do occur than de balance is changed in a positive way. The Defensive scenario benefits from a high discount rate as this scenario has limited long term benefits and relatively small short term investments.

In the second part of the sensitivity analysis it is found out if the preferred scenario changes when certain assumptions are edited. The results are to be analysed when conditions are favourable for the Natural scenario. The following assumptions are made:

- The price for sand will be higher. In this sensitivity analysis we assume the price to double (from 5 EUR/m^3 sand to 10 EUR/m^3 sand);

The process of sedimentation should lead to lower (zero) maintenance costs. In this sensitivity analysis we assume the maintenance costs to be zero;

- When the maintenance costs of civil engineering works get higher than expected, then this is beneficiary for the Natural scenario (leading to higher saved costs). We assume the maintenance costs to be 2,5% instead of 1,5%.

Table 5.8 Socio-economic costs and benefits of the three scenarios (in M€, interest 5,5%, 50 cm climate scenario) with high maintenance costs and high sand nourishment costs

	Defensive scenario	Offensive scenario	Natural scenario
costs	4.193	9.461	12.682
benefits	906	3.907	6.745
balance (benefits-costs)	-3.287	-5.554	-5.937
ratio (benefits-costs)	0,22	0,41	0,53

Table 5.8 show that the order of preference does not change. The Natural scenario does not generate better results than the Defensive scenario, even when the conditions are favourable. This indicates that the results are robust.

The results are to be analysed when conditions are favourable for the Offensive scenario. The following assumptions are made:

- When the maintenance costs of civil engineering works get higher than expected, then this is beneficiary for the Natural scenario (leading to higher saved costs). We assume the maintenance costs to be 2,5% instead of 1,5%.
- When the costs for sand nourishment turn out to be lower than expected. In this sensitivity analysis we assume the price to be half of the original price (EUR 2,5 instead of EUR 5/ m3 sand).

Table 5.9 shows the results when these assumptions are done.

Table 5.9 Socio-economic costs and benefits of the three scenarios (in M€, interest 5,5%, 50 cm climate scenario) with high maintenance costs and low sand nourishment costs

	Defensive scenario	Offensive scenario	Natural scenario
costs	2.934	7.414	14.235
benefits	906	3.907	6.745
balance (benefits-costs)	-2.028	-3.507	-7.489
ratio (benefits-costs)	0,31	0,53	0,47

The results show that the order of preference does not change. The Offensive scenario does not generate better results than the Defensive scenario, even when the conditions are favourable. This indicates once again that the results are robust.

6 Discussion

This scenario study is a good way to illustrate the potential of Building with Nature measures and provide insight in costs and benefits when such measures are applied on the larger scale. The scenarios are not complete, but they give examples of measures that can be applied on local or regional scales. In some cases, rough assumptions had to be made to compare the costs and benefits for the scenarios and strategies, which introduces some limitations. Many of these assumptions come forth from the lack of knowledge of effects of certain measures such as oyster reefs, nourishments or salt marsh maintenance. Nevertheless, strengths and weaknesses of separate strategies can be compared for different autonomous changes.

6.1 Scenarios compared

The three scenarios that are studied describe different mind-sets towards future management of the Southwest Delta. The Defensive scenario is aimed at conservation and keeping up with climate change to just ensure safety levels. This results in degradation of nature values and usage potential. The Offensive scenario is aimed at control and modification to serve human needs. This results in a delta that is designed to maximize safety and control over water bodies. The scenario does need rigorous maintenance. The Natural scenario on the other hand is based on system function and restoration of estuarine dynamics, which leads to far going changes. This results in a robust delta that is able to adapt to changing climate conditions without intensive maintenance.

6.2 Cost-benefit comparison

All three scenarios have higher calculated costs than benefits. This is expected, as the benefits of coastal protection are not calculated. It can however easily been seen that even losses of the natural scenario of -8.472 MEuro during 100 years, this would take an annual sum per capita (of Zeeland) of only some 200 Euros. The Defensive scenario is the most cost effective, followed by the Offensive scenario. The Natural scenario is most expensive. The high construction costs of managed realignments in the Natural scenario and Delta Dykes and nourishments in the Offensive scenario explain the negative balance. The absolute benefits, however, are ranked oppositely. The Natural scenario generates 6 billion euro benefits opposed to 3 billion euro for the Offensive scenario and 1 billion euro for the Defensive scenario. Some valuable insights can be obtained from the cost benefit analysis:

- For the Natural scenario the cost/benefit ratio stays stable over different climate scenarios. In the Offensive and Defensive scenario on the other hand, extra costs have to be made with more extreme sea-level rise. This indicates that the Natural scenario is more efficient in the adaptation to climate change. This is explained by the managed realignments applied at the large scale enabling coastal stretches to grow with sea-level rise. The Offensive scenario shows the steepest rise in costs for higher sea-level rise.

- The Offensive and Natural scenario show higher benefits for non-use and recreational values and aquaculture benefits, compared to the Defensive scenario. This difference is explained by a gradual deterioration of nature values in the Defensive scenario in particular in the Oosterschelde. Furthermore, in the Offensive and Natural scenario extra nature values are generated.

- The Offensive scenario is aimed at maximising human usage, which results in financial benefits of mostly energy generation, recreational expenditures and conservation of agricultural production.
- The Natural scenario contains large-scale application of managed realignments that show disproportionate construction costs and to a lesser extent loss of agricultural production.
- Sand nourishments are proposed as a potential solution for maintaining tidal flats with sea-level rise. This strategy is applied in the Offensive scenario. Our calculations show that for extreme sea-level rise scenarios the costs involved are disproportionate compared to the other scenarios. If such nourishments would not be carried out and the coastline was largely left alone (fed by sand of the ebb-tidal deltas) costs would become lower.

6.3 Building with Nature building blocks on the long term and large scale

Nourishments

Nourishments appear to be a good measure for coastal reinforcement in the Southwest Delta. Several studies suggest that when applied to forelands of dykes, wave dissipation will increase and maintenance costs can be reduced (Witteveen + Bos, 2007, Royal Haskoning, 2011). In addition, if due to the configuration of the basins no sediment import can take place, as in the current situation, it is a potential solution to maintain the total area of intertidal flats for Natura2000 requirements. In this respect it also appears to be a good adaptive measure: depending on the amount of sea-level rise it can be determined what sand volume is necessary to make the tidal flats keep up with sea-level rise. This strategy is applied in the Offensive scenario. The cost-benefit analysis for that scenario shows that if sea-level rise in the coming century is on the higher range of predictions, nourishments are an expensive measure. Especially if the nourishments are aimed at making the system more robust and the sediment deficit has to be replenished, as suggested by Mulder et al. (2011) and Van Zanten en Adriaanse (2008). In this case, the sand has to be mined in the North Sea, which will be more expensive. Also ecological implications increase if more sand has to be mined and nourished. The effect of large-scale nourishments on the ecosystem still deserves intensive study, as it will be associated with large and frequent perturbations.

Managed realignments

Managed realignments are a radical measure for coastal safety. Placing the dyke more inland means that former land will be transformed to intertidal area. This will affect land use practices (e.g. agriculture) and local circumstances and therefore needs careful consideration. The goal within this project was only to explore the potential of managed realigned areas regardless of these issues.

The implementation costs of managed realignments are very high. These costs mainly result from breaching primary dykes and constructing or strengthening secondary parallel dykes. In terms of costs this approach is very inefficient, especially in the lower range of sea-level rise scenarios (35cm). In higher ranges of sea-level rise (50, 85cm), however, the initial investments involved with managed realignments become more cost-effective. This is because large intertidal areas are assumed to grow with sea-level rise and form a robust coastal zone that requires minimal maintenance. In addition, these realignment areas will develop into estuarine nature areas with tidal flats and saltmarshes. Beside coastal defence these areas offer opportunities recreation and aquaculture and aquatecture practices.

Removal of dams
Reduced dynamics due to the dams in the Southwest Delta are the cause of most present day problems in the Southwest Delta, such as sand starvation and water quality issues. In addition, if sea-level rises, the dams inhibit intertidal areas to grow along with sea-level rise and result in an increasing unbalance between the sea and the Delta. This has many negative consequences for ecology (fish migration, euthrophication etc.). The construction of culverts in the dams, such as applied in the Defensive scenario, solves most of the issues related to reduced estuarine dynamics. However, in this situation, sand starvation and the decrease of intertidal area will continue to take place.
Removing the dams and reconfiguring the Southwest Delta into one long estuary (cf. Offensive scenario) has advantages as extreme conditions are tamed, and the system can develop along with a sea-level rise. If, however, natural sediment import does not occur (as assumed in the Offensive scenario) and the intertidal flats have to be maintained in that configuration, the costs would be high.
Removing all dams and bringing the Southwest Delta back into the situation of before 1953 results in the saving of the maintenance costs of the Delta Works. A remarkable insight gained from this study is that these costs make up a considerable expense. The dynamics bring back the system in a more balanced state, which, under our assumptions, solves the sand starvation issues entirely. In this open configuration, however, drastic measures have to be taken to guarantee safety.

Configuration of the delta
Reconfiguring the Delta into a more robust system that can guarantee safety may be a potential solution to adapt the Southwest Delta to climate change and at the same time provide safety in an efficient way. In the Offensive scenario we worked out one possible reconfiguration of the Delta. However, many more configurations can be thought up which make the Southwest Delta a more robust system: we only tried to show extreme end-members. Each new configuration has its effects on tides, storm surges, sediment transport, water quality and peak river discharges. These effects can be estimated using a hydraulic model of the entire delta.

Coastal buffer zones
Coastal buffer zones are an interesting alternative for present-day dyke reinforcement measures, which is already applied at a small scale. In our scenarios, they are only applied at stretches of dyke that are backed up by a secondary dyke. The measure optimizes the potential of the small polder areas along the dykes, and creates a broader coastal zone providing ecosystem services belonging to a healthy coastal zone. The parallel dykes provide a controlled area between these dykes, suitable for various forms of aquiculture and cultivation of saline crops. Furthermore these areas have recreation and nature potential.
Exact costs associated with coastal buffer zones depend on the dimensions of the secondary dyke, and the exact layout and functions in the newly formed coastal zone. Intensive aquaculture in the coastal buffer zone would lead to higher tangible benefits than for instance recreation.

Ecosystem engineers
Ecosystem engineers can be applied to protect, maintain and reinforce forelands and limit erosion. In the brackish and freshwater regions, reed lands can be developed, which could grow along with a rise in water table, with potential harvest of biomass. On tidal flats, constructed oyster reefs can make up a potential protection measure which may facilitate sedimentation as well. The advantage is that these reefs can grow along with sea-level rise. Salt marshes can be protected with artificial walls and reinforced by introducing robust soil

retaining species such as *Spartina*. An essential potential benefit for this measure is the effectiveness of salt marshes as wave beakers. However, the exact effect of salt marshes remains elusive (Alterra, 2012).
For the ecosystem engineers, the studies performed so far do not provide definite answers on their effectiveness. Therefore, the costs and benefits also still remain uncertain. Additional research is necessary for this new concept to determine the potential of these reefs, and explore the large-scale applicability.

Delta dykes
Many definitions of the Delta Dyke concept exist, ranging from a multi-functional dyke to a dyke that is dimensioned not to breach. For any Delta Dyke, a high initial investment is needed to build it. Still, the robust design and multifunctional potential make them an interesting solution in case of exposing the Delta to dynamics from the North Sea. Especially when sea-level rise is on the higher end of the predictions, the costs for the construction of Delta Dykes approach the total regular dyke reinforcement costs (cf. Offensive vs. Defensive scenario). With Delta Dykes however, safety is guaranteed and the Dykes can be combined with different functions. These benefits could however not be implemented in our cost-benefit analysis.

Energy polders
The historical development of the Southwest Delta has resulted in a series of small polders that after adjustments may be suitable for generating energy. Our cost benefit analysis suggests that the investments needed to create Energy Polders can be returned. Outstanding question is how much maintenance is needed to prevent the polder from silting up. One solution might be to use the deposited sediments as a source for dyke maintenance. A second question is whether the energy polder can be used in combination with other functions such as aquaculture or recreation. Until today, the energy polder is still an idea that needs further research to explore its potential and cost-effectiveness

Rich revetments
Rich revetments for the Southwest Delta are an addition to traditional dykes and other hydraulic infrastructure. They can be applied to ecologically optimise the hydraulic construction if the situation doesn't allow for innovative measures. The benefits of this optimisation are however difficult to valuate. This makes the rich revetments a difficult measure to implement if only tangible costs and benefits are taken into account. The first rich revetments carried out in Zeeland have to show the potential for habitat heterogeneity and biodiversity.

6.4 Future vision in the light of historical developments

One hundred years ago, nobody would have predicted the present day arrangement of The Netherlands. After all, many of the changes that have made up the present-day Netherlands result from historical events and demographical and economical development, none of which can be predicted. The most important development, perhaps, is the increase in population from just over 5 Million people in 1900 to almost 16 million people in 2000. Other associated developments are for instance the rise in number of cars needing infrastructure, intensification of agriculture and associated water demand, the two world wars, but also the discovery of gas on Dutch territory or the development of computers.
Interestingly, if it comes to the present layout of coastal protection, some futuristic designs made one hundred years ago may have come close to the present layout. In fact, several designs of the total closure of the Zuiderzee and partial land reclamation had already been drawn. Large coastal engineering works to control the sea were clearly fashionable. The first

plans for the closure of the sea-arms in the Southwest Delta are younger and originate from after the Second World War.

Still, for the actual decision to construct large engineering works, first two catastrophic storm surges had to take place: The 1916 storm surge along the Zuiderzee led to the construction of the Afsluitdijk and land reclamation, and the 1953 storm surge in Zeeland led to the decision of carrying out the Deltaplan that had been designed in the years before the storm. This suggests that catastrophic events had to occur to generate the investment needed for a paradigm shift. In both cases, the big initial investment of the rigorous interventions has been beneficial on the longer term. These examples show that although on the short term rigorous interventions are never cost-effective, on the longer term they may well be.

Present-day coastal defence strategies tend to move towards an approach in which nature is taken into account. However, interventions in which Building with Nature is implemented are not applied on the large scale so far. In the few projects in which Building with Nature is applied, it is implemented as an extra, supplementing the traditional design. For a larger area to be set up with Building with Nature solutions, a paradigm shift is necessary. For this to happen, at least the effects of the measures have to be well known to make an honest comparison with traditional measures.

In this study we have shown that there are many opportunities for using Building with Nature measures on a large scale in the Southwest Delta: The Delta can be completely reconfigured to grow along with sea-level rise. Any combination of the proposed building blocks and strategies can be applied in making the Southwest Delta more sustainable and resilient. Some of the measures, such as closing the coast with nourishments might even be quite cost effective. While designing the extreme scenarios, we experienced that the Delta Works limit the scale at which Building with Nature can be applied. Similarly, if the present boundary between water and land remains as it currently is, the opportunities for Building with Nature diminish further. In this case, only local applications of Building with Nature remain, such as Rich Revetments and local Nourishments.

7 Conclusions

In this study we explored the potential for Building with Nature strategies in the Southwest Delta by means of three extreme scenarios. Both the extreme scenarios and the Building blocks and strategies that they were based on have been analysed using a cost-benefit analysis. The main conclusions for the extreme scenarios are:

Defensive scenario:
- The most efficient scenario
- No large investments have to be made
- With higher sea-level scenarios the costs in this scenario rise, and the system increasingly grows in unbalance with the hydrodynamical and sedimentary conditions
- Least benefits

Offensive scenario:
- Control over dynamics
- High investments have to be made
- Moderate benefits, mainly coastal protection, energy production, non-use value of nature and recreation
- Rising costs with higher sea-level rise scenarios, mainly due to the chosen nourishment strategy

Natural scenario:
- Highest initial investment
- Highest benefits
- Stable costs and benefits in the perspective of climate change
- Largely self-maintaining

More general conclusions that can be drawn from this study are:
- Reintroducing dynamics by removing or reconfiguring dams in the Southwest Delta leads to high initial costs to guarantee safety (by building Delta Dykes and/or constructing Managed Realignments). Nonetheless, this strategy delivers the most benefits. In addition, if future sea-level rise is on the higher side of the predictions, the initial investment becomes more cost-effective as less maintenance is necessary and a more robust system will develop which is in equilibrium with the dynamics.
- Applying small scale Building with Nature measures only to optimize coastal safety and increase water quality is the most cost effective solution. However, in the minimal version, the sedimentary system in the Oosterschelde will slowly deteriorate, as it is not in equilibrium with hydrodynamics. The benefits of these small scale Building with Nature measures are lowest.
- Many costs and benefits of Building with Nature measures remain elusive. This is true for both large-scale effects for which elaborate hydrodynamical modelling studies are necessary as small-scale effects of measures such as the effect of oyster reefs, reed marshes and salt marshes.
- Sand nourishment is a strategy of dealing with sand starvation and sea-level rise in an adaptive way: for a given time period it can be determined how much sand has to be added to the system to maintain a balance. However, if sea-level rise is on the higher side of predictions, these nourishments turn out to be an expensive solution. In addition,

the sedimentary system will remain out of balance if the applied strategy is not aimed at replenishing the progressively growing sediment deficit.

- The maintenance costs of the Delta works are surprisingly high. Removing the Delta Works and reinforcing the dykes to guarantee safety in the area costs money, but on the other hand maintenance costs for the dams are saved and can be spend elsewhere.
- Keeping the Delta works and the boundary between water and land as they are now greatly diminishes the potential for Building with Nature on the larger scale.

8 Recommendations

As any study, this study has limitations. Most are due to the fact that for many Building with Nature building blocks, the effects are still uncertain. Therefore, assumptions had to be made about the effects of several Building Blocks and Strategies. To be able to make a more comprehensive cost-benefit analysis, it is essential that more information becomes available about:

- Effects of salt-marshes, intertidal flats and reed marshes on the wave dissipation on dykes
- Effects of oyster reefs on sedimentation and their potential to grow with sea-level rise
- Ability of reed marshes to grow along with water level rise. There are many C^{14} datings on phragmites (reed) peat in the Dutch subsurface which could shed a light on this issue
- Ability of managed realignments to grow along with sea-level rise
- Degree of perturbation caused by sand mining and sand nourishments on the scale of the Delta
- Potential of Energy polders and Coastal buffer zones for aquaculture

Development and optimisation of the scenarios in which the configuration of the Southwest Delta was altered, could be optimized by using a hydrodynamic model of the entire Southwest Delta. In this model, it is essential that dams can be randomly removed and placed, and new channels can be tested. By utilising such a model study, an optimal scenario for water quality, hydrodynamics and sedimentary processes could be developed.

As for the Delta Works it is recommended that a study is carried out in more detail on how and when to fase out each of the Deltaworks during the centuries to come in the light of climate change and sea-level rise. Such studies should take also into account the autonomous development of the Outer Delta grounds, as large parts of the closed works are momentarily changing strongly.

9 Acknowledgements

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A Inventory of problems in the Southwest Delta (in Dutch)

Memo

Aan
projectteam BwN ZW4.1

Datum	Kenmerk	Aantal pagina's
20 augustus 2010	1202061-000-BGS-0001	11
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Onderwerp
Inventarisatie visies ZW Delta

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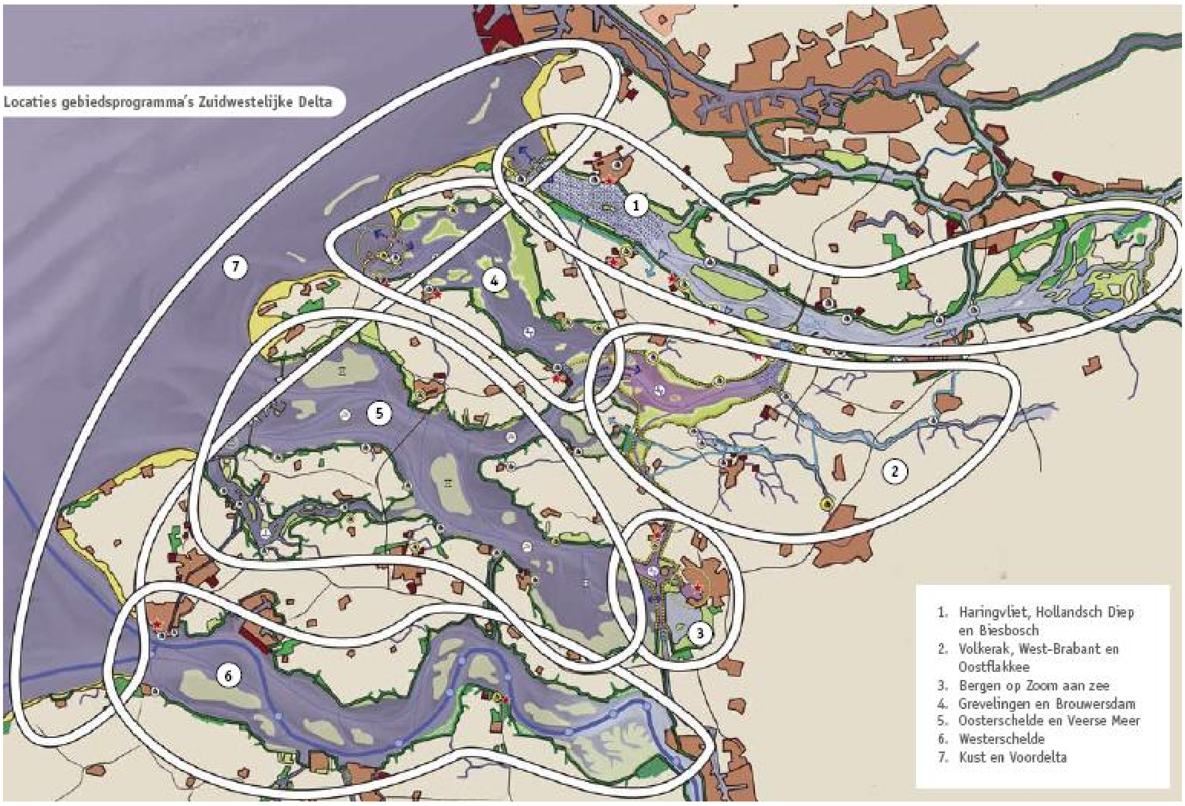
1 Inleiding

Deze inventarisatie is gemaakt t.b.v het Building with Nature project, "ZW4.1: Adaptation measures in perspective: towards a long term vision for the Southwest Delta". De inventarisatie is voornamelijk gebaseerd op het *Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+* (Stuurgroep Zuidwestelijke Delta, versie voor consultatie, 1 april 2010), met aanvullingen uit andere visies. Dit uitvoeringsprogramma geeft inzicht in de relatie tussen de besluiten en projecten voor de korte termijn (2015) en de noodzakelijke planvorming in de zuidwestelijke delta op de middellange (2020) en lange termijn (2050/2100) als gevolg van verandering van het klimaat. Het uitvoeringsprogramma is de concrete uitwerking van de integrale visie op de deltawateren 'Delta in Zicht' (2003), bestaande provinciale waterplannen en structuurvisies, waterbeheerplannen van waterschappen, de Nota Ruimte (2006), de nota Pieken in de Delta (2006) en het Nationaal Waterplan onderdeel Zuidwestelijke Delta (2009). Daarom geeft het een goed startpunt voor het ontwikkelen van een lange termijn visie (doel van dit BwN project). Deze memo geeft een samenvatting van het uitvoeringsprogramma voor de gehele zuidwestelijke delta en per waterbekken en gebied. Het gaat om de volgende gebieden:

- Haringvliet, Hollandsch Diep en Biesbosch
- Volkerak, West-Brabant en Oostflakkee
- Bergen op Zoom aan zee
- Grevelingen en Brouwersdam
- Oosterschelde en Veerse Meer
- Westerschelde
- Kust en Voordelta



2 Gehele Zuidwestelijke Delta

Huidige situatie
Een gebied dat grotendeels onder de zeespiegel ligt en goede bescherming vraagt tegen stormvloeden en dijkdoorbraken. Als gevolg van de Deltawerken is de veiligheid vergroot, maar dit is plaatselijk ten koste gegaan van de natuurlijke functie. De verschillende waterbekkens zijn in grote mate van elkaar geïsoleerd geraakt. Afgezien van de Westerschelde zijn zoet-zout gradiënten en estuariene dynamiek grotendeels verdwenen. De ideale en de huidige situatie worden per gebied onderstaand verder samengevat.

Visies
Visies gevonden voor de zuidwestelijke delta als geheel:

- *Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+* (Stuurgroep Zuidwestelijke Delta, versie voor consultatie, 1 april 2010)
- *Hoogtij voor laag Nederland. Werken met de natuur voor een veilige en mooie delta.* 2008, Bureau Stroming iov WWF

Ideaal

Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+ (Stuurgroep zuidwestelijke delta, 2010): Een veilige, veerkrachtige en vitale zuidwestelijke delta. Veilig betekent dat er voldoende bescherming is tegen overstromingen. Veerkrachtig gaat over een gezond watermilieu en ruimte voor de overgangen tussen zoet en zout en tussen nat en droog. Vitaal betekent gebieden met goede voorzieningen en een eigen, herkenbare identiteit.

Hoogtij voor laag Nederland (Bureau stroming, 2008): Een Delta die weer generaties mee kan: klimaatbestendig, met een nieuwe plek voor water en natuur, daarbij passende woonmilieus en met nieuw economisch perspectief.

Oplossingen voor bestaande problemen

In de visie “Hoogtij voor laag Nederland” worden de volgende oplossingen voor bestaande problemen beschreven:

- flexibele veiligheid
    - megaterpen voor wonen en werken
    - omgeving zoveel mogelijk vrij geven voor natuurlijke dynamiek en natuurlijke processen
- flexibele kust
    - handhaven waar strand en duinen breed zijn
    - landinwaarts verdedigen waar dat verantwoord is
- open armen; zeearmen openen door ze waar nodig te voorzien van moderne constructies die bij gevaar gesloten kunnen worden
- herontwikkeling van polders
    - nieuwe functies voor polders met weinig bewoning en weinig economisch perspectief
    - deze vaak diepe polders op laten slibben, woningen verplaatsen of op palen of terpen zetten, of drijvend gemaakt.
    - zo ontstaan mogelijkheden voor viskweek, zoute teelten, natuurlijke zoutwater moerassen
- efficiënter omgaan met zoet water; efficiënt gebruik en transport van zoet water, door het verleggen van innamepunten stroomopwaarts, landbouw aanpassen, waterbesparing en gebruik maken van aanwezige zoetwaterbellen.
- ruimte voor veerkracht Noordzee

In Hoogtij voor laag Nederland worden de volgende adviezen gegeven aan de Deltacommissie, op de volgende gebieden:

1- nieuwe kansen voor de visserij door open armen en beschermde zeegebieden;
2- veilige woon- en bouwvormen;
3- landbouw geeft het estuarium de ruimte;
4- klimaatbestendige zoetwatervoorziening.

3 Haringvliet, Hollands Diep en Biesbosch

Huidige situatie
Het Haringvliet is een vrijwel gesloten riviermond met natuurontwikkeling verspreid over het gebied. Sinds 1970 is de met de voltooiing van de Haringvlietsluizen de verbinding met de Noordzee verbroken. Er heerst nog een getijverschil van zo'n 20 cm omdat het getij via het Spui in het Haringvliet kan doordringen en via de Dortse Kil in het Hollandsche Diep (bron: Delta 2000).

Functies
- Scheepvaart
- Zoetwaterbekken ter bestrijding van verzilting West Nederland
- Natuur
- Recreatie
- Industrie

Ideaal
Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+ (Stuurgroep zuidwestelijke delta, 2010): Het Haringvliet en Hollandsch Diep vormen in 2050 een natuurlijke riviermonding met een overgang van zoet naar zout, een hernieuwd getij en veel ruimte voor de natuur en recreatie die daarbij horen. De Biesbosch is een zoetwatergetijdengebied met ruimte voor recreatie, zoetwatervoorziening en waterberging. Het gebied blijft belangrijk voor de scheepvaart.

Hoogtij voor laag Nederland (Bureau stroming, 2008): Open armen voor de Zeeuwse en Zuid-Hollandse Delta: Alle zeegaten zijn weer geopend in de 22^{e} eeuw. Een nieuwe generatie "Maeslant-keringen" waarborgt de veiligheid bij extreem hoog water. Ondanks de hogere zeespiegel en het extremere klimaat worden we goed beschermd door duinen, dijken en overstromingsgebieden. De veiligheid wordt verder gegarandeerd door ecologische processen. De zandplaten in en oevers van de zeearmen dempen de kracht van het water en fungeren als natuurlijke klimaatbuffer. De natuurlijke rijkdom die zich ontwikkelt kent alleen zijn gelijke in de Waddenzee. Het beschermde gebied geeft een nieuwe economische impuls. Er zijn snelle shuttles tussen eilanden, maar ook van Rotterdam naar Antwerpen. Landbouw heeft zich aangepast en de zoetwaterbehoefte is geslonken.

Problemen
- Door lagere stroomsnelheid versterkte sedimentatie van verontreinigd slib, en daardoor weinig waterleven
- Oeverafkalving en verslechterde riet en biezenvelden
- Verdwijnen brakke biotoop
- Snelle verondieping door toenemende sedimentatie
- Uitdroging en inklinking hoger gelegen oevers door verdwijnen hoogtij
- Verdwijnen droogvallen slikken en fourageergebieden
- Haringvlietsluizen grote barriere voor organismen
- Gespuide water komt in de Voordelta terecht als grote onnatuurlijke zoetwaterbellen. Veel sterfte.

Maatregelen
Op een kier zetten van de Haringvlietsluizen ("getemd getij") met bijbehorende compenserende maatregelen om de huidige beschikbaarheid van zoetwatervoorziening op orde te houden.

Verder wordt in de visie het Benedenrivierengebied in tijden van Klimaatverandering (Klimaat voor Ruimte, 2009) aanbevelingen gedaan voor maatregelen, welke binnen het programma Kennis voor Klimaat verder uitgewerkt zullen worden.

4 Volkerak, West-Brabant en Oostflakkee

Huidige situatie

Het zoete Volkerak-Zoommeer kampt al jaren met blauwalgen tijdens droge, warme periodes. In 2002 en 2003 heeft Rijkswaterstaat een verkenning gedaan naar mogelijke oplossingen voor het blauwalgenprobleem. In 2004 is op initiatief van het Bestuurlijk Overleg Krammer-Volkerak de planstudie annex m.e.r-procedure gestart. Hierin is de effectiviteit van alternatieve oplossingen onderzocht en is het effect daarvan op het milieu en gebruiksfuncties beoordeeld. Uit de planstudie blijkt verzilting van het meer de enige oplossing te zijn voor de blauwalgenproblematiek. Verzilting van het meer vraagt echter om een alternatieve zoetwatervoorziening en een goede scheiding van zoet en zout water(bron: informatiesite Volkerrak Zoommeer, www.volkerrakzoommeer.nl).

Functies

- Getijvrije scheepvaartroute Antwerpen Rotterdam
- Zoetwatervoorziening en afwatering voor de landbouw
- Natuur en landschap in ondiepe water- en oevergebieden
- Recreatie
- Beroepsvisserij

Ideaal

Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+ (Stuurgroep zuidwestelijke delta, 2010): Het Volkerak vormt met de Eendracht en het Zoommeer een zout bekken dat via een doorlaat in de Philipsdam in directe verbinding staat met de Oosterschelde en daardoor weer onder invloed van - beperkt - getij. West-Brabant is het contactgebied tussen land en water met een opgewaardeerd netwerk van rivieren, waterlopen en kreken die zorgen voor de zoetwatervoorziening en opslag van zoet water, maar ook voor de verbinding met het Volkerak-Zoommeer. Het goederenvervoer tussen Rotterdam en Antwerpen is duurzaam en veilig ingepast in het gebied.

Volkerak het mooiste van twee werelden (Bureau Stroming, 2007): Ofwel een gebied met lage dynamiek en sterke zonering (rust en ruimte worden gekoesterd en ontwikkelingen zoveel mogelijk op enkele plaatsen geconcentreerd) ofwel een gebied met hoge dynamiek en verspreide ontwikkeling (ontwikkelingskansen worden zoveel mogelijk benut), of een goed compromis tussen beide. De visie laat kansen zien op het gebied van Woningbouw, industrie, recreatie, klimaat(buffer) en natuur. De voorkeur gaat uit naar een schoon, zout en dynamisch Volkerak, waar de kust en het ricierengebied elkaar ontmoeten, en ook de stad en de natuur, en economische vooruitgang en landschappelijke ontwikkelingen.

Ruimtelijk kwaliteitskader Volkerak-Zoommeer (Bureau Stroming, 2008): In deze visie wordt als ideale situatie een optie met geheel open zeearmen gekozen, en een tussenoplossing voor een situatie waarin het Volkerak-Zoommeer kan worden benut als waterbergingsgebied én de estuariene dynamiek wordt vergroot. Deze tussenoptie bestaat uit de volgende componenten:

- Oosterschelde en Grevelingen staan in verbinding met de Noordzee; de eerste via de huidige stormvloedkering, de ander via een beperkte opening die ca 500 m3/sec zeewater doorlaat.
- Oosterschelde en Grevelingen zijn verbonden met het Volkerak – Zoommeer; de eerste via een opening die minimaal 300 $m^3 s^{-1}$ doorlaat, de ander via een zo groot mogelijke opening, zodat Volkerak en Grevelingen een eenheid worden.
- Het Volkerak is verbonden met het Hollands Diep via een beperkte opening. De toevoer van rivierwater wordt afgestemd op de behoefte van Volkerak-Zoommeer, Grevelingen en Oosterschelde samen, zonder dat de risico's op algengroei te groot worden.

Problemen

- Verdwijnen intergetijdegebied
- Erosie van oevers
- Troebel, algenrijk en waterplantarm water

Maatregelen

In het Nationaal Waterplan is een principebesluit opgenomen om uiterlijk in 2015 weer zout water toe te laten vanuit de Oosterschelde op Volkerak-Zoommeer. 'Om de blauwalgenproblematiek in het Volkerak-Zoommeer op te lossen kiest het kabinet ervoor om uiterlijk in 2015 op het meer zout water uit de Oosterschelde toe te laten. Op die manier verzilt het water van het Volkerak-Zoommeer en ontstaat er een beperkte getijdendynamiek.'

In het Nationaal Waterplan is opgenomen dat het kabinet in 2010 een bestuursovereenkomst met de regio wil sluiten waarin de stappen worden vastgelegd naar een uitvoeringsbesluit in 2012. Het uitvoeringsbesluit gaat over de te nemen maatregelen voor het handhaven van de huidige beschikbaarheid van zoet water voor de landbouw, de drinkwatervoorziening en de industrie. De besluitvorming moet aansluiten op de besluiten over waterberging op het Volkerak-Zoommeer in het kader van Ruimte voor de Rivier, de studie naar kansen voor meer transport over water in de Rijn-Scheldeverbinding (MIRT-verkenning Antwerpen- Rotterdam) en de MIRT-verkenning voor de Grevelingen.

5 Bergen op Zoom aan zee

Huidige situatie

Bergen op Zoom is afgesloten van de Oosterschelde en kampt met waterkwaliteitsproblemen in de Binnenschelde en het Zoommeer, die stankoverlast van blauwalgen en soms massale sterfte van vis en watervogels veroorzaken. Dit maakt deze gebieden onaantrekkelijk voor recreanten, omwonenden, en fl ora en fauna. Ook bij het Markiezaatsmeer (Natura 2000-gebied) is er een risico dat de waterkwaliteit op de middellange termijn verslechtert en omslaat in een door algen en bodemwoelende vis gedomineerd systeem.

Ideaal

Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+ (Stuurgroep zuidwestelijke delta, 2010):
Bergen op Zoom krijgt zijn ligging in de delta terug en er ontstaan goede mogelijkheden voor recreatie, wonen en de aanleg van jachthavens. Het Zoommeer valt onder dit gebiedsprogramma, samen met het Markiezaatsmeer en de Binnenschelde. Verbinden van de laatste twee meren met het zoute Volkerak-Zoommeer biedt perspectieven voor estuariene

natuur, zeker als het Zoommeer een betere verbinding krijgt met de Oosterschelde. Het goederenvervoer tussen Rotterdam en Antwerpen passeert op korte afstand en is duurzaam en veilig ingepast in het gebied.

6 Grevelingen en Brouwersdam

Huidige situatie
De Grevelingen is een afgesloten zout meer zonder estuariene dynamiek. Als gevolg hiervan treedt zuurstofloosheid aan de bodem op, wat tot aanzienlijke sterfte van het bodemleven en achteruitgang van de waterkwaliteit leidt. In de MIRT-verkenning Grevelingen zijn het verbeteren van de waterkwaliteit, opwekken van energie uit getijdenbeweging en versterken van de recreatiesector onderwerp van onderzoek.

Ideaal
Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+ (Stuurgroep zuidwestelijke delta, 2010): Het gebied is aan de zeezijde gecontroleerd verbonden met de Noordzee en aan de oostzijde permanent verbonden met het Volkerak-Zoommeer. Resultaat is een estuarien watersysteem met beperkt getij dat overtollig rivierwater ook op langere termijn kan bergen en spuien. Een getijdencentrale in de Brouwersdam levert voor de omringende eilanden CO2-neutrale energie. Het gebied is tevens ‘metropolitaan park’: uitloopgebied voor Rotterdam, met een woon- en recreatiefunctie.

Hoogtij voor laag Nederland (Bureau stroming, 2008): Open armen voor de Zeeuwse en Zuid-Hollandse Delta, zoals beschreven bij Haringvliet, Hollands Diep en Biesbosch.

Grevelingen: Van Meer naar Delta (BAM Infra, AM, Deltares, 2009): In de toekomst zal de Zuidwestelijke Delta weer een waar voorbeeld zijn voor delta’s in alle delen van de wereld. Een bloeiende economie, een ecologische situatie waar men trots op mag zijn en een veilig woongebied, ook bij hoog water. De Grevelingendelta zal een veilig en schoon gebied zijn, waar de toerist en bewoner de ruimte, schoonheid en natuurlijke dynamiek van de delta ervaart. Er is beperkt getij, dat doorloopt tot in het Krammer-Volkerak. De waterkwaliteit is duurzaam verbeterd. Het gebied biedt ruimte voor mosselkweek, onderwatersport, een hoge soortenrijkdom. Ontstane schorren spelen een rol in de kustverdediging. Veel oorspronkelijke natuurwaarden zijn hersteld. Veiligheid wordt gewaarborgd door peilregulering.

7 Oosterschelde en Veerse Meer

Huidige situatie
Sinds de aanleg van de Oosterscheldewerken stroomt er minder water in en uit de Oosterschelde. De getijdengeulen zijn te groot voor de kleinere hoeveelheid water. Het water stroomt daardoor langzamer dan voorheen en heeft onvoldoende kracht om sediment te verplaatsen van de geulen naar het intergetijdengebied. Bij storm spoelt er wel zand van het intergetijdengebied in de geulen. Al het zand dat in de geulen terecht komt, blijft daar liggen. De afbrekende krachten werken nog wel, maar de opbouwende krachten niet. Het evenwicht is verstoord, de afbraak van intergetijdengebied overheerst. Dit proces staat bekend als de “zandhonger”. Voor het stillen van de zandhonger is vierhonderd à zeshonderd miljoen kubieke

meter zand nodig. Dit is 30 tot 50 keer het jaarlijkse suppletievolume van de gehele Nederlandse kust. Aanbrengen van deze hoeveelheid zand vanuit zee is vanuit logistiek en kostenoverwegingen niet haalbaar (bron: Verkenning verminderd getij, Rijkswaterstaat, 2008).

Er loopt een MIRT-verkenning naar de effecten van de ‘zandhonger’ (geleidelijk verdwijnen van schorren, slikken en platen in de geulen van de zeearm), naar de achteruitgang van estuariene dynamiek en naar maatregelen om die te vertragen of te stoppen.

De waterkwaliteit en de ecologie van het Veerse Meer zijn door het herstel van de verbinding met de Oosterschelde sinds 2004 sterk verbeterd.

Ideaal
Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+ (Stuurgroep zuidwestelijke delta, 2010): De Oosterschelde en het Veerse Meer vormen samen het veilige hart van de delta waarin de kwaliteiten van natuur, weidsheid, transport, visserij en recreatie worden gekoesterd en benut.

Hoogtij voor laag Nederland (Bureau stroming, 2008): Open armen voor de Zeeuwse en Zuid-Hollandse Delta, zoals beschreven bij Haringvliet, Hollands Diep en Biesbosch.

8 Westerschelde

Huidige situatie
Het estuarium met zijn meergeulenstelsel, hoge zandplaten en brede intergetijdengebieden staat onder druk van menselijk ingrijpen en voldoet niet aan de doelen van Natura 2000. Een natuurherstelprogramma is gestart om het estuarium te behouden en te herstellen. De baggerwerken om de vaargeul binnen deze rivier op voldoende diepte te brengen en te houden, worden zo uitgevoerd dat de natuurkwaliteiten niet worden aangetast.

Ideaal
Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+ (Stuurgroep zuidwestelijke delta, 2010): De Westerschelde is een veilig, gezond en dynamisch estuarien ecosysteem dat optimaal toegang biedt tot de Scheldehavens en tot een aantal kleinere havens die met name van belang zijn voor visserij en recreatie.

Het gebied is een belangrijke kraamkamer voor vis. Er is voldoende ruimte voor natuurlijke dynamische, fysische, chemische en biologische processen. De waterkwaliteit is op orde.

Voor de diepte van de vaarweg is een evenwicht gevonden tussen de sociaal-economische kosten en baten en het in stand houden van de fysieke en natuurlijke systeemkenmerken van het Schelde-estuarium.

Hoogtij voor laag Nederland (Bureau stroming, 2008): Open armen voor de Zeeuwse en Zuid-Hollandse Delta, zoals beschreven bij Haringvliet, Hollands Diep en Biesbosch.

Problemen

- Vermindering komberging (door inpolderen, dijkverhogingen etc.), waardoor de getijgolf zich sneller door het estuarium kan voortplanten
- Toename vertroebeling
- Verlies aan slikken en schorren
- Verstarring van de geulen (vermindering dynamiek)
- Toename van platen ten koste van ondiepwatergebied
- Slechte waterkwaliteit
- Verontreinigde bodem

Visie

Door de Vlaamse en Nederlandse overheid is in 2001 de Langetermijnvisie Schelde-estuarium vastgesteld (Projectbureau LTV, 2001). De Langetermijnvisie is een technisch-inhoudelijk document en is gericht op drie geprioriteerde functies:

- Veiligheid (tegen overstromen)
- Toegankelijkheid (van de Scheldehavens)
- Natuurlijkheid (van het fysieke ecologische systeem)"

Als hoofddoelstelling noemt de Langetermijnvisie Schelde-estuarium (2001): "Het Schelde-estuarium is in 2030 een gezond en multifunctioneel estuarien watersysteem dat op duurzame wijze gebruikt wordt voor menselijke behoeften."

Het Streefbeeld 2030 beschrijft welke doelen op de lange termijn worden nagestreefd:

- De instandhouding van de fysieke kenmerken van het estuarium is uitgangspunt van beheer en beleid
- Maximale veiligheid is belangrijke bestaansvoorwaarde voor beide landen
- Als trekpaard voor de welvaart zijn de Scheldehavens optimaal toegankelijk
- Het estuarien ecosysteem is gezond en dynamisch
- Nederland en Vlaanderen werken bestuurlijk-politiek en operationeel samen.

De instandhouding van de fysieke kenmerken van het systeem Schelde-estuarium richt zich op:

- Een open en natuurlijk mondingsgebied;
- een systeem van hoofd- en nevengeulen met tussenliggende platen en ondiepwatergebieden in de Westerschelde, ook wel aangeduid als ' de morfologische diversiteit van het meergeulensysteem';
- en een riviersysteem met meanderend karakter in de Zeeschelde.
- Daarnaast treft men een grote diversiteit aan van schorren, slikken en platen in zout, brak en zoet gebied, gecombineerd met natuurlijke oevers.

Handhaving van de fysieke systeemkenmerken van het estuarium is een randvoorwaarde. Het morfologisch beheer is gericht op het instandhouden van de systeemkenmerken en op het instandhouden en waar mogelijk verbeteren van de ecologisch belangrijke gebieden in het estuarium.

Maatregelen

- Uitbreiden natuurlijke oeververdediging
- Aanpassen huidig baggerstrategie van het verplaatsen van baggerslib van het oostelijk deel naar het westelijk deel
- Ontpoldering Hedwigepolder

9 Kust en Voordelta

Huidige situatie
De Voordelta is een dynamisch gebied met een hoge ecologische productiviteit door de aanvoer van voedingsstoffen via de deltabekkens. De kust bestaat uit duinen en harde waterkeringen. Momenteel worden de zwakke schakels aan de Delflandse Kust, op Walcheren en Zeeuws-Vlaanderen versterkt. Versterkingen bij het Flaauwe Werk zijn afgerond.

De voordelta is eigenlijk al een vrij gezond gebied. Na de aanleg van de Deltawerken zijn de zandplaten toegenomen en na enkele jaren gestabiliseerd. Hierdoor treedt er minder kusterosie op. Er is wel een (te) hoog gehalte aan voedingsstoffen, maar dit heeft geresulteerd in een hoge productiviteit. Door de afwisseling zoet – zout en diep en ondiep water is het een leef- en fourageergebied voor zeehonden en diverse beschermde vogelsoorten. Aangewezen als Nature-2000 gebied. Door de aanleg van Maasvlakte 2 gaat in totaal zo'n 2455 ha zandbanken en ondiepe zee verloren en enkele vogelsoorten zullen nadelige gevolgen ondervinden omdat de kwaliteit en omvang van hun fourageer en rustgebieden achteruitgaat. Compensatie is verplicht, en daarom is er een beheerplan opgesteld met maatregelen voor deze compensatie (Beheerplan Voordelta, 2008).

Functies
- Drinkwatervoorziening in de duinen
- Natuur
- Transport
- Recreatie
- Veiligheid
- Visserij
- Zandwinning/olie- en gaswinning, windenergie

Ideaal
<u>Ontwerp-uitvoeringsprogramma ZW Delta 2010-2015+ (Stuurgroep zuidwestelijke delta, 2010):</u>
Een rijke en gezonde kustzee met hoge natuurwaarden, natuurlijke zand- en voedselstromen, condities voor hersteld zeeleven en natuurlijke vormen van kustbescherming.

<u>Hoogtij voor laag Nederland (Bureau stroming, 2008):</u> zachtere overgangen van zee naar land, open zee-armen met waar dat nodig is een nieuwe generatie stormvloedkeringen. In de kustzone dragen grote windparken bij aan de waardering voor de Noordzee. De bieden houvast aan soorten die elders in de Noordzee ontbreken. Middels een netwerk van beschermde zeegebieden wordt de biodiversiteit hersteld. Boomkorvisserij wordt verduurzaamd.

Problemen
- Sterke fluctuaties in zoutgehalte door uitwatering van de Maas en Rijn via de haringvlietsluizen leiden tot sterfte van mossels en kokkels.
- Verhoogd nutrientengehalte (heeft ook voordelen)

Maatregelen/wensen
- Regelmatiger spuiregime Haringvlietsluizen
- Beter zicht op zandhuishouding in de Voordelta

10 Geraadpleegde visies

Gehele zuidwestelijke delta:

- Veilig Veerkrachtig Vitaal. Ontwerp-uitvoeringsprogramma Zuidwestelijke Delta 2010-2015+. 2010. Stuurgroep Zuidswestelijke Delta.
- Hoogtij voor laag Nederland. Werken met de Natuur voor een veilige en mooie delta. 2008. Bureau Stroming, in opdracht van het Wereld Natuur Fonds.

Voor afzonderlijke gebieden:

- Volkerak het mooiste van twee werelden. Naar een perspectief voor Volkerak-Zoommeer én omgeving. 2007. Bureau Stroming, in opdracht van Vereniging Natuurmonumenten.
- Ruimtelijk kwaliteitskader Volkerak-Zoommeer. 2008. Bureau Stroming, in opdracht van Rijkswaterstaat projectbureau Waterberging Volkerak-Zoommeer.
- Grevelingen: van Meer naar Delta. 2009. BAM Infra, AM, Deltares. Winnaar Delta Water Award 2009.
- Benedenrivierengebied in tijden van klimaatverandering. 2009. Onderzoeksprogramma Klimaat voor Ruimte, rapport KvR 014/2009.
- Langetermijn visie Schelde estuarium, Projectbureau LTV, 2001.
- Verkenning verminderd getij, Rijkswaterstaat, 2008.
- Delta 2000 – Inventarisatie huidige situatie Deltawateren, RIKZ, 2000.
- informatiesite Volkerrak Zoommeer, www.volkerrakzoommeer.nl, geraadpleegd juli 2010.
- Beheerplan Voordelta – spelregels voor natuurbescherming, 2008.

B Factsheets Building with Nature Building Blocks

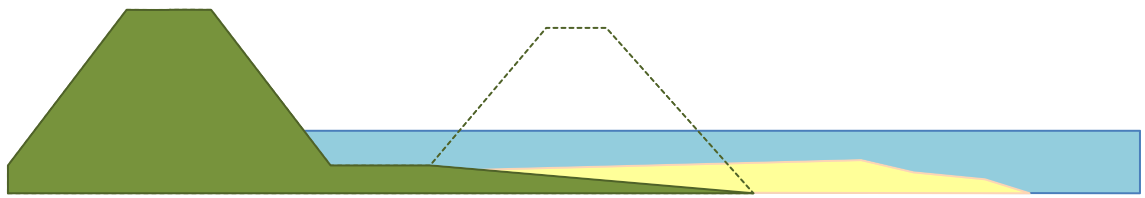
Building with Nature

EcoShape

Managed realignment

Marijn Tangelder & Tom Ysebaert

IMARES
WAGENINGEN UR



Description

Controlled inundation of land by setting back sea defence is an increasingly used method for coastal protection and anticipation to climate change (French 2006). In the United Kingdom dyke setbacks, called “managed realignment”, is more and more applied and considered as a cost-effective and sustainable response to loss of biodiversity and sea level rise (Garbutt 2008). It is also applied in other countries such as the United States, Germany and Belgium. By re-inundating land the coastline is placed backwards and new intertidal area is created. The area is enclosed by a secondary dyke on the landside to ensure safety of the hinterland. The goal is to create the right circumstances for succession of saltmarsh vegetation. Once saltmarshes develop the vegetation will enhance sedimentation and the area will become higher and is able to grow with sea level rise. Saltmarshes can reduce wave energy and improve the stability of the dyke.

Application

Managed realignment is mostly used in low lying estuarine and coastal areas to counter-act coastal erosion and coastal squeeze as a consequence of sea level rise or other causes and improve coastal stability. Furthermore it is a method that is used to compensate for loss of intertidal areas (tidal flats and salt marshes) and as water retention area during extreme water levels in narrow river mouths.

Advantages

- Possible reduction of coastal defence costs mainly due to decreased maintenance and a lower allowable safety standard.
- Attenuation of wave energy by intertidal habitats. Waves reaching the shore are less powerful and sea defence can therefore be of reduced height and strength or even be absent.
- Provide long term reduced risk of flooding and coastal erosion, because salt marshes are able to grow with the sea level, given sufficient sediment is available.
- Prevention of “coastal squeeze” by removal of the sea defence, salt marshes are able to migrate shore wards with the rising sea level.
- Provide a wide range of ecosystem services besides coastal protection like mitigation of CO_2 emissions, nutrient cycling, improvement of air and water quality, support of fish population for fisheries and contribution to an attractive landscape for visitors (Barbier, Hacker et al. 2011).
- Creation of new intertidal habitats which are valuable from a conservation point of view for birds, fish, macrobenthos and the support of the estuarine food web.
- Potential for recreation and aquaculture or cultivation of saline crops.

Disadvantages

- Former land use has to give way. This is a radical change for landowners, residents and people in the surroundings that recreate in the area. Often realignment causes high (social and political) controversy because of the resettlement that is involved and (agricultural) land is intentionally flooded by the sea. The choice of this measure therefore deserves careful consideration.
- Relocation of houses, buildings and infrastructure is very costly.
- Loss of agricultural land.

- Managed realignment is a relatively young concept. There is little experience and knowledge on best practices and feasibility.

Design

Design can greatly differ amongst managed realignment sites, depending on goals (coastal protection, nature development, retention) and specific local conditions. Pontee (2007) distinguishes three main categories: banked realignment, breached realignment and regulated tidal exchange.

1. Banked realignment

Banked realignment concerns complete dyke removal. With this measure a fully open connection with the estuarine or marine environment is restored. It is also helpful in creating more water storage capacity for example in narrow river mouths. However this design is not often used because of the high costs involved in dyke removal. Also lack of shelter can cause erosion that prevents salt marsh development and a higher wave attack on the secondary dyke. The Welwick site along the Humber Estuary in North England is one of the few examples where complete dyke removal took place (Pontee 2007) and 1400m dyke was removed. This was done to enhance and maintain mudflat formation which was the main goal. Banked realignment enables higher water movement levels within the site with the absence of the formal sea defence, thereby improving the probability that mudflat habitat will be maintained (Institute of Estuarine & Coastal Studies 2008).

Aerial view of the Welwick managed realignment site prior to preparation of the site (Humber Estuary, UK)(Institute of Estuarine & Coastal Studies 2008)

2. Breached realignment

With this method the coastal defence is maintained and provided with one or more inlets depending on the size and shape of the area. This method concerns less excavation then banked realignment and provides more shelter to the re-inundated area which limits erosion and impact on the secondary dyke by reducing wave energy. In the Humber estuary coastal management applies breached realignment at several sites to enhance coastal protection and mitigate for coastal squeeze. The interaction with the estuarine ecosystem, however, is more limited. The inlet design is determining water flow and volumes. The width of the inlet should at least be broader than the width of the main ebb tidal gullies in the area. Previous experience

Aerial view of Paul Holme Strays managed realignment site (Humber Estuary, UK) (Institute of Estuarine & Coastal Studies 2008) showed that if inlets are too narrow, high flow velocities occur which can damage the breached dyke (Dixon, Morris et al. 2008). A study by Townsend (2008) describes a method for inlet design that is based on the maximum allowed flow velocity before erosion occurs, the elevation of the area in regard to sea level and current conditions. Also the orientation of the inlet can influence the tidal energy and flow velocities coming into the area (Van Oevelen, Van den Bergh et al. 2000).

3. Regulated tidal exchange

Use of a culvert/sluice system in the coastal defence enables regulated tidal exchange to the re-inundated area. A high level and low level sluice in the dyke enable inflow during high tide and discharge during low tide. The position of the sluices in the dyke determines the tidal regime in the area. In a river mouth where fresh as well as salt water influence is present the sluice positioning and design can also determine water quality (salinity and nutrient) inflow (Maris, Cox et al. 2007) and determines the amount of water and sediment inflow. Regulated tidal exchange is mainly used for water retention motives, for example along the freshwater tidal zone of the Scheldt estuary (Belgium), where more retention is created by allowing reduced tide and dyke overflow at several sites along the estuary. However potential of these sites concerning sedimentation and the ability of the area to grow with sea level rise also looks promising. By limiting currents and wave action, limited erosion occurs (Peeters, Claeys et al. 2009). Because water depth is not determined by the natural feedback (increase of elevation means decrease in water depth when inundating) but remains constant, continuous high sedimentation rates are possible (Vandenbruwaene, Maris et al. 2011). Vandenbruwaene (2011) calculated that an area with regulated tidal exchange could grow up to 2-2,5 times faster than a natural saltmarsh over 75 years. Drawbacks are high construction costs due to the sluices and limited exchange with the estuarine ecosystem.

Aerial view of Lippenbroek along the Scheldt estuary with regulated tidal exchange (www.sigmaplan.be)

Guidelines and boundary conditions

Table 1: boundary conditions

Criteria	Threshold	Habitat	Comments	References
Site selection	Location	Saltmarsh	Formerly reclaimed land where saltmarshes were present before embankment and where there is limited erosion (relatively sheltered) are most suited for managed realignment.	(French 2006)
	Land use	Saltmarsh	Areas which are relatively undisturbed in terms of geo-chemical soil conditions. For example a former meadow area is more likely to succeed to saltmarsh than a ploughed field	(French 2006)
Elevation	MHWS-MHWN	Saltmarsh	Minimum of 400-500 inundations per year. From 1m below MHWN colonisation by pioneer vegetation takes place.	(Toft and Maddell 1995) (French 2008)
	MHWN-MLWS	Intertidal flat		
Slope	Possible:0-7% (1:0-1:18) Optimal:1-2% (1:0-1:64)	Saltmarsh	Slope determines the drainage. A gentle slope in seawards direction reduces flow velocity and enhances sedimentation.	(Burd 1995)
Size	Fetch < 2000m	Saltmarsh Intertidal flat	The "fetch" (length or width) and depth are determining for the degree in which waves can develop and case resuspension of sediment. A study by French et al describes erosion of -10mm/year in realignment areas with a fetch of 2000m and sedimentation of 7-16mm/year with fetch 400m.	(French, French et al. 2000)
Shape	Length/width ratio	Saltmarsh Intertidal flat	An elongated area that is far more deep than wide supposedly has a has lower initial accretion, because most of the sediment has settled by the time the tide has travelled to the back of the area.	(Van Oevelen, Van den Bergh et al. 2000)
Suspended sediment	1-10 mg/l survival * 10-100 mg/l growth*	Saltmarsh	Survival of saltmarshes depends on the degree of sea level rise. *Besides the suspended sediment concentration the sedimentation rate also depends on elevation of the area which determines the water depth and plant characteristics/age of the saltmarsh and estuarine characteristics (river discharge and tide).	(Borsje, Van Wesenbeeck et al. 2011) (Li and Yang 2009) (Temmerman, Govers et al. 2004)

Costs

Costs of managed realignment sites widely differ and there is no standard guideline that indicates costs. This is because the concept is still young and few data are available but also because of many variables that influence costs. Breached realignment is the most frequently used method. Numerous factors can influence costs of managed realignment site, for example:

- Land of construction (costs of realignment in undevelopment countries are lower than in developed countries)
- Costs of the inland area that will be re-inundated
- Compensation to land owners
- Costs for dismantling buildings, roads etc.
- Costs for a new inland sea defence

De Nocker (2010), summed up the costs of existing managed realignment projects in the South western Delta. In the following tables the costs are shown of banked realignment (Table 2), regulated tidal exchange combined with a tidal energy generator (Table 3) and breached realignment (Table 4).

Table 2: Examples of costs of banked realignment projects in the South western Delta.

Banked realignment	Investment costs (M€)	Operation en maintenance costs (M€/ jr)	Loss of agricultural production M€/ jr)	Total costs (M€, present value, 5,5 % interest)	size polder (ha)	Investmentcosts (x 1000 €/ ha, PV, 5,5% interest)
Braakman groot	279,2	3,1	4,5	425,0	1.609	264,1
Braakman klein	161,1	1,3	0	186,0	617	301,5
Molenpolder	21,4	0,3	0,1	29,1	75	388,0
Hellegatpolder	29,1	0,4	0,6	48,3	139	347,5
Serarendspolder	21,6	0,3	0,2	31,2	54	577,8
Hedwige-Prosperpolder	55,1	0,7	1,8	103,1	417	247,2
Zimmermanpolder	33,0	0,4	0,7	54,1	164	329,9

Source: De Nocker et al, 2010, edited

Table 3: Examples of costs of regulated tidal exchange / energypolder projects in the South western Delta.

energypolder/ regulated tidal exchange	Investment costs (M€)	Operation en maintenance costs (M€/ jr)	Loss of agricultural production M€/ jr)	Total costs (M€, present value, 5,5 % interest)	size polder (ha)	Investmentcosts (x 1000 €/ ha, PV, 5,5% interest)
Braakman groot	374,3	4,6	4,5	548,9	1.609	341,1
Braakman klein	203,2	2,0	0	241,6	617	391,6
Molenpolder	24,4	0,3	0,1	32,1	75	428,0
Hellegatpolder	31,0	0,4	0,6	50,2	139	361,2
Serarendspolder	21,0	0,3	0,2	30,6	54	566,7
Hedwige-Prosperpolder	68,7	1,0	1,8	122,4	417	293,5
Zimmermanpolder	38,6	0,5	0,7	61,6	164	375,6

Source: De Nocker et al, 2010, edited

Table 4: Examples of costs of breached realignment projects in the South western Delta.

Inlaag/breached realignment	Investment costs (M€)	Operation en maintenance costs (M€/ jr)	Loss of agricultural production M€/ jr)	Total costs (M€, present value, 5,5 % interest)	size polder (ha)	Investmentcosts (x 1000 €/ ha, PV, 5,5% interest)
Hedwige-Prosperpolder	10,9	0,1	1,8	47,3	417	113,4
Kalkense Meersen	21,5	0,0	0,1	23,4	639	36,6

Source: De Nocker et al, 2010, edited

The costs are dependant on the scale of the project, the comparison between Braakman groot and Braakman klein shows this.

Production loss (agricultural)
By removing or breeching the primary dyke, the land behind the dyke is given back to the sea and loses its former function. If the land use behind the primary dyke was anything else but nature, production loss occurs (see third column of table 1, 2 and 3 for examples of production loss costs) Depending on the type of land use the costs will vary. In the Southwestern Delta, especially in Zeeland, the most common land use behind primary dykes is agriculture. Mostly grains (40%), potatoes (21%), sugar beets (11%) and vegetables (12%).

Table 5 shows the average production costs and revenues for common agricultural products. Data are referential for a standard farming company farming at clay ground in the south western part of the Netherlands.
To calculate the loss of agricultural production due to managed realignment, multiply the agricultural area in ha. lost because of managed realignment by the balance (revenues – costs) per ha.

Table 5: production and cost figures of common agricultural produce in the South western Delta.

	quantity (kg/ha)	price (euro/ kg)	revenues (euro/ha)	production costs (euro/ha)	balance (euro/ha)
consumption potatoes	49.000	0,09	4.165	2.142	2.023
sugar beets	68.000	0,035	2.380	1.588	792
wheat (winter)	9.000 (+ 4.500 straw)	0,10 (0,05 straw)	1.125	555	440
Maize	15.345	0,13	1.933	1.364	824

Source: Kwantitatieve informatie akkerbouw en vollegrondsgroenteteelt, 2006.

However the Delta, especially the Zuid Holland isles, also have a substantial area of greenhouses. If because of managed realignment the greenhouses have to be removed or reallocated the costs of production loss will be a lot higher.

Agricultural production loss also occurs when no agricultural land is lost but the land becomes more salinated due to an increased influence of the sea. Due to the increased salt level in the ground plants are lost or plants growth is inhibited. This production loss can be quantified by estimating the total agricultural area which is affected by the salt damage multiplied by the percentage of salt damage due to the managed realignment. Basically non-salt tolerant crops , like flower bulbs, can be grown without salt damage whenever the chloride-level in the groundwater is lower then 153 mg Cl per litre (the “threshold” in Table 6) (Roest e.a., 2003). If the chloride level exceeds this threshold each mg Cl will cause a production loss of 0,0182% of the revenue (the “slope” in Table 1). This means that a salt level of approximately 350 mg/l will cause a production loss of around 4% ((350-153)*0.0182).

Table 6: Average threshold and slope for salt damage per crop group

.	threshold (mg/l Cl)	slope (%/ mg/ l Cl)	**average yield (EUR/ ha)**
flower bulbs	153	0,0182	15.000
flowers	378	0,1890	15.000
fruit trees	642	0,0264	11.600
potatoes	756	0,0163	4.640
maize	815	0,0091	1.050
vegetables	917	0,0158	8.000
greenhouses	1.337	0,0141	
grass	3.606	0,0078	1.260
sugar beets	4.831	0,0057	2.470
wheat	1.288	0,0218	1.030

Source: Roest e.a., 2003, yield: LEI, 2005.

In total agricultural loss consists of the following items:

- Loss of production
- Costs made when changing crops
- Costs of retraning personnel
- Costs of loss of landless production, manure disposal

Benefits

Besides sea defence, managed realignment sites also provide benefits. They can provide ecosystem services and have potential for multifunctional use as recreation, aquaculture and cultivation of saline crops. In this paragraph the benefits of managed realignment will discussed.

Reduction in dyke reinforcement costs

Saltmarshes attenuate wave energy, therefore the secondary dyke can be less strong and high and maintenance costs are reduced. Maintenance cost savings will vary from site to site according to wave climate, coastal topography and consequent defence works (Turner, Burgess et al. 2007). Table 7 shows how saltmarshes before the sea defence influence dyke height and costs involved based on a report by the English Environment Agency (2006).

Table 7: Relation between saltmarshes and dyke costs in the UK, based on EA (1996)

Saltmarshes before dyke (m)	Dyke height (m)	Costs of sea wall (€/meter)
0	12	6000
6	6	1800
30	5	960
60	4	600
80	3	480

Costs of dyke raising are high, so considerable savings are feasible when salt marshes are formed before the dyke. Blom (2007) gives an indication for the cost of construction of a dyke (heightening and widening) of € 2750, - per meter. In an essay, Teun Morselt and Berry Gersonius (2010) present a fictitious but realistic case study in which they calculate the needed dyke enhancements and their costs due to different climate change scenario's. In Table 8 the investment costs are shown for a fictitious dyke with the same properties as dykes on the coast of Holland and Zeeland. Depending on the climate scenario, the fictitious dyke is heightened 0,5 to 1,5 meter. The dyke in the case study is 10 km long which equates to costs ranging from 3.8 to 5.5 million per kilometre dyke.

Table 8: Assumptions heightening the dyke

Water level increase	Crest height (m +NAP)	Increase in crest height (m)	Investment costs (mil. Euro)
0,5 m (5,5 instead of 5,0 metres)	12,66	0,66	38,0
1,0 m (6,0 instead of 5,0 metres)	13,35	1,35	46,0
1,5 m (6,5 instead of 5,0 metres)	14,04	2,04	55,0

Source: (Van Nieuwenhuizen 2010) teamanalyse Blueconomy/UNESCO-IHE

In a sensitivity analysis study of water retention in the Southwest Delta, Bulthuis et al (2010) calculate the costs of the necessary dyke reinforcements. In their calculations they use prices of € 5 to 10 million per kilometer dyke.

Finally, according to a study of Hillen et al (2010) the average costs for raising and strengthening Dutch dykes are between 4 and 11 million per kilometer in rural areas. For dykes in urban areas, these cost are between 14 and 22 million Euros per kilometer (price level 2009).

Non use of nature

The tidal mudflats and salt marshes of the foreshore contribute to the foraging area of birds in the southwestern delta. The conservation of nature can be a factor in the choice between certain solutions. Both from the standpoint of 'intrinsic value' of nature as well as from the prosperity that we as a society derive from the fact that nature is preserved (without direct use by us). Using the Conditional Valuation method, the value we attach to the preservation of estuarine nature can be estimated. As part as the Sigmaplan study the non-use-value of different types of floodplains was researched. One of the types of floodplains was regulated tidal exchange and another corresponded with banked realignment.

The willingness to pay for the nature and ecosystems which originated after introducing regulated tidal exchange was the highest, € 16,33 per household per year. People were willing to pay € 15,62 per household per year for the ecosystems that arise after banked realignment is introduced.

Clean surface water

Mudflats and salt marshes bring the benefit of "clean surface water 'because they degrade nitrate. Nitrate is degraded by plant uptake and denitrification. During the process of denitrification, the ammonia is converted to nitrogen gas by bacteria. The amount of denitrification in tidal marshes is approximately 176 kg per ha per year under the influence of fresh water and about 107 kg N per hectare under the influence of brackish water (Cox et al, 2004).
The mudflats and salt marshes will also take nitrate, phosphate and carbon burial place by sedimentation and accumulation of slowly degradable material. This will extract N, P and C from the water in salt marshes and mud flats. Results of calculations with the OMES model show approximately 148 kg N per ha is buried (Cox et al, 2004). This model study also shows that in intertidal areas, salt marshes and mud flats, about 1,500 kg C per hectare per year is deposited. Measurements at the Elbe river (fresh water conditions) show that the burial of phosphate is 4 to 56 kg P per ha (Dehnhart and Meyerhoff, 2002).
Finally, mudflats and salt marshes can capture metals and organic compounds like PAC's, PCBs, etc. from water. Little is known about the capture of organic compounds but it is known that heavy metals are captured by accumulation of sediment. Metals such as Copper, Chromium, Zinc, Lead, Cadmium, Nickel, Mercury and Arsenic are removed from the seawater because they're caught in sediment which accumulates on the bottom. Based on available data, Ruijgrok (2006) calculated a quantity of 7,686 kg per ha / yr of metal is deposited in the salt marshes and mud flats for the Zeeschelde basin.

Another way in which managed realignment, contributes to clean surface water is simply because agricultural activities stop. During the spread of fertilizer on fields a small part of the fertilizer reaches the surface water in ditches. This causes nitrogen (N) , phosphorus (P) and metals like cadmium, copper, nickel, lead and zinc to enter the surface water. The emission of N, P from fertilizer that reaches the surface water is dependent of the ditch area (km2) which borders on the agricultural grounds multiplied by an emission factor, which is the N and P load per ditch area (tonne/km^2/year). The ditch area that borders on agricultural grounds is calculated by multiplying the agricultural area with the ditch density (10 km/km^2), the number of ditch sides (2), the average ditch width (0,002 km) and the fraction of ditch sides which border on agricultural ground.
For the Netherlands as a whole the agricultural area and the N and P load per ditch area are stated in Table 9, 10 and 11 (Deltares/TNO, 2012); The amount of heavy metals in grassland and infields, and in chemical fertilizer, are stated in Table 12 and 13.

Table 9 Agricultural area

Type of agricultural ground	total Dutch ditch area (km2)
Grasslands	326,1
Infields	295,0
Total	625,1

Table 10

Fertilizer	kg N per km2 ditch
Manure (animal fertilizer) • Grasslands • Infields	 0 0
Chemical fertilizer • grasslands • infields	 2075 560

Table 11

Fertilizer	kg P per km2 ditch
Manure (animal fertilizer) • grasslands • Infields	 0 0
Chemical fertilizer • Grasslands • infields	 31 58

Table 12: The amount of heavy metals in grasslands and infields is calculated with respect to the amount of N in animal manure.

Animal fertilizer	Cadmium (mg /kg N)	Copper (mg /kg N)	Nickel (mg /kg N)	Lead (mg /kg N)	Zinc (mg /kg N)
grasslands	4,1	3,135	86,7	95,9	4,566
Infields	4,0	3,326	84,6	106,2	6,029

Table 13: The amount of heavy metals in chemical fertilizer are expressed with respect to the amount of N and P in fertilizer.

Chemical fertilizer	Cadmium (mg /kg N or P)	Copper (mg /kg N or P)	Nickel (mg /kg N or P)	Lead (mg /kg N or P)	Zinc (mg /kg N or P)
Phosphor	105,2	178,4	257,6	21,0	2242
Nitrate	0,36	8,4	-	84	25

Nitrate purification can be monetized based on the costs of sewage treatment in order to remove nitrate from the water, for nitrate this is around €2,20. This number is a proxy of the value of clean water. In the same way phosphor, carbon and metals are monetised. For P, C and metals the following prices are used (Ruijgrok, 2007):

treatment cost per kg P:	€ 8,50 / kg P
treatment cost per kg C:	€ 0,148 /kg C
treatment cost per kg metals:	€ 0,31 / kg Cadmium, copper etcetera

Capture of N, P, C and metals is related to the growth of mud flats and salt marshes, which is caused by sedimentation processes. This implies that the capacity to capture N, P,C and heavy metals is finite. When the salt marsh is mature, no more sedimentation occurs, and thus no more deposition takes place. With rising sea levels however, the mud flats and salt marshes can continue to grow.

Protection against climate change

Plants capture CO_2 by growing, transforming it into biomass. This is how salt marshes contribute to protection against climate change. The net carbon capture, the difference between fixation and decomposition, is large for ecosystems with a high net primary production, that is to say grow fast. This is for example the case for reed lands. However this is a relatively short term effect (several decades) because when the ecosystems is matured the net primary production approaches zero.

Other ecosystems are slow to decompose. This means that the net carbon capture is large on a long term scale (several centuries). This is the case for salt marshes. The carbon fixation in salt marshes is in the dead organic materials in the soil. The net carbon capture is smaller on an annual basis for salt marshes compared to reed beds but it lasts for centuries. Mud flats and salt marshes capture about 1,5 ton per ha per year in the soil (Ruijgrok et al., 2006).

Recreation

After managed realignment has taken place, if all goes well, salt marshes start to grow and a diversity of plants and animals start to inhabit the area. Salt marshes are important for birds as foraging and resting places. These aspects make them attractive for nature-lovers to recreate. The positive effects of salt marshes on recreational experience can be reflected in an increase in the number of visits and / or improve the quality of people who already are (but a more attractive landscape with nature to enjoy). Whether more salt marshes in the Delta will lead to more leisure-activities and thus to more spending, is questionable. More likely is that visits to the newly formed salt marshes will be at the expense of the number of visits to other nature areas nearby. This provides no additional benefits from spendings.

Recreationists and tourists not only spend money recreating in nature, they also derive a sense of prosperity from nature for which they are willing to pay a certain amount of money. For coastal nature such as mud flats and beaches people are willing to pay ranging from EUR 0.87 to EUR 1.93 per visit (Ruijgrok, 2006).

Opportunities for saline agriculture

A study by De Mesel et al. (2011 (in preparation)) describes several forms of aquaculture and cultivation of saline crops that are possible in a re-inundated saltwater tidal area. As the main goal of a realigned area is elevation increase by sedimentation, land use forms should be extensive without hampering the sedimentation process. Table 14 describes several forms saline land use with a potentially high market value, based on De Mesel et al.(2011 (in preparation)) and related studies .

Table 14 Aquaculture and saline crop yield in an managed realignment area based on a study by De Mesel et al. (2011 (in preparation)) and related studies.

Type	Species	Method	Yield	Reference
Shellfish	Blue mussle –*Mytilus edulus*	Mussel growth on poles ("Bouchot") in the intertidal zone	41920€/ha/year	www.fao.org
	Pacific Oyster – *Crassostrea gigas*	Oyster growth on "tables" in the intertidal zone	25000€/ha/year	www.fao.org
	European flat Oyster – *Ostrea edulis*	Oyster growth on "tables" in the intertidal zone	20900€/ha/year	(Van der Hiele, Heringa et al. 2008) and related references
Worms	Ragworms - *Nereis virens*	Extensive digging for rag worms at low tide	?	?
Sea weeds	Tough Laver - *Porphyra umbilicalis*	Marcoalgae attached to floating devices	651	(Lobban and Wyne 1981)
	Hudson - *Gracilaria verrucosa*	Marcoalgae attached to floating devices	435	(Xin 1989)
Zilte groentes	Common glasswort –*Salicornia europaea*	Harvest from wild growth on saltmarshes	84000€/ha/year	(Van de Voort, Dekking et al. 2005) and related references
	Sea aster – *Aster tripolium*	Harvest from wild growth on saltmarshes	35000€/ha/year	(Goosen 1999)

Long term benefit: Independence of climate scenario.

An added advantage of eco engineers is their ability to adapt to their environment. Thus, as water levels vary due to climate change, the bio-builders can adapt to the variations and maintain their function of coastal protection. For example, if Spartina grows on a salt marsh it will accumulate organic material. In time the salt marsh will grow because of this sedimentation. As sea levels rise, the sea will continue to supply organic material. Subsequently the salt marsh will keep on growing. Because of this natural growth, construction costs of coastal protection structures like dykes can be limited, as are costs for maintenance and repair. On the other hand, it should be realised that many eco-engineers can be vulnerable to diseases or extreme weather events, such as ice surges. These can reduce the safety during prolonged periods of time.

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Ecosystem engineers

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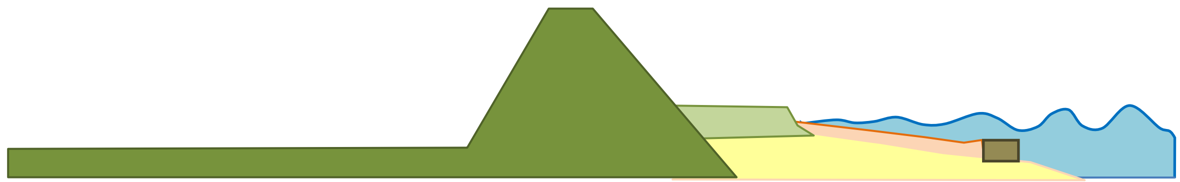
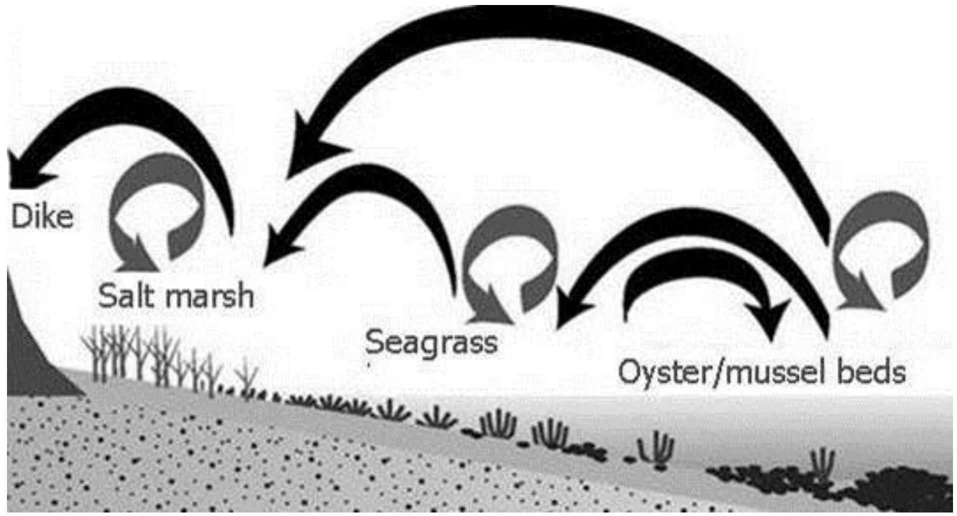
IMARES WAGENINGEN UR



Description

Ecosystem engineers are plants or animals that influence their environment with their presence or activities(Jones, Lawton et al. 1994). Many ecosystems are greatly affected by ecosystem engineering, such as coastal salt marshes, where macrophytes trap sediment (sand or clay particles) by reducing hydrodynamic energy (Bouma, De Vries et al. 2005). Other examples of ecosystem engineers in tidal environments are reed marshes, willow tidal forests, mangroves, sea grass beds, coral reefs and bivalve reefs. There is growing recognition that the ecosystem engineering concept can contribute to ecological applications such as restoration and ecosystem management (Byers, Cuddington et al. 2006). In recent years the interest in using them in coastal defense has grown. Especially the ecosystem engineering properties of reducing wave energy and trapping sediments make species such as reef building oysters and salt marsh plants interesting target species. It is believed that the use of ecosystem engineers in coastal management can contribute to a more sustainable, cost-effective way of protecting our coasts, especially in the light of climate change and sea level rise. Secondly, there is also a need for methods of coastal protection that incorporates the natural dynamics and processes of the ecosystem, allowing a more resilient and robust future coastline. Only in this way the many ecosystem services coastal habitats in general and ecosystem engineers in particular provide can be safeguarded.

Application



Ecosystem engineers can be used to stabilize and protect shorelines and intertidal habitats (tidal flats and saltmarshes) against erosion and to minimize wave attack on the coast. Ecosystem engineers can induce positive facilitation cascades in which a certain engineer (e.g. an oyster reef) can have positive effects on the growing and survival conditions of another ecosystem engineer (e.g. sea grass). Also ecosystem engineers possibly can help to extend sustainability (i.e. lifetime) of sand nourishment sites by reducing erosion of the nourished sediment. By creating the right preconditions for settlement and growth a specific ecosystem engineer can develop and persist over time. The additional advantage is that several of these structural ecosystem engineers that inhabit intertidal habitats can grow to keep up with sea level rise (e.g. salt marshes).

Ecosystem engineers: shellfish reefs

Application

According to De Vries et al. (2007) and Borsje et al. (2011) mussel and oyster reefs are promising ecosystem engineers to stabilise intertidal flats and saltmarshes in front of the dykes because they reduce hydrodynamic energy (waves and currents) and enhance sedimentation. These shellfish reefs can therefore perform similar functions as groynes and dams, but have additional advantages such as the creation of valuable habitat and the possibility to keep pace with sea level rise.

Boundary conditions and design

Experience with shellfish shows that the Pacific Oyster (*Crassostrea gigas*) is a suitable ecosystem engineer. This is because this oyster creates extensive reefs, formed by densely packed individual oysters growing upward and outward on top of each other. New oysters settle on top of conspecifics and create a complex, three-dimensional, hard surface that is persistent over time and that is strong enough to withstand wave attack. These reefs influence local ecology by creating shelter, increasing sedimentation and organic matter content through bi deposition (Piazza, Banks et al. 2005) and enlarge biodiversity by creating new habitat for fish, crustaceans and other species (Borsje, Van Wesenbeeck et al. 2011). These reefs can also act as foraging ground for birds during low tide.

Properties of a natural Pacific Oyster (*Crassostrea gigas*) reef		
Weight of living oysters and empty shells in a reef	24-34 kg/m^2	(Wijsman, Dubbeldam et al. 2008)
Dry flesh weight in relation to total weight of individual	1,8%	(Perdon and Smaal 2000)
Dry flesh weight oyster reef	432-612 gram/m^2	
Filter capacity individual	5,8 l/h/ gram dry flesh weight	(Kater 2003)
Efficiency rate oyster (100% inundation)	89%	(Haure, Huvet et al. 2003)
Filter capacity oyster reef	0,04 m^3/day/m^2	
Wave attenuation	Up to 40%[1]	(Borsje, Van Wesenbeeck et al. 2011)
Salinity concentration		
Elevation		
Substrate		

[1] This is a result from a flume experiment with a Pacific Oyster reef made of 148 shells/m^2, 0,071 m in average height and 3,1m long. The oysters were placed 7,9m from the wave generator in 0,25m water depth in a wave flume of 13,5 by 0,5 meter. Average wave height was 3,34m (Borsje, Van Wesenbeeck et al., 2011).

- Pilot oyster reefs Oosterschelde – Building with Nature

In the Oosterschelde in the Southwest Delta in the Netherlands a large scale pilot is in progress which studies and evaluates the use of Pacific Oyster reefs in reducing the erosion of the intertidal zone. In addition to reduction of wave energy it focuses on the role of these reefs in the stabilisation of tidal flat edges. The pilot is executed within the Building with Nature innovation programme and conducted by collaborating parties IMARES Wageningen UR, Rijkswaterstaat, NIOZ and Deltares. Oyster reefs are placed at two locations: near the dyke and on the outer tidal flat near low water level on the south side of eastern Schouwen-Duivenland. This pilot started in 2009 and is still running.

a. location of artificial oyster reefs in the Oosterschelde b. off shore reef, c. near shore reef

The pilot reefs that were constructed are 200 m long, 10 m wide and 0,25m high. The artificial reefs were made of wire mesh gabions filled with oyster shells.

Costs

Construction
30-50 €/m^2

Maintenance
The artificial oyster reef should be colonised by oyster larvae and develop to a self-sustaining natural reef.

Benefits

The term eco-engineers (or bio-builders) is a generic term. Several kinds of animals and plants have the ability to stabilize and protect shorelines. But they do not always function the same way and they do not necessarily have the same benefits. Because of these differences we make a distinction between the benefits of:

- Salt marshes, which can be formed or enhanced by bio-builders like Spartina.
- Dunes; including the growth of Marram grass which enhances dune formation
- Oyster or Mussel reefs
- Reed lands

Reduction in dyke reinforcement costs
Oyster reefs, beds of seaweed and salt marshes offer protection against the sea. They break the force of waves before they reach the dyke. Because of this wave energy reduction, dykes will suffer less from wave-attacks and reinforcements of the dykes can be less frequent or less intensive. The impact of bio-engineers on the reduction of dyke reinforcement depends on many factors for instance the type of bio-engineer, location and dimensions of the bio-engineers, inundation depths etcetera. The effectiveness is also dependent on the characteristics of the incoming wave height and wave period. So it’s hard to say how much reduction in dyke reinforcement is possible but the English Environment Agency (2006) reported the relation between area of salt marsh before the dyke and dyke height. This is shown in Table 1.

Table 1: ***Relation between saltmarshes and dyke costs in the UK, based on EA (1996)***

Saltmarshes before dyke (m)	**Dyke height (m)**	**Costs of sea wall (€/meter)**
0	12	6000
6	6	1800
30	5	960
60	4	600
80	3	480

A study by Hillen et al. (2010) describes the costs for heightening dykes in the Netherlands based on several studies:

- 9-11 M € km for 1 meter higher in rural areas
- 13,8-21,6 M € km for 1 meter higher in urban areas

Maintenance costs of dykes are estimated at 0,1 M €/km/year in the Netherlands (ACPM 2006).

An indication of possible savings on dyke reinforcements by the existence of tidal flats and salt marshes, comes from a study on the effects of sand hunger in the Oosterschelde . In this study Van Zanten en Adriaanse (2008) describe the effects of sand starvation on dyke reinforcements. When the intertidal area in front of a dyke becomes lower (or disappears completely) as a result of the sand demand, then higher waves will reach the dyke. This will create a greater load. The effects of sand demand have been considered in the design of the current dyke reinforcements, but these effects have been underestimated, resulting in a need for extra investment for dyke reinforcement over the next 50 years. Depending on the impact of other factors such as climate change, the expected extra costs will vary from € 25 to 45 million in the most favourable case to € 90 to 260 million in the worst case. This proves that the presence of bio-builders in salt marshes and oyster- or mussel reefs can result in considerable savings on dyke reinforcements.

Non use of nature

The conservation of nature can be a factor in the choice between certain solutions. Both from the stand point of 'intrinsic value' of nature as well as from the prosperity that we as a society derive from the fact that nature is preserved (without direct use by us). Over the years some valuation studies (using the Conditional valuation) have been done to estimate the value we attach to the preservation of estuarine nature.

The tidal mudflats and salt marshes of the foreshore are important foraging areas of birds and therefore contribute to the preservation of nature. Overkamp (1994) examined the willingness to pay for maintaining Rottemeroog and found an amount of EUR 35, - per household. Although this study did not specifically target biodiversity conservation, this number still gives an estimate of the non-use value of coastal nature (tidal mudflats). This price gives an all or nothing indicative of the disappearance of the entire bank of Rottumeroog. Ruijgrok and Lorenz (2004) measured an average willingness to pay for non-use of flood plains with salt marshes and mud flats in Flanders of EUR 16, - a year per household. For the Oosterschelde Ter Haar (2011) examined the willingness to pay for measures in the Oosterschelde to preserve sandbanks. He explored, using an Internet survey, the willingness to pay for preservation of 10% of the shoals (or 33%, or 67% or 100%) and incorporated herein the necessary costs for these variants. Thus creating a market for the costs of action rather than an appreciation for social goods for which no market exists. He found different (lower) results. On average, respondents approximately are willing to pay EUR 6,40 for the preservation of tidal mudflats in the Oosterschelde. If all households in the Netherlands would be willing to pay this amount, approximately 75% of the tidal flats in the Oosterschelde can be saved.
Not much is known about the non-use value of dunes. A questionnaire survey study which measured the non-use of coastal nature was a conducted by Ruijgrok (2000). She found a willingness to pay of € 5,50 a year for the non-use value of beach and dunes.
Ruijgrok and Vlaanderen (2001) found a willingness to pay of approximately EUR 11 per household per year for the non-use value of reed covered land- water transitions. As far as we know, no research is done on the subject of the non-use value of mussel- or oyster banks.

Recreation

Salt marshes have a diversity of special plants and animals. They're important for birds as foraging and resting places. These aspects make them attractive for nature-lovers to recreate in. The positive effects of salt marshes on recreational experience can be reflected in either an increase in the number of visits or improved quality of the landscape (more attractive). Whether more salt marshes in the Delta will lead to more leisure-activities and thus to more spending, is the question. Salt marshes are usually not easily accessible and thus not many people will choose it as a daytrip destination for example for hiking.

Dunes, on the other hand, are attractive for recreational use. This is clearly shown by the number of people who choose to spend their vacation near the beach. For example, for years on a row the North sea is the most popular place to go to on Holiday in Holland. Merely 1% of Holland exists of dunes still, three quarters of all Dutch plant and bird species are found here. So dunes are attractive for sun lovers as well as nature lovers. Whether more dunes will lead to more leisure-activities and thus to more spending, usually depends on the number of people living in the area. If the area is not densely populated it is likely that visits to the newly formed dunes will be at the expense of the number of visits to other areas nearby. This provides no additional benefits from spendings. If, on the other hand, the area is located near densely populated areas like for instance a large city like The Hague, newly formed dunes will attract extra visitors. This is because of the shortage of recreational area in and around the city. In the SCBA ‘Recreatie Zuidvleugel’ (Witteveen + Bos, 2007) it was clear that new recreational areas will lead to extra visitors and thus to more spendings.

The mussel or oyster banks need hard substrate to grow on. This hard substrate acts as a reef on which not only mussels and oysters can grow but also other plants and animals like actinia (sea anemone). This reef will give shelter and food for other animals which make it an attractive place for divers. Annually tens of thousands of divers come to visit the province Zeeland. Together they make approximately 800.000 dives a year.
Most divers have a high education and an above average income. They come to Zeeland as dive enthusiasts and this makes them a special interest group. Special interest groups tend to spend more money during their visits. This is also the case for divers in Zeeland: on average they spend about €65,- to €107,- a day on tourism in Zeeland. Besides these spendings they spend another €25,- tot €30,- a day on the diving itself. For comparison, the average tourist spends between €27,- en €65,- per day (Kenniscentrum Kusttoerisme, 2011).
Almost 40% of the Dutch and Belgian divers are not familiar with the diving opportunities in Zeeland. This percentage is even larger for German, French and English divers. This means there is potential for growth in the number of divers.

Recreationists and tourists not only spend money recreating in nature, they also derive a sense of prosperity from nature for which they are willing to pay a certain amount of money. For coastal nature such as mud flats and beaches people are willing to pay ranging from EUR 0.87 to EUR 1.93 per visit (Ruijgrok, 2006).

Clean surface water

Mudflats and salt marshes bring the benefit of ''clean surface water 'because they degrade nitrate. Nitrate is degraded by plant uptake and denitrification. During the process of denitrification, the ammonia is converted to nitrogen gas by bacteria. The amount of denitrification in tidal marshes is approximately 176 kg per ha per year under the influence of fresh water and about 107 kg N per hectare under the influence of brackish water (Cox et al, 2004).
Also in mudflats and salt marshes nitrate, phosphate and carbon burial takes place by sedimentation and accumulation of slowly degradable material. This will extract N, P and C from the water in salt marshes and mud flats. Results of

calculations with the OMES model show approximately 148 kg N per ha is buried (Cox et al, 2004). This model study also shows that in intertidal areas, salt marshes and mud flats, about 1,500 kg C per hectare per year is deposited. Measurements at the Elbe river (fresh water conditions) show that the burial of phosphate is 4 to 56 kg P per ha (Dehnhart and Meyerhoff, 2002).
Finally, mudflats and salt marshes can capture metals and organic compounds like PAC's, PCBs, etc. from water. Little is known about the capture of organic compounds but it is known that heavy metals are captured by accumulation of sediment. Metals such as Copper, Chromium, Zinc, Lead, Cadmium, Nickel, Mercury and Arsenic are removed from the seawater because they're caught in sediment which accumulates on the bottom. Based on available data, Ruijgrok (2004) calculated a quantity of 7,686 kg of metal per ha per year is deposited in the salt marshes and mud flats for the Zeeschelde basin.

Reed lands are also able to break down nitrates and phosphates, uptake N and P, and thereby removing it from the water. Purification of the water only takes place when the vegetation is removed and not immediately reintroduced into the environment (eg litter). The disposal of N is approximately 150-200 kg N per ha. The removal of phosphates is approximately 20 kg P per ha. (Toet, 2003). The removal of N and P by cutting or mowing is optimal when it happens in October. Reed can also contribute to clean surface water the same way salt marshes do, by capturing metals and C in sediment. About 109 kg of metals per ha per year and 1.222 kg C are caught in the sediment (Ruijgrok et al, 2006).

Protection against climate change

Plants capture CO_2 by growing, transforming it into biomass. This is how salt marshes and reed beds contribute to protection against climate change. The net carbon capture, the difference between fixation and decomposition, is large for ecosystems with a high net primary production, that is to say grow fast. This is the case for reed lands. However this is a relatively short term effect (several decades) because when the ecosystem is matured the net primary production approaches zero.
Other ecosystems are slow to decompose. This means that the net carbon capture is large on a long term scale (several centuries). This is the case for example for salt marshes. Where the carbon fixation for reed beds is in the living material, the carbon fixation in salt marshes is in the dead organic materials in the soil. The net carbon capture is smaller on an annual basis for salt marshes compared to reed beds but it lasts for centuries. Reed lands capture approximately 6,8 ton C per ha per year, mud flats and salt marshes capture about 1,5 ton per ha per year in the soil (Ruijgrok et al., 2006).

of ecosystem change for salt marshes.

Ecosystem services	Ecosystem processes and functions	Important controlling components	Ecosystem service value examples	Human drivers of ecosystem change
Raw materials and food	generates biological productivity and diversity	vegetation type and density, habitat quality, inundation depth, habitat quality, healthy predator populations	£15.27· $ha^{-1}·yr^{-1}$ net income from livestock grazing, UK (King and Lester 1995)	marsh reclamation, vegetation disturbance, climate change, sea level rise, pollution, altered hydrological regimes, biological invasion
Coastal protection	attenuates and/or dissipates waves	tidal height, wave height and length, water depth in or above canopy, marsh area and width, wind climate, marsh species and density, local geomorphology	US\$8236· $ha^{-1}·yr^{-1}$ in reduced hurricane damages, USA (Costanza et al. 2008)	
Erosion control	provides sediment stabilization and soil retention in vegetation root structure	sea level rise, tidal stage, coastal geomorphology, subsidence, fluvial sediment deposition and load, marsh grass species and density, distance from sea edge	estimates unavailable	
Water purification	provides nutrient and pollution uptake, as well as retention, particle deposition	marsh grass species and density, marsh quality and area, nutrient and sediment load, water supply and quality, healthy predator populations	US\$785–15 000/acre capitalized cost savings over traditional waste treatment, USA (Breaux et al. 1995)†	
Maintenance of fisheries	provides suitable reproductive habitat and nursery grounds, sheltered living space	marsh grass species and density, marsh quality and area, primary productivity, healthy predator populations	US\$6471/acre and \$981/acre capitalized value for recreational fishing for the east and west coasts, respectively, of Florida, USA (Bell 1997) and \$0.19–1.89/acre marginal value product in Gulf Coast blue crab fishery, USA (Freeman 1991)†	
Carbon sequestration	generates biogeochemical activity, sedimentation, biological productivity	marsh grass species and density, sediment type, primary productivity, healthy predator populations	US\$30.50· $ha^{-1}·yr^{-1}$‡	
Tourism, recreation, education, and research	provides unique and aesthetic landscape, suitable habitat for diverse fauna and flora	marsh grass species and density, habitat quality and area, prey species availability, healthy predator populations	£31.60/person for otter habitat creation and £1.20/person for protecting birds, UK (Birl and Cox 2007)	

† One acre = 0.4 ha.
‡ Based on Chumra et al. (2003) estimate of permanent carbon sequestration by global salt marshes of 2.1 Mg C· $ha^{-1}·yr^{-1}$ and 23 September 2009 Carbon Emission Reduction (CER) price of the European Emission Trading System (ETS) of €12.38/Mg, which was converted to US\$2000.

Long term benefit: Independence of climate scenario.
An added advantage of eco engineers is their ability to adapt to their environment. Thus, as water levels vary due to climate change, the bio-builders can adapt to the variations and maintain their function of coastal protection. For example, if Spartina grows on a salt marsh it will accumulate organic material. In time the salt marsh will grow

because of this sedimentation. As sea levels rise, the sea will continue to supply organic material. Subsequently the salt marsh will keep on growing. Because of this natural growth, construction costs of coastal protection structures like dykes can be limited, as are costs for maintenance and repair.

Ecosystem services

Ecosystem services, processes and functions, important controlling components, examples of values, and human drivers of ecosystem change for salt marshes according to Barbier et al. (Barbier, Hacker et al. 2011).

Ecosystem engineers: Spartina anglica

Dunes develop when pioneers like *Ammophila arenaria* (Marram grass) grow on sand transported by wind and waves. In some areas they form a crucial barrier of protection against the sea. Formation of dunes has been stimulated by planting *Ammophila arenaria* as ecosystem engineer to enhance capture of sand particles and dune formation.

Also saltmarshes can play an important role in formation of new land and coastal protection by reducing waves. Möller et al. (2001) has determined by field experiments that wave attenuation by salt marshes is 50% higher than by tidal flats.
The salt marsh vegetation can reduce the wave energy as :-
1. the roughness of the plants produce greater energy loss from waves
2. the vegetation binds the sediment together, thus increasing soil stability
3. the leaves and stems increase the rate of vertical accretion by acting as wave baffles (French 2001).

As a wave moves across a vegetated surface, the energy levels and wave height decrease exponentially. The amount and rate of decrease is a function of wave height approaching the marsh, distance travelled through the marsh, depth of water and density and size of plants.
In the context of the wider estuary environment, saltmarsh maintenance or enhancement is increasingly being considered as a means of providing a long term and more sustainable approach to coastal defence. It also has the added advantage of enhancing the conservation importance of a natural habitat.

Spartina anglica ("Spartina" in short) is a salt mash plant that has been used to enhance salt marsh formation by sedimentation. In 1924 their roots were first transported to the Netherlands. In 1929 Spartina was planted on tidal flats in the Southwest Delta of the Netherlands. Because this pioneer can grow lower in the tidal range than native species, it can enhance sedimentation at lower elevations. By the introduction and planting of Spartina the development of salt marshes especially in the Westerschelde has been stimulated (Kornman and Schouwenaar 2001).

Spartina anglica

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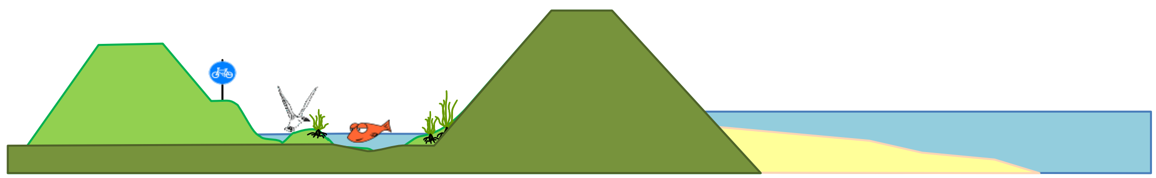
Building with Nature

EcoShape

Coastal buffer zone: “inlaag”

Marijn Tangelder & Tom Ysebaert

IMARES WAGENINGEN UR



Description

An “inlaag” is a predominantly salt/brackish zone along the coast between two dykes. Historically these areas arose when people built a spare inner dyke parallel to the coastal defence when there was a threat of dyke failure. The principle of a coastal buffer zone is interesting from a coastal protection point of view and elaborated here. Because of the presence of a secondary dyke, the primary coastal defence can suffice with lower safety standards as for example reduced height. Limited overflow during extreme high water conditions is acceptable because the secondary dyke will stop the water from inundating the land behind the secondary dyke. This is interesting from a cost and dyke maintenance point of view. The area between the dyke is not suitable for high quality land use as housing, but can serve as nature and recreation area and also has potential for aquaculture.

Inlagen of the Oosterschelde

Historically an “inlaag” was used in the Netherlands as buffer zone between the sea and the inhabited area behind the dykes. If an area seemed no longer safe to inhabit because of a progressing sea a secondary inner dyke was built. This dyke was meant to provide protection in the unfortunate case the primary dyke would fail. Nowadays “inlagen” are still preserved or reconstructed along the coast of Schouwen-Duivenland and Noord-Beveland in the Southwest Delta in the Netherlands. The area between the dykes is usually unattractive for agriculture due to high salinity concentrations in the soil (seepage). Most of these areas are therefore nature reserves. Due to the historic character an “inlaag” also holds high cultural values.

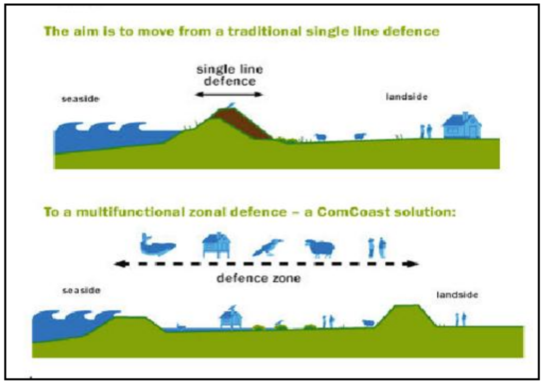
Inlaag Noord-Beveland (www.kustfoto.nl)

Application

A coastal buffer zone enables zonation of flood risk. The flood risk in the buffer zone can be higher than normal standards. The advantage is that the primary dyke does not have to be raised when sea level rises. In fact, limited overflow can be permitted. Because the raising of a dyke is very expensive this will considerably save costs. When allowing water and higher groundwater levels in the area between the dykes this can also reduce land subsidence. On the other hand to allow overflow the crest and landward side of the primary dyke has to be strengthened. Depending on the frequency of overflowing, the area between the dykes is subject to occasional flooding which puts limitations on land use. By choosing low-lying, coastal areas with extensive land use (nature areas), the adverse effects on land use practices are brought to a minimum.

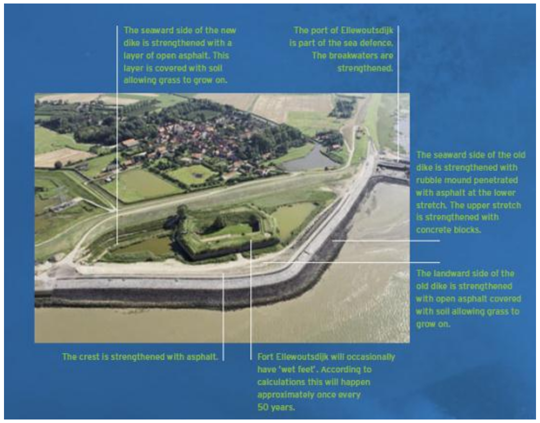
The principle of a coastal defence zone is already practised.

Coastal Laboratory – Southwest Delta, Netherlands.



The establishment of the Coastal Laboratory (“Kustlaboratorium” in Dutch) is an initiative of the Zeeuwse Landschap foundation in cooperation with several other parties. The goal is to investigate potential synergy between coastal safety, aquaculture innovation, nature and recreation (www.kustlaboratorium.nl). The development site is located on the south coast of Schouwen-Duiveland near Burghsluis. The test site will be developed between two parallel dykes along the coast and serve as a coastal buffer zone.

ComCoast: Combining functions in Coastal Defence Zones



ComCoast is a four-year collaboration of North Sea countries Belgium, Denmark, Germany, Netherlands and United Kingdom. The program develops and demonstrates new ways of management and organization of the coastal zone by means of pilots (www.coamcoast.org). The core of this programme is to apply a zonation in flood risk by allowing dyke overflow during extreme high water conditions and built a secondary defense. In addition, the programme is also aimed to investigate social value of these areas. An example is the project Ellewoutsdijk where two parallel dykes were strengthened and together form a flood protection zone.

Boundary conditions

Site suitability

Areas that are interesting for the application of a coastal buffer zone are mostly low-lying areas where a secondary dyke is already present. In areas where land has been reclaimed in the past inland, former sea dykes are often present. Some of these areas are dominated by salt water seepage which makes the land less valuable for agriculture of housing for example. These areas very suited for the application of a coastal buffer zone.

Dykes

Some adjustments need to be made to ensure dyke stability:

- The primary dyke should be able to overflow, therefore the inner slope of the dyke should be strengthened and hardened to prevent erosion during overflow.
- The secondary dyke should be strong enough to withstand water flowing over the primary dyke.

Safety standards

Finally the coastal buffer zone can suffice a higher flood risk. Where flood risk standard for inhabited areas are set to 1/4000 year of even 1/10.000 year a standard of 1/100 or even 1/50 is allowable in the buffer zone. This will considerably reduce costs on dyke maintenance and strengthening.

Construction & design

Preferably a coastal buffer zone is applied where two parallel dykes (one shore side, one inland dyke) are already present. This will save the expense of constructing a second dyke. Based on the ComCoast pilot at Ellewoutsdijk (www.comcoast.org) a concrete example of a coastal buffer zone is summed up below:

- The crest of the primary dyke is strengthened with asphalt
- Flood risk 1/50 is allowed. Once every 50 years on average, a few decimetres of water will collect between the two dykes, and once every 100 to 250 years, 1 m or 2 m of water will collect. This will not pose a threat to the safety of the land behind the secondary dyke.
- The landward side of the old dyke is strengthened with open asphalt covered with soil allowing grass to grow on.

- The seaward side of the new dyke is strengthened with a layer of open asphalt. This layer is covered with soil allowing grass to grow on.

Costs

The costs and the benefits of an inlaag are discussed here based on the evaluation study of polder Breebaart (Witteveen + Bos, 2007). This study gives a good impression of the potential costs and benefits of an inlaag. The Breebaart Polder is located between a primary and secondary dyke and forms an inlaag. By making the primary dyke resistant to wave overtopping, an inlaag can serve as an alternative to traditional dyke enhancement.

Construction

The construction of an inlaag is done by making the primary dyke overtopping resistant and (if needed) strengthening the secondary dyke. In the Breebaart polder the costs of constructing an inlaag are compared to the costs of heightening the dyke. The saved costs are:

- € 2.750.000,- per kilometer (2010)
- € 3.500.000,- per kilometer (2050)

Maintenance

The maintenance of an overtopping resistant (primary) dyke is also less than a heightened dyke. According to the Breebaart study the following costs are saved:

- € 254,- per kilometer per year (period 2010 - 2050)
- € 338,- per kilometer per year (period 2050 - 2100)

On the other hand, when creating an inlaag more maintenance is needed for the secondary dyke. The maintenance costs of the secondary dyke in the Breebaart polder are: € 3.500 per kilometer per year.

Benefits

In the Breebaart study the social, economic and ecological effects of an overtopping resistant dyke are compared to traditional dyke enhancement for different land use types. The possible land use types in the polder were agriculture, saline agriculture, greenhouses, nature, nature combined with recreation and housing. The following benefits effects of an inlaag are described below:

- Saved costs of dyke enhancement
- Saved space
- Increase in flooding risk
- Opportunities for saline production
- Recreation
- Cultural-historical value of sleeping-waking dykes
- Non-use value of nature

Saved costs dyke enhancement
By making use of the inlaag as coastal defense, costs of heightening the primary dam can be saved. The Breebaart study shows that these costs are substantial (see the paragraph 'Costs').

Saved space
Dyke enhancement also includes widening the dyke and thus loss of usable area. If behind the primary dyke agriculture, or saline cultivation takes place or greenhouses or buildings can be realized, the raising of the primary dyke means a decrease in productive area. Creating an inlaag by making the secondary dyke overtopping resistant, saves space compared to heightening the primary dyke. This benefit can be calculated by the area that otherwise had been lost by the heightening of the primary dyke multiplied by the profit per hectare.

In the Breebaart Polder there was a decrease in productive area of merely 1.2 ha for the traditional agricultural alternatives, saline agriculture, greenhouses and housing. Yet the loss of productive space was one of the most important effects. The loss of space due to the heightening of the dyke leads to a loss of profits and loss of nature benefits. The costs and benefits due to less surface area vary by type of land use. The effect in this study was limited because the dyke heightening was only 2,3 m. At other locations, where dykes need to be heightened more, the loss of productive space consequently will have a greater influence on the result.

Increase in flooding risk

Flooding risks are generally defined as (the integral of) the probability of flooding multiplied by the consequences of the flooding. Or simpler: probability x consequence. By creating an inlaag the primary dam can remain relatively low. This may result in water overtopping the primary dyke during a storm. The inlaag serves as temporary water retention area. Behind the secondary dyke, the risk of flooding has to be as high as behind a traditional dyke. The flooding risk of the inlaag itself however is higher. The increase in the flooding risk is a negative benefit and is calculated by the change in the likelihood of flooding multiplied by the damage that occurs during a flood. Logically, the damage depends on land use. If the inlaag is comprised of (wet) nature the detriment is zero. If, however, the land is used for farming, then part of the crop or the entire crop is lost. This depends on the amount of overtopping water and the inundation depth, the length of time the water remains on the field, the salt sensitivity of the crop, and in what stage of growth the crop is during the flooding. Obviously, the flooding may also cause damage to buildings and infrastructure within the inlaag.

Although the overtopping frequency and the inundation depth of the overtopping resistant dyke in the Breebaart-study is limited, damage could occur. The amount of damage varied by land use type. No negative effects of the overtopping water were found for saline agriculture, nature and nature and recreation within this study,. There was some light damage, mainly to the infrastructure, when the land use was agriculture and no damage was done to housing in the inlaag. The latter can be explained by the design. Houses in the Breebaartpolder-design were situated on mounds. However, when greenhouses were situated in the inlaag, significant damage occurred, to the structures as well as the crops. Despite the low risk of overtopping and limited inundation depth, flooding risk is high in the case of greenhouses in the inlaag. Elsewhere in the Netherlands, the risk of overtopping can be higher and/or a larger inundation depth may occur. This could result in a higher flooding risk which, depending on the type of land use, could have a much larger impact on cost-benefit ratio.

Opportunities for saline agriculture

Inlagen are particularly suitable for the cultivation of saline crops, since the required salt sea water can be directly accessed. From the saline crops ‘Glasswort’ (Salicornia) and ‘Sea Lavender’ are the best known. To date, the production is small, approximately 5-8 ha. of these crops are cultivated. For sea vegetables the production is about 15,000 kg / ha. According to research by Alterra (2006), it is feasible of cultivating about 300 ha of Salicornia in the Netherlands. Whether the prices will remain as high when there is so much more produced, is to be seen.

Other production possibilities which are suitable for an inlaag, include the cultivation of sole or turbot in ponds or basins. Fresh sole is a popular product but the number of sole caught is limited by regulations. This results in a high price per kilo. The price for a kilo sole in 2011 was € 11.14 / kg. For turbot the price was € 10.34 / kg (CBS, 2012).

Experiments with seaweed cultivation and the cultivation of shellfish, lobster and crawfish in ponds are taking place on several locations in the Southwestern Delta. For instance, since 2005 mussels are cultivated in the inlaag of the Scherpenissepolder. The cultivation of these mussels takes place at the landward side of the dyke. Currently, this is one of many examples of pilots of saline crop production. Large scale saline crop production has not yet taken place, so costs and benefits are therefore not yet clear.

Recreation

When inlagen are assigned as nature areas, they are attractive for nature lovers. Administrators of inlagen, for example Natuurmonumenten, make use of this knowledge by constructing bird screens and installing telescopes for bird watching. Inlagen also offer good opportunities for biking and hiking. Whether assigning more inlagen as nature areas in the South Western Delta will lead to more recreational activities and thus to more spending, is doubtful. More likely is that visits to newly designated nature areas will be at the expense of the number of visits to other nature areas nearby. So more nature areas in inlagen will provide no additional benefits .

In addition to actual spending that is a benefit of a nature area, recreationists and tourists also attribute a sense of prosperity to nature. It appears that an amount of EUR 0,59 per visit is used for the recreational amenities of natural banks of reeds. For coastal nature such as mud flats, salt marshes and beaches a willingness to pay ranging from EUR 1.93 to EUR 0.87 per visit is measured (Ruijgrok, 2006)
The study of the Breebaart polder shows that the recreational amenities are different for a traditional dyke than for an overtopping resistant dyke. This is caused by a change in the attractiveness of the view. The traditional dyke is higher then an overtopping resistant dyke and thus takes away more of the sea view. The overtopping resistant dyke is more attractive for all types of land use, with the exception of greenhouses in the inlaag.

Cultural and historical of the sleeping-waking dykes

Inlagen often have a long history originated from fear for dyke breeches. At locations where there was fear of a dyke breech, a ‘spare dyke’ was constructed, the inlaag-dyke or the sleeping dyke (the primary dyke is called the waking dyke). To construct this spare dyke, soil from the inlaag was used. This is the reason why inlagen usually are lower than nearby land. The older inlagen tell the history of the battle of men against the sea and thus are of cultural and historical importance.

An inlaag can only keep on functioning as a save flood defense if the secondary dyke is well maintained. By carrying out maintenance on the sleeping dyke the cultural and historical value will be saved for future generations. Also, by maintaining the inlaag-dyke, the landscape keeps his original form and appearance. It is known that people are willing to pay for this. However, the cultural heritage has to be near their house. Therefore the willingness to pay is solely calculated for people within 10 kilometres from the dyke.

To date, there is no research done on the willingness to pay for the conservation of specifically sleeping - waking dyke complexes. The most relevant study comes from Ruijgrok (2004). She analysed the bequest value of the Tieler- en Culemborgerwaarden in the Betuwe and used a three facetted approach. With this approach one price for archaeology, landscape and architectonics is determined. The result of this study was that the willingness to pay for ‘maintaining cultural and historical values’ is about EUR 11 per household per year.

Non-use value of nature

Inlagen usually have a low ground level with a swampy and soggy ground which makes them less suitable for agriculture or animal husbandry. Most inlagen are therefore designated as nature areas with swampy grasslands, reed beds or open water. The low ground level also causes saline seepage to be present. The inlagen are rich in birds which use the area as fourage and nesting area but also as a high tide refuge. The flora in inlagen is rich and varied, dependent on local conditions.

Even when the inlagen are not exploited or have no recreational use, people are willing to pay for these nature areas. This is called the non use value of nature. It is the value that people give to the existence of nature en the ability to pass it on to next generations without using it themselves. Research from Ruijgrok (2006) shows that on average people are willing to pay €25 to preserve grasslands, €11 for reed beds and brush woods en €25 for salt marshes and mudflats. Depending on local circumstances, (a mix of) these nature types are usually present in inlagen. In the social evaluation of the Breebaart

Polder a non use value for nature in the polder is determined. The evaluation showed that people living within a radius of 10 kilometers from the Breebaart polder are willing to pay € 20 per household for nature in the Breebaart polder.

Results of the Breebaart study

A comparison was made between the overtopping resistant dyke and traditional dyke raising with similar land use. In this way, the effects of different types of coastal defenses (overtopping resistant versus traditional dykes) are considered. This makes the results applicable to other locations where land use remains the same and the only decision to be made is which type of coastal defense to apply.

Table 1 shows the summary of costs, benefits and balances of this equation. For all land uses the costs consist mainly of the maintenance of the secondary dyke. For housing the costs are far higher because of the construction of dwelling mounds on which the houses have to be build to prevent flooding damage. The costs of the use of greenhouses in the inlaag is far higher because of the extra flooding risk; more damage to structures and crops is done when the inlaag is flooded.

The benefits of all land uses are considerable, 10,5 million euro's net present value over a period of 100 years. This is largely because of the saved costs of not having to heighten the primary dyke. Benefits are larger for housing because of the extra pleasure of living on a dwelling mound in an inlaag.

Table 1: Comparison of the overtopping resistant dyke to traditional dyke enhancement with constant land use, present value in euro's in the Breebaart study.

traditional dijkenhancement		**overtopping resistant dyke**	**Cost (€ x 1000)**	**Benefit (€ x 1000)**	**Balance (€ x 1000)**	**Cost-benefitratio**
agriculture	↔	agriculture	351	10.489	10.138	29,9
saline agriculture	↔	saline agriculture	293	11.588	11.295	39,5
greenhouses	↔	greenhouses	4.698	10.586	5.888	2,3
nature	↔	nature	323	12.007	11.684	37,2
nature and recreation	↔	nature en recreation	429	12.088	11.658	28,2
housing	↔	housing	6.626	20.628	14.001	3,1

The main conclusions from the study are:
• From a societal point of view an overtopping resistant dyke is more advantageous than traditional dykes, whatever the type of land use.
• This is mainly due to the costs saved by the construction of a overtopping-resistant layer compared to heighten the existing dyke. When a primary dyke also contains structures such as sluices or culverts, the balance becomes even more positive.
• Saline agriculture, brackish nature and nature combined with recreation are the most suitable land uses for an overtopping resistant dyke. The societal costs of the overtopping resistant dyke are very low while the benefits are high. Greenhouses, agriculture and housing are the least suited to exploit on land behind an overtopping-resistant dyke.
• The main characteristics of the location which determine the final cost-benefit balance are:

  - the difference in flooding risks between the a traditional dyke and an overtopping resistant dyke (depending on the overtopping frequency and depth of inundation, the type of land use and spatial design), and
  - the difference in construction costs between the two types of dykes (depending on the required elevation, the overtopping construction, the presence of structures in the primary dam, and the presence of a secondary dyke).

In the Breebaart Polder the overtopping frequency of the overtopping resistant dyke is low and the inundation depth is limited. This results in a low flooding risk. This relatively low flood risk ensures that in the Polder Breebaart even housing, agriculture and greenhouses ensure a positive balance. When conditions are different (e.g. more frequent flooding, greater inundation depth) more damage to buildings and crops will be done, resulting in a greater flooding risk and a less positive (or negative) balance for housing, greenhouses and agriculture.

Ecosystem services & multifunctional use

Besides sea defence coastal zonation sites also provide other goods and services (ecosystem services) and have potential for multifunctional use as recreation, aquaculture and cultivation of saline crops.

Areas that are applied as coastal buffer zones are usually low-lying areas along the coast, subject to salt water seepage unsuitable for cultivation of crops and livestock. Most of these areas are therefore nature area. Because of the variation in salinity of fresh, brackish to saline, vegetation is diverse. The brackish water area with shallow pools provides a valuable foraging, roosting and nesting area for birds. Especially with high water birds will move here to find their food. This coastal nature enclosed by dykes also provides opportunities for recreation. There are opportunities for walking and cycling along the dykes along the area. It is also a good place for bird watchers for many different types of birds to be spotted. The (near) availability of salt water and relatively controlled conditions that make inserts has potential for aquaculture and saline crops. The following table describes possible cultures in these kinds of areas.

Aquaculture and saline crop yield based on a study by De Mesel et al. (2011 (in preparation)) and related studies.

Type	**Species**	**Method**	**Yield** €/ha/year	**Reference**
Shellfish	Blue mussel –*Mytilus edulus*	Breeding in ponds	41920	www.fao.org
	Pacific Oyster – *Crassostrea gigas*	Breeding in ponds	25000	www.fao.org
	European flat Oyster – *Ostrea edulis*	Breeding in ponds	20900	(Van der Hiele, Heringa et al. 2008) and related references
Worms	Ragworms - *Nereis virens*	Breeding in ponds	75000	(Hoekstra, Kool et al. 2005)
Fish	European seabass - *Dicentrarchus labrax*	Breeding in ponds	2340	www.fao.org
Sea weeds and algae	Tough Laver - *Porphyra umbilicalis*	Breeding in ponds	651	(Lobban and Wyne 1981)
	Hudson - *Gracilaria verrucosa*	Breeding in ponds	435	(Xin 1989)
Saline crops	Common glasswort –*Salicornia Europeae*	Harvest from wild growth on saltmarshes	84000	(Van de Voort, Dekking et al. 2005) and related references
	Sea aster – *Aster tripolium*	Harvest from wild growth on saltmarshes	35000	(Goosen 1999)

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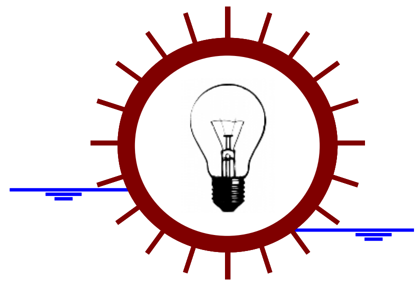
www.kustlaboratorium.nl
www.comcoast.org
www.fao.org

Energy polder

Erik Arnold, Marten Hillen (Royal Haskoning), Ruben Abma (Witteveen + Bos)



Description

In an energy-polder the energy of the tidal movement in an area is transformed into electricity using turbines. The concept of an energy-polder is profitable in areas where a large tidal movement occurs and if plans to flood areas exist. When constructing an energy polder in the Southwest Delta an existing polder will be placed under the influence of tidal movement again. Figure 1 gives an impression is shown of an energy polder in Prosperpolder and Hedwigepolder.

Figure 1: Impression of an energy polder in Prosperpolder and Hedwigepolder before (left) and after construction (right) (Source: Haskoning, 2009)

Application

The suitability of a polder as an energy-polder strongly depends on the following (area) features:

1. Tidal difference
2. Height of secondary levees
3. Average surface elevation of the polder
4. Surface area of the polder
5. Current use of the polder
6. Distance to the tidal channel

The tidal range (1), the height of the secondary levees (2), the average surface elevation (3) and the surface area (4) of the polder, determine to a large extent, the amount of water that can flow in and out the polder under the influence of the tidal movements. These factors thus determine the energy yield. The investment costs are highly dependent on the current use of the polder (5) and the distance to the tidal channel (6). In order to gain public support and reduce the cost for the plan as much as possible, the polder will be most suitable when the number of houses that have to be removed is as small as possible. At many locations in the Western Scheldt a (covered) foreland exists in front of the primary flood defense. When using such areas as energy polder also adjustments should be made in the foreland. The smaller the distance to the tidal channel, the smaller the investment required for the water to run into the polder.

In the offensive scenario of the Southwest Delta energy polders are implemented. In terms of searching suitable areas, the tidal range (for an energy polder) must be as large as possible. Locations (at the eastern end) in the Western Scheldt are possibly the most suitable (see Figure 2.1). In addition, many polders along the Western Scheldt are surrounded by secondary flood defenses which make these polders suitable as a basin. In Figure 2, in addition to the eastern part of the Western Scheldt, the Eastern Scheldt storm surge barrier, the Brouwersdam and Haringvlietdam appear as areas of interest for energy. This energy is generated by the difference in water height between the sea and the basins, which is a different concept than polder tidal energy extraction.

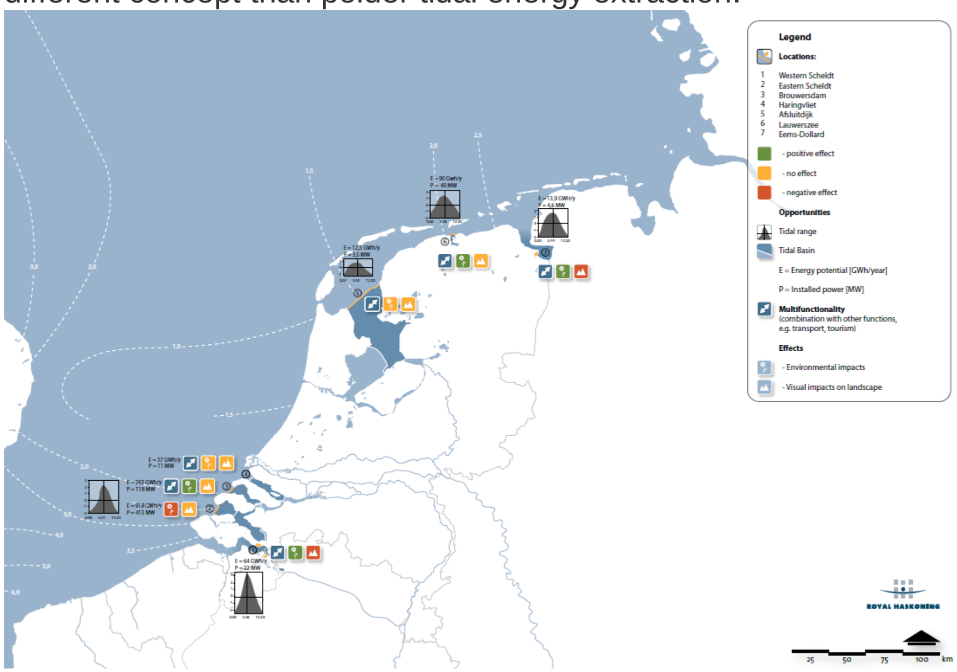


Figure 2: Interesting sites for generating energy along the Dutch coast (source: Deltares, 2009)

Construction

To be able to generate energy from an energy polder a number of facilities are required:

1. Strengthening secondary dykes
2. Power plant construction, with the following components:
   a. turbines
   b. sluices
   c. construction for water inlet and outlet

When a polder is selected for generating energy, it will be under influence of tides. Measures have to be taken to the surrounding secondary dykes to serve as primary water defense structures. Special attention should be paid to the stability of the earthworks, the height and the permeability of the secondary dyke.

In addition, facilities have to be constructed for generating energy, such as turbines for electrical power generation. During high tide the energy polder is filled with water through the sluices, during low tide the energy polder is emptied by the turbines which generate energy. In addition, a construction for water inlet and outlet is needed to bring the water to the turbine and sluices. Figure 3 shows the top view of a concept tidal power-plant for the Hertogin Hedwigepolder [Haskoning, 2009]. The type of turbine that is used depends on the water drop and the total number of turbines in relation to the amount of water that can be stored in the energy polder.

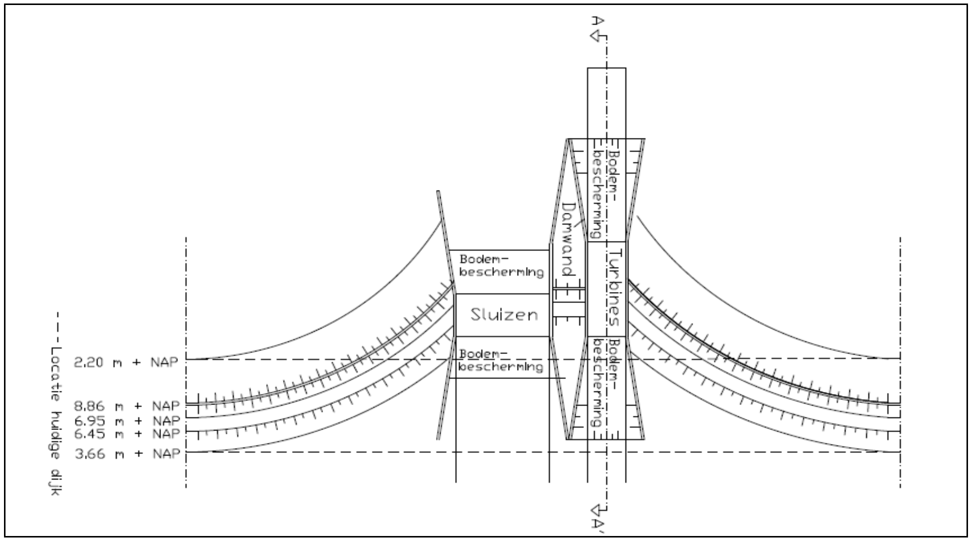


Figure 3: Top view of tidal power station (source: Haskoning 2009)

Costs

Construction

The cost estimate of the energy polder is based on a study by Haskoning (2009), in which the costs of construction of an energy polder are determined for three promising locations: Hertogin Hedwigepolder, Hertogin Hedwigepolder in combination with the Prosperpolder in Belgium and the Frederica- and Zimmerman Polder. Table 4.1 shows the construction costs of the three energy polders.

The cost estimates only include the cost of the construction of turbines, equipment and the engineering works. Costs for land acquisition and adjustments to the secondary dykes are not included in the cost estimate because this strongly depends on the location. In the design of an energy polder secondary dykes have a water retaining function. Depending on the condition of the secondary dykes adjustments will have to be carried out to transform them into water retaining dykes. In addition, the cost depends strongly on the number of houses that are situated in the polder. The more houses, the higher the costs of acquiring the land. These costs are not included in table 4.1. Depending on the location, the total costs can turn out to be up to 20-50% higher.

Energy polder			
	Surface area (km^2)	**Average surface elevation (m + NAP)**	**Construction costs (M€)**
Hedwige polder	3.0	1.9	28
Hedwige en Prosper polder	13.3	Hedwige: 1.9 Prosper: 1.3	169
Frederica- en Zimmerman polder	5.7	Frederica:1.3 Zimmerman: 1.6	70

Tabel 4.1: Costs of an energy polder per km2 (source: Haskoning, 2009)

Management and maintenance

We tentatively estimate these costs to 1 to 2 per cent of the construction costs.

Benefits

Strengthening of secondary dykes

The construction of a tidal energy generator will often mean that the secondary dykes have to be strengthened because they are not build with recurrent flooding in mind. The exact costs will vary per location depending on actual dyke height, strength of the dyke and inundation depth.

Generation of tidal energy

Energy produced from tidal waterpower qualifies for grants from the government. If the energy is produced with a tidal energy generator which uses a tidal range of less than 5 meters, the producer receives € 0,118 /kWh (Ministerie van Economie, Landbouw en Innovatie, 2011). Therefore, the profit is dependent on the capacity (amount of MW) of the energy polder.

Avoided CO_2 emission

Energy generated by burning fossil fuels, produces CO_2. A tidal power generator is a sustainable way of producing energy, there are hardly any CO_2 emissions. Therefore a tidal energy generator avoids CO_2 emission that would otherwise be produced from using the energy that comes from the electricity grid.
On average 0,566 kg CO_2 is emitted by producing 1 kWh of energy (Senter Novem (2007) Cijfers en tabellen. In opdracht van het ministerie van VROM). A tidal waterpower generator with, for example, a capacity of 50 GWh / year will save 566 tonnes of CO_2-emission a year.
In 2005 the Emissions Trading Scheme (ETS) has started. This is the trade market for CO_2-emmisions. A CO_2-emission right is the right to emit 1 ton CO_2. Like other trade markets the prices of CO_2 rights may vary daily. The price of 1 tonne CO_2 was around € 7,00 in April 2012. But, as said, prices fluctuate heavily (www.emissierechten.nl).

Loss of agricultural yields

The land behind the primary dyke is often used for agricultural uses. With the construction of a tidal energy generator this land is being flooded twice a day and thus loses its value as agricultural grounds. This means a loss of agricultural yields. Depending on the agricultural use (grassland for dairy farms, or production of beets or corn) and the area of the basin the yield loss will be larger or smaller. Because an energy polder and regulated tidal exchange (a form of managed realignment) are physically the same, (except for the tidal generator) this benefit is the same as the loss of agricultural production in managed realignment. For data to calculate the amount of production loss we therefore refer to the factsheet ‘Managed realignment’.

Nature value

The basin of the tidal energy generator is being flooded by seawater twice a day, conditions similar like natural salt marshes. This means that chances are that specific salt marsh vegetation will find its way to the basin and a salt marsh habitat will develop. Preservation of nature values can be a factor in the consideration between measures. This happens from the perspective of “intrinsic value” of nature as well as the prosperity that a society obtains from the preservation of nature values. This value for nature what will arise, is exactly the same for tidal energy polder as for regulated tidal exchange. We therefore refer to the factsheet managed realignment.

Outstanding questions

- During the transition of an area into an energy polder, the tidal water will be introduced in a controlled manner. For the discussion on the ecological effects in the area and the ecological values, further ecological and morphological analysis is required.
- In order to obtain more insight into the feasibility of energy polders, a better understanding of the costs needed. In this factsheet indicative cost estimates with substantial uncertainties are provided. For an accurate cost estimate, the promising locations have to be examined separately because of the great location dependence of the cost.

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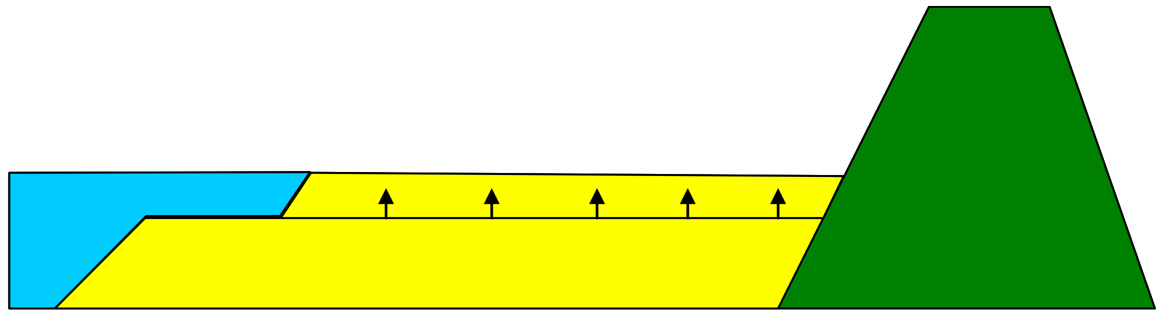
Nourishments

Jebbe van der Werf, Ane Wiersma (Deltares)
Ruben Abma (Witteveen + Bos)
Building with Nature wiki



Description measure

Shore nourishment or beach nourishment — also referred to as replenishment — is a maintenance measure by which sediment from outside the area is added to a (usually eroding) shallow foreshore. A wider beach or a higher foreshore can reduce dune erosion or storm damage to coastal structures by dissipating energy across the surf zone. Shore nourishment is typically part of a larger coastal maintenance strategy. It is usually a repetitive process, since it does not remove the physical forces that cause erosion: it just mitigates their effects. Regular beach nourishment, i.e. placing a relatively small amount of sand at the moment it is needed in line along the shore or on the beach, has the disadvantage of frequently disturbing the coastal ecosystem. To avoid this disturbance and at the same time make new room for environmental processes, different types of beach nourishment are proposed, in which the sand volume is not just placed in line along the beach or the foreshore (wiki-Building with Nature).

Application

Nourishments of sand are mostly applied to maintain beaches or shallow foreshores such as intertidal areas in front of dykes. These foreshores often act as a buffer for safety by dissipating wave energy. Due to the extra segment of water that is created by the rise in sea-level, a sediment deficit in many shallow foreshores will be created leading to a decrease in area. Nourishments can be an effective measure to fulfill the sediment demand of the flats and maintain a dynamic equilibrium between erosion and sedimentation.

Nourishments can be applied in a number of ways, here we distinguish:

- Apply the necessary sand directly on the areas that need to be raised
- Apply the necessary sand at a strategic location in such a way that natural processes can re-distribute the sand over the target area in a way that natural processes can keep up with the sedimentation (feeder beach / sand engine principle)
- Apply an excess of sand pushing the imbalance between sedimentation and erosion of a coastal area into the direction of sedimentation (sand engine + principle)

Applying the nourishments as feeder beaches, large concentrated nourishments have potential for the following reasons:

Advantages

- Concentrated nourishments feeding the surrounding coastal area can simultaneously facilitate several (eco-system) services, like safety against flooding, nature development, and recreation.
- The area to be nourished will be disturbed less frequently although the initial sand volume will be much larger.
- This is beneficial for the ecology: vegetation and dunes have more time to grow or making it possible for the ecosystem to recover on emerged nourishments and the benthos at the seabed can fully develop. This nature development could attract more tourism and recreation.
- Mobilisation of the dredging equipment is required only once instead of regularly in the case of disposing smaller volumes regularly. This allows for optimization in construction methods.

Disadvantages

- The evolution of the nourishment depends on the tides, wind and waves and can therefore not be fully predicted. This may lead to unforeseen or poorly predictable situations which should be managed in an adaptive manner.

Left: Impression of a nourishment in Lake IJsselmeer near Workum; right: the sand engine in front of the Dutch coast.

Along the Frisian coast of Lake IJsselmeer, no natural tides are present since the lake was cut off from the sea by the 30 kilometer long dam, the Afsluitdijk. Sand flats surrounding this former sea are still present as shallow foreshores in front of the dykes. In this wave dominated area, pilots with dynamic sand nourishments are being executed to investigate the potential to maintain these shoals and strengthen the coast. On the tidal flat Galgeplaat in Zeeland, the morphological changes and recolonisation by fauna after the perturbation is being investigated.

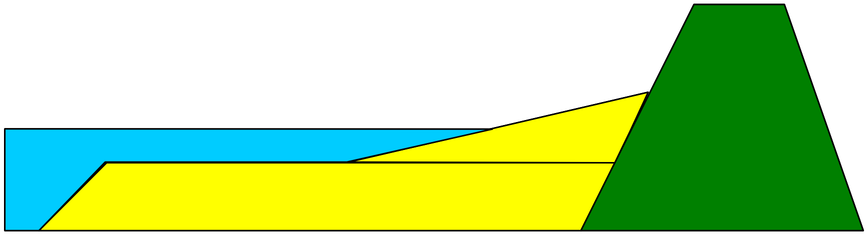
Boundary conditions

- Presence of a natural shallow foreshore;
- Easy access to recoverable sand to reduce the costs;
- High (enough) dynamics in the area to transport sediment;
- A low percentage of fine sediments in the sediment to be nourished as they may cause negative environmental effects;
- Knowledge of the processes acting in the area.

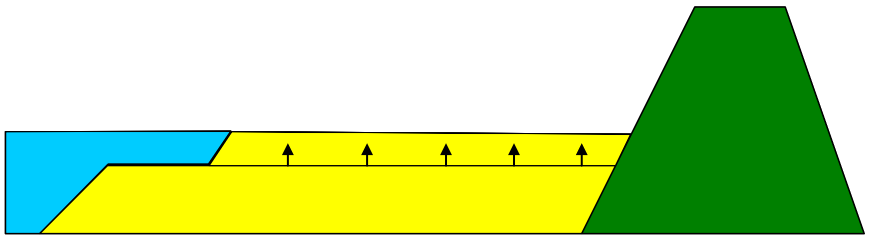
Design and construction

A nourishment can be constructed from land and from water. From water is usually preferred as transport costs are being reduced significantly. Here we distinguish three types of nourishments:

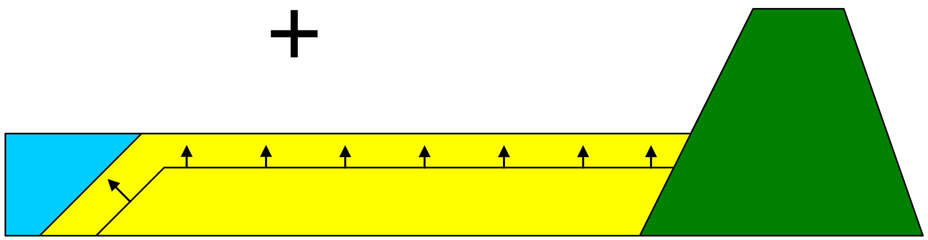
"Traditional Nourishment": On a tidal flat or shoal, sand extracted from elsewhere is placed from a ship. If necessary, the sand is redistributed to the preferred elevation.



Sand engine / feeder beach: The sand is placed on a favorable location from the water, after which natural processes redistribute the sand in such a way that nature can keep up with the increased supply of sand. This leads to maintenance of the system in which the sand is applied in. A regularly applied version of this concept is a channel-edge nourishment



Sand engine+: A surplus of sand is brought up on a strategic location from the water. Natural processes redistribute the sand in such a way that on the longer term, nature can keep up with the increased supply of sand. The system in which the sand is applied will prograde and the coast will strengthen.



Functions

Artificial coastal sand nourishments are applied for various reasons:

- to compensate losses due to (structural) erosion, and hence maintaining biodiversity;
- to enhance the safety of the hinterland against flooding;
- to broaden a beach or create new beaches e.g. for recreational purpose;
- to reclaim new areas such as peninsulas or artificial islands for urban or industrial development;
- to feed the surrounding coast with sand at a rate governed by nature.

Costs

Construction

The costs involved in constructing a nourishment are mainly a function of the volume of sediment needed and the shipping costs (and therefore the nearby availability of recoverable sand). The volume is dependent on the sediment demand of the involved system and the repetition time.

Estimates for the costs of one cubic meter of sand have been estimated at 3-12 euro/m^3 (De Ronde et al, 2010) to 4 euro/m^3 for sand from the Eastern Scheldt (Van Zanten and Adriaanse, 2008). The higher estimates are from sand mined from the North Sea, which increases the costs significantly. In Witteveen + Bos (2010) different nourishment strategies were thoroughly explored. The estimated prices for a cubic metre of sand varied from €5.20 for sand from the Eastern Scheldt to €13.70 for sand from the North Sea.

Benefits

Benefits from nourishments are mainly the costs saved from dyke reinforcements. Other benefits of sand nourishments are the value people grant nature, the recreational experience and potential for shellfish aquaculture and harvesting.

Cost reduction dyke reinforcement

Tidal flats may disappear as a result of the sand hunger. One of the consequences is that the primary water defense structures will face increased wave impact. The traditional solution is to reinforce the stone armoring. Blom et al. (2007) searched for alternatives, amongst which sand nourishments. Over a stretch of 63 km of dykes along the Eastern Scheldt it is possible to employ nourishments. The costs involved are ca. 64 M€ (on average about 1M€ per kilometer). This is about half the cost of replacing the armoring. It is however not the most low priced solution: the nourishments are about 50% more expensive than covering the armoring with a layer of asphalt. The asphalt doesn't lead to improvement of nature and recreational values.

Nature value

Tidal flats maintained by nourishments contribute to the foraging area of birds. Preservation of nature values can be a factor in the consideration between measures. This happens from the perspective of “intrinsic value” of nature as well as the prosperity that a society obtains from the preservation of nature values. In recent years several studies have been performed to the value we grant estuarine nature. Overkamp (1994) investigated the willingness to pay for the preservation of the small tidal-flat island of Rottemeroog and determined a value of €35,- per household. Although in this research the preservation in biodiversity this figure does give an indication of the non-use value of coastal nature (tidal flats). This price ticket gives an all-or-nothing indication for the disappearance of the entire island of Rottumeroog. For the Eastern Scheldt, Ter Haar (2011) investigated the willingness to pay for measures to maintain the tidal flats. Through an internet inquiry the preparedness to preserve 10%, 33%, 67% or 100% of the tidal flats was explored. This led to a market situation for the price of measures instead of a valuation for a societal product for which no market exists. On average, respondents are prepared to pay €6.40 for the preservation of tidal flats and salt marshes. Extrapolated over the Netherlands, this would mean that about 75% of the tidal flats and salt marshes could be preserved.

Recreational value

The positive effects of a fore shore nourishment to the recreational experience can express itself in an increase of the number of visitors and / or an improvement of the quality of the landscape and nature values for the people who were visiting anyway.

Research shows that no big increase in visitors can be expected. Using an inquiry, Thijs and Schuurmans (2010) explored whether the construction of the Sand Engine in front of the Delfland coast would lead to extra visitors. Only 20% of the respondents indicated that they would come back to follow the development of the nourishment. For the remainder of the respondents the sand engine is not a reason to return to the Delfland coast. The motives for people to come to the area out of interest for the area (4%) and experience nature (7%) were not mentioned often as a reason to visit the area. It is not excluded that the sand engine will attract more visitors, but these won’t be large numbers.

This leaves us with improved quality for regular visitors. An inquiry in which pictures from situations with and without fore shores were valued (De Vries et al., 2008) suggests that fore shores have a positive influence on the experience. Especially the presence of birds, and to a lesser degree vegetation, appears to be appreciated. This study however only took into account dams with a fore shore, and the pictures did not include sand nourishments.

Shellfish aquaculture

In the framework of measures against sand hunger in the Eastern Scheldt, the influence of nourishments on opportunities of oyster and mussel cultures has been assessed. Production of shellfish mainly takes place in the shallow parts of the Eastern Scheldt (but not on intertidal areas). Therefore, the advantages of nourishments on shellfish farming will be limited. Shellfish farmers in fact fear the opposite effect as a result of sediment being deposited on the culture plots (Buter, 2007).

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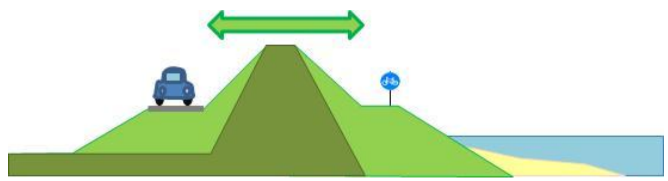
Delta Dyke

Erik Arnold, Marten Hillen (Royal Haskoning), Ruben Abma, (Witteveen + Bos)



Description

For a Delta Dyke (Fig. 1) various definitions are used. Moreover, different names are used for similar concepts: Multi Dyke, Climate Dyke and Super Dyke. All indicate a very robust embankment which has multiple functions in addition to the flood defense function. In this description the definition for Delta Dyke is the same as used by the National Water Plan (NWP, 2009):

"A dyke that does not break when under extreme circumstances a limited amount of water flows over the top and which is calculated on the currently estimated effects of climate change from 2100 to 2200."

This definition is ambiguous and includes several properties of dykes: erosion resistance, stability and height. For the first two properties the NWP uses the term "resistance to breaching' (NWP, p. 72), which we presume to be the same as ‘’breach free’’ (Silva & van Velzen, 2008). This means that the only failure mechanism of the dyke is overtopping (water level is higher than the dyke).

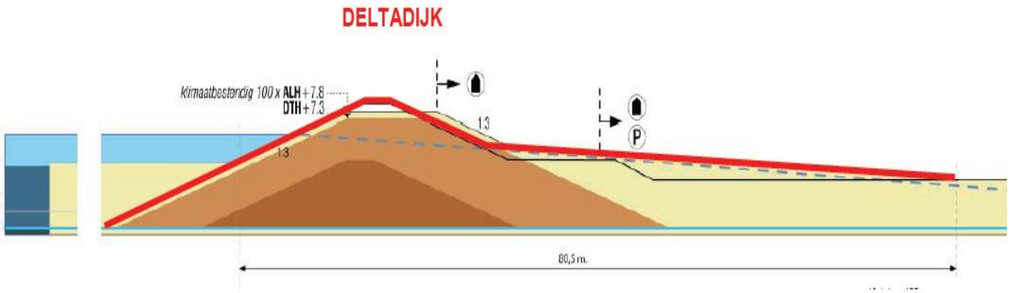


Figure 1: schematic impression of a Delta Dyke

Application

A Delta Dyke can in principle be used anywhere in the Southwest Delta where currently (sea) dykes are situated. The limiting factor for the construction of a Delta Dyke is the (relatively) large space taken up by the Delta Dyke and the investment which needed. At locations where many buildings are present integration can be difficult and expensive. By enabling buildings on a Delta Dyke, this limiting factor can be eliminated. This means however, that existing buildings along the dyke must first be demolished and rebuild on the newly constructed Delta Dyke. This is expensive.

Construction

Figure 2 shows a schematic drawing of a dyke situated along the Eastern Scheldt and the Western Scheldt. The construction of the dyke for the Eastern Scheldt and Western Scheldt is similar, only the top of a dyke along the Western Scheldt is higher (approx. 10 m NAP) than of a dyke along the Eastern Scheldt (approx. 8 m NAP). This is because the water level along the Western Scheldt is higher during a storm than along the Eastern Scheldt. The reason is that the Eastern Scheldt is closed during high water on the North Sea by means of the Eastern Scheldt storm surge barrier.

In order to make the conventional dykes in the Southwest Delta climate proof using the Delta Dyke concept, the dykes should be constructed wider and, if situated near an open estuary, the Delta Dyke should also be higher. Figure 3 is a schematic diagram showing a Delta Dyke along the Western Scheldt.

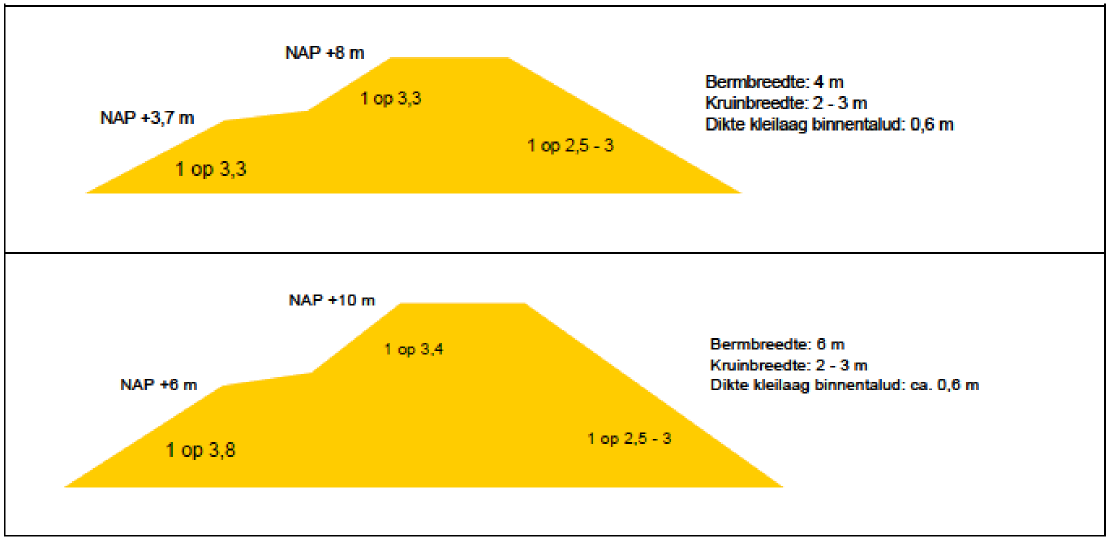


Figure 2: Schematic drawing of conventional dykes along the Eastern Scheldt (top) and Western Scheldt (bottom)

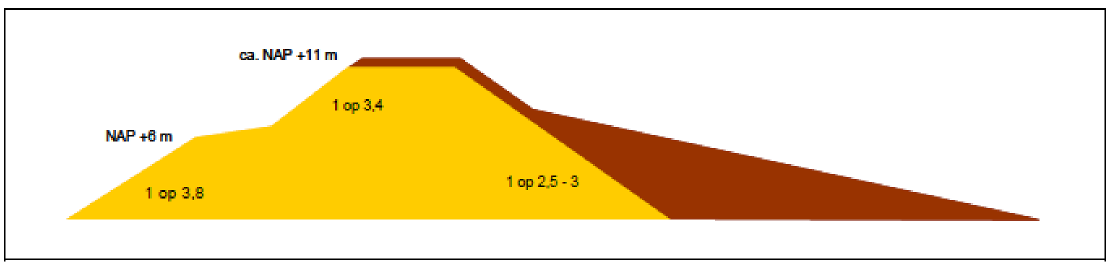


Figure 3: Schematic drawing of a Delta Dyke along the Western Scheldt

Raising the berm

Until 2100-2200, due to the effect of climate change, a significant rise in sea level is expected (possibly > 1m). Although a

limited amount of overtopping is allowed on a Delta Dyke (approx. 30 liters per second), the existing dykes have to be raised to prevent dyke breach due to a large amounts of water coming over the dyke.
This is less the case for dykes situated in an enclosed estuary which can be closed during high water levels. By using the decimation height of the dykes, the necessary reinforcement height can be determined. In Figure 4 the decimation heights are given for the Eastern Scheldt and Western Scheldt, which is roughly 0.4 to 1.0 m.

Figure 4: Decimation heights for the southwestern delta (RWS-Water Service, 2008)

Construction of a berm at the inner toe of the dyke

In order to prevent that the dyke collapses when a limited amount of water flows over the dyke, the inner slope must be reinforced by means of an inner berm (macro stability). A thick layer of clay is placed at the inner berm covered with grass, to increase the erosion resistance against overtopping water.

Costs

Estimating the cost of a Delta Dyke is a complex task. Information gathered from existing dyke reinforcement shows that the costs can vary widely because actual integration is much more expensive than an idealized model dyke (see Table 1). In this section an estimation of the expected costs of a Delta Dyke in the Southwestern delta is given.

The cost estimate is based on dyke reinforcement projects conducted in the Netherlands (see Table 1). This involves raising the dykes in the Netherlands because project data is available. For the extra costs of construction of an inner berm at the toe of the dyke an assumption is made. Table 1 includes costs associated with the actual land acquisition integration which can be a significant part of the total costs.

The Netherlands	
Dike (Millions € per km)	Dike heightening (per m) 9 – 10.8 (rural) (Kok et al., 2008) 18 – 21.6 (urban) (Kok et al., 2008) 4 – 11 (rural) (Eijgenraam, 2006) 6.9 (rural) (Fugro and Arcadis, 2006) 13.8 (urban) (Arcadis and Fugro, 2006)

Table 1: Costs dyke reinforcement (raising the dykes) in the Netherlands Hillen et al (2010)

The cost estimate is based on the following principles (Table 2):
- The dykes along the waters in the Southwest Delta are located mainly in rural areas.
 Based on cost study by TU Delft (Hillen et al, 2010), the costs for raising the dyke by one meter in rural areas is assumed 10M € / km;
- The cost of construction of an inner berm is assumed to cost an additional 10M € / km for a raise in dyke embankment from 0 to 1 meter and 15M € / km for a raise of 2 meter.

Indicative costs raising dyke and construction inner berm per kilometer
Total construction cost Delta Dyke = (cost raising existing dykes/km + construction costs inner berm/km)

Area	Decimation Height	Cost Estimate
Western Scheldt	1 m	(10M€/km + 10M€/km) = 20M€/km
Eastern Scheldt	0 m	(0M€/km + 10M€/km) = 10M€/km
Eastern Scheldt without barrier but with Overscheldt	2 m	(20M€/km + 15M€/km) = 35M€/km

Table 2: Cost estimates for the construction of Delta Dykes in the Eastern and Western Scheldt

Indicative costs of construction of a new Delta Dyke per kilometer

When removing the Eastern Scheldt storm surge barrier and constructing the Overscheldt, new Delta Dykes have to be constructed (Table 3). **Total** construction cost for the new Delta Dyke = (cost raising existing dykes/km + construction costs inner berm / km).

Area	Minimum costs	Maximum costs
Overscheldt	40M€/km	80M€/km

Table 3: Cost estimate of the construction of new Delta Dykes for the area near the Overscheldt

Other studies on Delta dykes

In the quick scan breach free dykes (Silva and Van Velzen, 2008), ratios are listed for the costs of transforming an ordinary dyke to a Delta Dyke. For the south-western estuary[1] these costs are 1.22 billion Euros for a total length of 310 km dyke. The costs of making these Delta Dykes climate proof to 2050 represent an additional investment of 1.44 billion Euros. This figure is based on an increase in dyke height of 0,50 m in order to face future sea level rise. For the whole of

[1] This does not include the entire Southwest Delta.

the Netherlands this means an investment of around 11.5 billion Euros (this equates to an average 4.6 million per kilometre). However, according to the report, a reduction of approximately 80% of the costs is possible when converting the dykes to breach free and climate proof is combined with the restoration of the dykes according to the Flood Protection Program.

Knoeff and Ellen (2011) arrive at a much higher amount for the construction of Delta Dykes. Their estimate is about 20 billion for the Netherlands. The average costs vary per water system, from 6 million per kilometre along the IJssel, Maas and IJsselmeer to 12 million per kilometre along the coast. The average is 8 million per kilometre. They also achieve savings by combining the construction of Delta Dykes with regular dyke reinforcement projects. The extra investments in Delta Dykes are then estimated at 20% to 60% of the abovementioned costs.

Benefits

Reduction of flood risk

Delta Dykes are very robust. They are dimensioned at a probability of failure one hundred times smaller than the present standard. For a sea bank along the coast of Holland, for example, an average probability of flooding of 1/10.000 per year is required. It is assumed that for a breach free dyke at the same place an average chance of breaching of 1/1.000.000 or 0.0001% per annum will apply (Silva and Van Velzen, 2008). The advantage of a breach free dyke is a decrease in the risk of damage to crops, building and constructions behind the dyke. Also the risk of casualties and the chance of an evacuation decreases.

In his inaugural speech Professor Vellinga (2008) outlined the benefits of a breach free (wide) dyke. The biggest advantage is the low amount of damage when floods are unexpectedly high. Figure 5 shows his estimates of the difference in damage between a regular dyke and a breach free dyke (Delta Dyke). When water levels rise higher than 5 m + NAP, damage occurs. There is a lot more damage with a traditional dyke compared to a Delta dyke. An extra-wide implementation of a Delta Dyke also offers new planning opportunities and thus new financial possibilities.

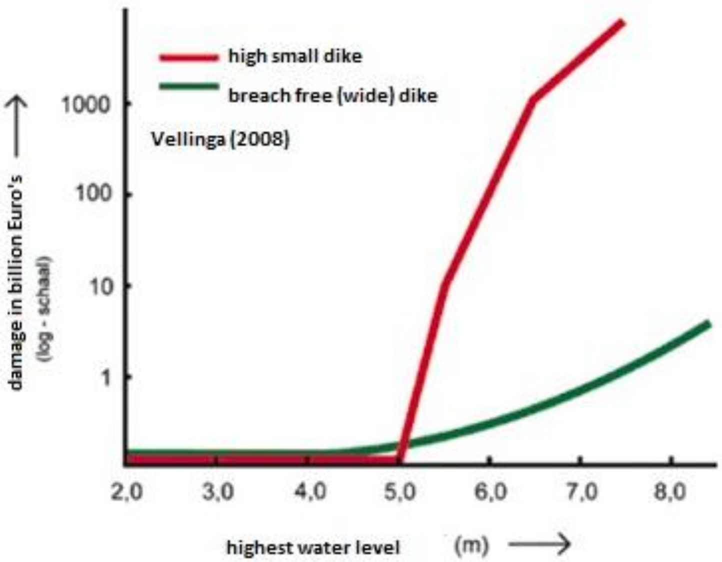


Figure 5: Tentative damage curve for narrow and wide dyke (Velling, 2008).

The (material) flood damage is calculated in Dutch studies using the damage and victim module of the flood information system HIS-SSM. In this damage module a link between the depth of water after a flood and the damage to various types of objects and land use is made. The module takes into account direct material damage (damage to movable and immovable property), the direct damage caused by downtime of companies (operating loss) and indirect damage[2] caused by the flooding.

The extent of damage depends of course on the land use of the dyke ring area. If the area is densely populated, the amount of material damage caused by a dyke breach is much more extensive than when there are just a few buildings and the area is barely inhabited. Also the number of casualties (deaths and wounded) depends on this. As a result, large differences in avoided costs will arise in the Southwest Delta when Delta dykes are constructed. In the SCBA

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[2] Indirect damage includes (a) damage to upstream and downstream businesses outside the area because of the (partial) loss of sales or supplies and (b) the damage due to impassability of delivery routes. The latter is estimated based on travel time loss caused by detours along non-flooded (and possibly heavily congested) routes.

‘Waterveiligheid 21e eeuw’ (Deltares, 2011) is calculated how many victims are involved per dyke ring area. In Table 4 the data for the dyke ring areas in the Southwest Delta are displayed.

Dyke ring area	damage (million €)	Number of affected people	Number of casualties
IJsselmonde	4000	90000	590
Pernis	480	4500	700
Rozenburg	260	15000	15
Voorne-Putten-West	1500	41000	110
Voorne-Putten-Midden	580	16000	45
Voorne-Putten-Oost	2900	67000	570
Hoekse Waard	530	11000	40
Eiland van Dordrecht	2600	40000	310
Land van Altena	1800	27000	170
Goeree-Overflakkee-Noordzee	190	4400	5
Goeree-Overflakkee-Haringvliet	55	1200	< 5
Schouwen Duiveland-West	320	4100	10
Schouwen Duiveland-Oost	830	11000	50
Tholen en St. Philipsland	580	8700	65
Noord-Beveland	150	2300	5
Walcheren-West	190	5500	5
Walcheren-Oost	2300	49000	180

Zuid-Beveland-West	930	14000	180
Zuid-Beveland-Oost	720	5500	130
Zeeuwsch Vlaanderen-West	500	3700	10
Zeeuwsch Vlaanderen-Oost	850	17000	110
West-Brabant	750	3600	15
Geertruidenberg	320	7500	30
Donge 2	600	41000	210

Table 4: Damage expectancy as calculated by HIS SSM and the number of victims and deaths in 2011 calculated for the dyke ring areas in the Southwest Delta (SCBA Waterveiligheid 21e eeuw, Deltares, 2011)

Negative benefit from required extra space.

The construction of a Delta Dyke involves broadening (and where necessary heightening) of the dyke and thus loss of usable area. If behind the dyke agriculture or saline cultivation is practiced, or greenhouses or housing are build, the creation of a Delta Dyke means a decrease in productive area. This negative benefit can be calculated by the area lost, due to the widening of the existing dyke to Delta width, multiplied by the profit per hectare.

Super Dyke Construction

A Super Dyke is actually an extra-wide Delta Dyke. The dyke is broadened so the crest can be used for various functions including housing. (Super) wide breech free dykes can be appealing from a planning point of view for example when reconstructing urban areas. From a technical point of view such width is not necessary to create a breach free dyke and high costs are involved.

Benefits Super dyke

Depending on the land use on and behind the dyke, an extra wide Delta Dyke can also be financially appealing. In particular when houses can be build or business activities can take place on the dyke, it is possible that the revenues exceed the high cost of constructing a super dyke. In Japan, super dykes are not an uncommon sight any more (Figure

6). Here dozens of kilometres of super dyke are built. The construction is often combined with redevelopment of an area. This takes place especially in densely populated areas where rivers flow into the sea.

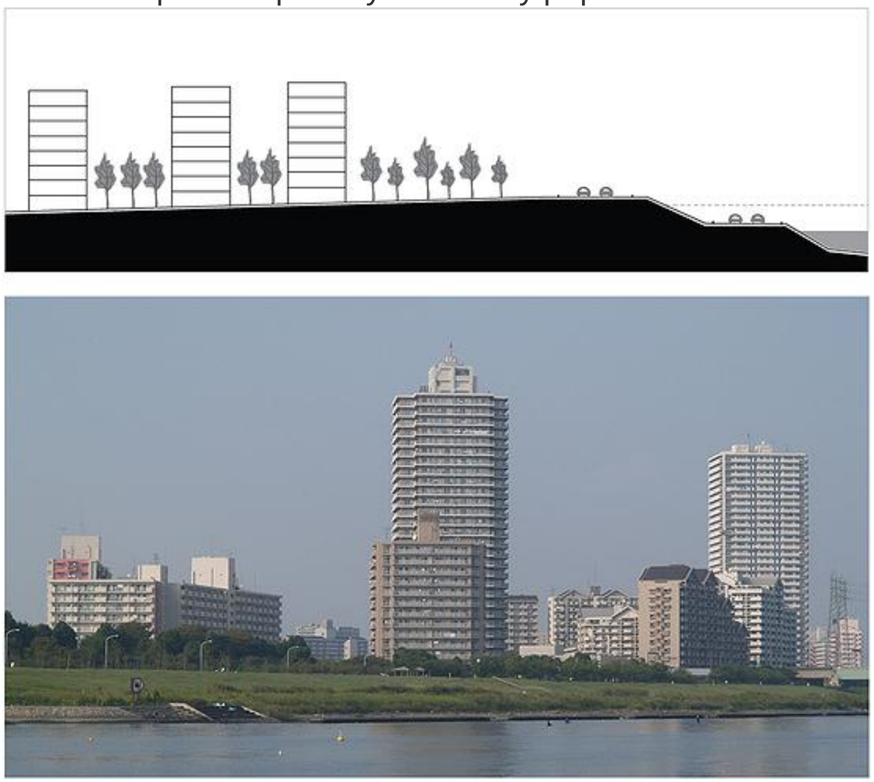

Figure 6: Example of a super dyke with high rise buildings in Japan. (www.kennislink.nl)

For The Netherlands, in a study for the WNF (Van Winden, Tangelder et al., 2010) to a possible long-term development of the Haringvliet, three concepts of Delta Dykes have been worked out for application in various areas (Figure):

- Delta Dyke in suburban areas: broad dyke of 190 meters wide which creates space for fields and pastures, infrastructure and sub-urban living.

- Delta Dyke in urban areas: relatively narrow dyke of 90 meters wide which makes it applicable in densely populated areas. The dyke can be set up for urban living and infrastructure.

- Delta Dyke in rural areas: broad dyke of 200 m wide. Terraces on the sea side enable growing of salt tolerant vegetables and/or nature/recreation and infrastructure. The widest part of the dyke is suitable for recreational living, nature areas and small pastures.

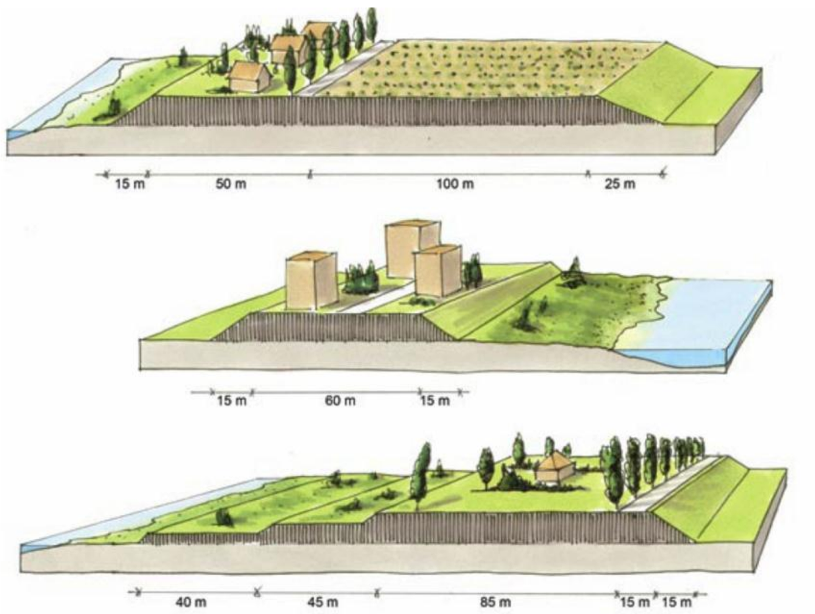

Figure 7 Three possible designs for the application of Delta Dykes (Van Winden, Tangelder et al., 2010).Upper panel: sub-urban Delta Dyke; Middle panel: Urban Delta Dyke and lower panel: Rural Delta Dyke.

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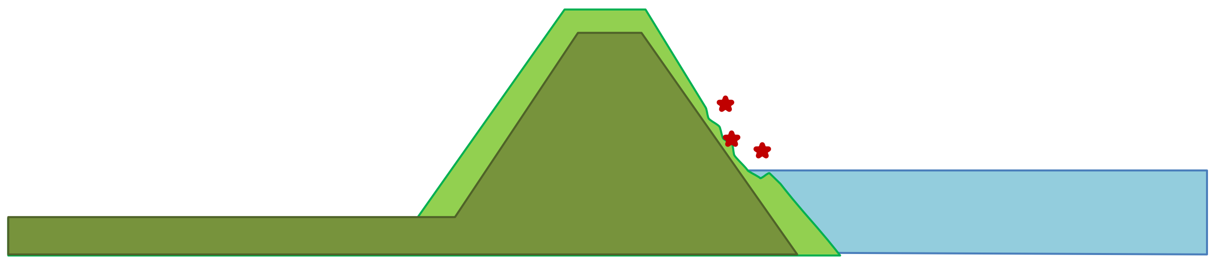
Rich revetments and foreshores

Source: Building with Nature wiki, Ruben Abma (Witteveen + Bos)



Description measure

Traditionally revetments are designed to provide a safety. This leads to large scale monotonous application of materials and shapes that are not optimized for habitat diversity. The Rich Revetment concept aims to create highly variable habitats in the intertidal and subtidal zone of dykes and foreshores while maintaining safety levels. This approach utilizes a variety of different materials, gradients and shapes to create differences in height, hiding places in a variation of environments with different exposure levels to current and waves. In some designs water is stored in tidal pools. Other designs create highly structured surfaces to provide shelter and attachment opportunities for many species of animals and plants. These solutions are suitable for engineers involved in dyke (re)construction and maintenance project or other water related infrastructure such as harbours, quays and piers.

Application

Rich Revetments provide an ecological added value where only hard solutions, leaving no space for natural processes, are possible. Examples are slopes of dykes (Figure 1), dams, quays, jetties etc.

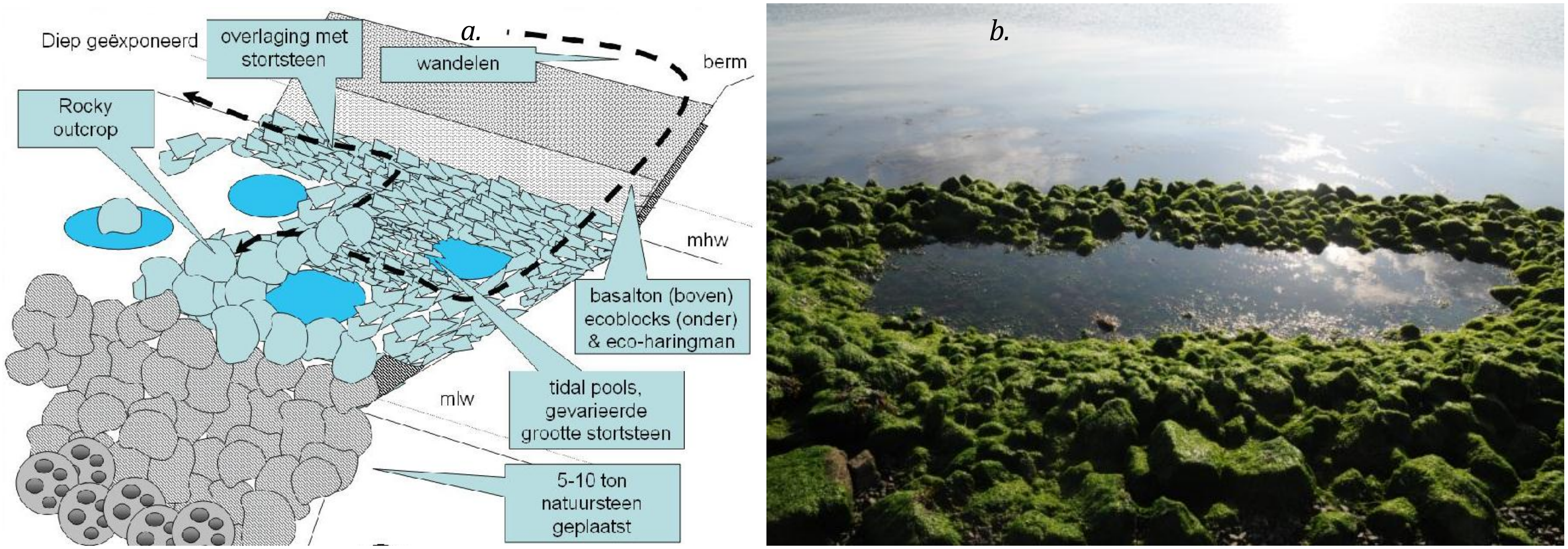


Figure 1, design of a Rich Revetment (www.innoverenmetwater.nl). b. Rich Revetment at the Koude- en Kaarspolder near Yerseke where a dyke is fit out with a puddle (www.ecoshape.nl).

Advantages

- Existing threatened/weak revetments are replaced by a fully functional eco-revetment. The remaining existing dyke is therefore maintained at its required safety level.
- Production of intertidal hard substrate habitat, these habitat types can be lost during maintenance. Re-creation or extension could provide valuable habitats to the surrounding ecosystem.

- Provide ecosystem services besides coastal protection like support of fish population for fisheries and contribution to an attractive landscape for visitors (Barbier, Hacker et al. 2011).
- Provision of connectivity along the shore, in the form of a continuous ribbon of diverse hard substrate habitats. Potential to link previously disconnected areas of high natural value.
- Potential for recreation for instance on diving sites and recreational fishing.
- Potential for collection of edible plants and animals.
- When the physical conditions or design constraints require hard solutions, the rich revetment concept still provides opportunities for added services.
- Construction of a rich revetment solution could provide mitigation and compensation measures with respect to requirements of environmental legislation such as water framework directive and natura 2000.
- A rich revetments design can be a robust design that does not require additional maintenance.
- No loss of existing foreshore, because the footprint is equal to the classic revetment solution. This will reduce conflicts with environmental protection regulations, especially Natura 2000.

Disadvantages

- Construction of rich revetments could add to the costs of the project.
- Added attractiveness for recreation could add additional safety risk for the public
- Provision of connectivity along the shore, could provide habitat for invasive species as stepping stones (see for instance DELOS project, http://www.delos.unibo.it/).
- In some countries, creating pools in revetments is not allowed due to danger of breeding mosquitos.

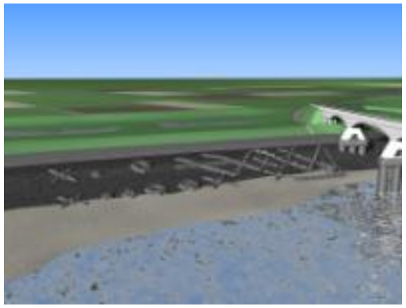
Design

Below, a number of different field cases are presented providing some application of the concept of Rich Revetment. Design or application can greatly differ amongst sites, depending on goals (coastal protection, nature development, retention) and specific local conditions. Experiences from these cases can be used as inspiration for future designs. For more information on the Building with Nature cases we refer to the case description pages in the Building with Nature wiki.

<u>**Rich revetment project - Yerseke**</u>

The pilot project in Yerseke is the first location in the Netherlands that uses tidal pools, called ecobasins in the "toe" of the dyke. The "toe" is the fortified link between the slope and the front shore. The dyke toe consists of stones, protecting the dyke against erosion and to support the dyke cover. As a pilot, ecobasins were constructed on the dyke along the 1 km dyke. 10 short pools (basin type 1) and 2 long pools (basin type 2) where created. The basins are waterproof, that is that during low-tide they will not empty. Within the basins various stone types and sortings provide fixation for algae and shelter for juvenile fish and macrofauna. The basins at the toe of the dyke are sealed with sheet asphalt and then filled up with lava stone. The dyke toe is located near the low tide line, so that water remains in the basins after high tide. So far, conclusions are that in all basins the total number of species have increased. Basins that fall dry contain less species than basins in which water remains during low tide.

Ecodesigned foreshore structures - Eastern scheldt strengthening



For several locations along the Eastern and Western Scheldt the dyke foreshore needed to be strengthened in 2009. The requirements for this contract to ensure the dyke stability was originally focussed on economical aspects only. Notwithstanding the fact that from protection laws there was no necessity to adjust the technical design, the special ecological value of 2 locations in the Eastern Scheldt was recognized.

The approach to enriching the foreshore involved creating as many different habitats as possible. The engineering design called for a variety of different materials, gradients and shapes to create differences in height, hiding places, and variations in the exposure to and shelter from the current. To ensure flexibility, the engineers came up with a modular system of building blocks consisting of round, criss-crossed and atoll-shaped piles of stones and linear elements, all in varying sizes. Combining these building blocks made it possible to achieve more variety at a larger scale.
The development of the underwater landscape is monitored by divers. They take photographs of the marking stones. A fast recovery was stated as well as a high biodiversity. Also rare organisms settle within the landscape. The site has developed as a popular diving spot, this enlarges the supportive group for these types of alternatives.

Eco concrete - IJmuiden

The breakwaters of the entrance of the North Sea Channel at IJmuiden (The Netherlands) protect the port against wave attack. The breakwaters consist of concrete blocks. The surface of the blocks, and cracks and spaces between these blocks are habitats for a diversity of marine flora and fauna like algae, insects, crabs and shellfish, fish and birds (including a red list species). Because of this, it is important that during and after renovation of breakwaters, the affected hard substrate habitats will recover quickly.

In order to stimulate the growth of marine species on the breakwaters, the aim of this pilot study was to test slabs with various textures and geometric shapes attached to the concrete blocks for algal and macro-faunal colonisation.

In conclusion, small adaptations of both texture and structure of concrete constructions within the intertidal zone of the marine environment lead to better settlement and growth conditions for algae and macrobenthos to settle and grow. Thus primary and secondary production is enhanced, without decreasing the safety level of the port.

Harbouring opportunities -- Rotterdam

Port areas consist mainly of man-made constructions, such as seawalls, piles and pontoons. These hard structures are favoured as a settling substrate by different organisms, such as algae, mussels, sponges and oysters. However, substrates in harbours are often smooth hampering establishment of organisms, and provide little hiding place for larger animals such as fish, lobsters and crabs. Traditional harbour design results in a smooth underwater environment. Possibilities to create simple but effective profiled structures in harbour areas are investigated in pilot study.

In order to create a more profiled underwater environment this pilot aimed to come up with designs for suspended artificial substrates to promote the settlement of mussels and consequently contribute to water quality in harbours. Aim was to enlarge available substrate for settlement, increase biomass of filter-feeders (e.g. mussels) and to enhance habitat diversity in port areas. For the Rotterdam harbour two specific structures were selected for further elaboration: polehulas and pontoonhulas. The hulas resemble Hawaiian skirts and consist of bands with ropes that could be wrapped around poles or attached to pontoons.

Use of artificial substrates, such as hulas, can increase the amount of biomass considerable. Thirty-four weeks after construction presence of a polehula results in an increase of biomass per m 2 with an average factor of 8.5 compared to a reference pole with no hula around it. On polehula's also different algae species were found.

Wave reducing poles - Nieuwe Waterweg

One of the first experiments carried out in the framework of Rich Revetment are the wave reducing poles. The poles serve as attachment site for all kinds of plants and animals and simultaneously reduce the height of incoming waves. This project experiments with different types of poles (wood and concrete) and ropes (nylon and sisal) to determine the best design.

The poles provide a hard substrate for the establishment of all kinds of plants and animals. E.g. mussels can filter the water and add to the water quality. These mussels are an important food source for birds. Behind the poles, the birds can find a sheltered area for foraging.

A wave reducing pole forest only reduces the wave load. It can be an alternative in case of a shortage or inadequate crown height trim, but does not solve an unstable embankment or dyke with probability of piping. Calculations with the SWAN wave model have been performed for the wave reducing willow forest in for the Noordwaard. A similar broad pole forest is a (very) expensive construction but the wave reducing poles can be an alternative for wave reducing reef. The poles should be sturdy enough for storm conditions, sufficiently deep rooted and sufficient high above the waterline.

Wave reducing dyke -- Noordwaard

In order to make room for the river "Nieuwe Merwede", a section of the polder Noordwaard (about 2000 hectare), presently protected by the river dyke will change into land on the outside of the dyke, exposed to regular flooding. The area has several functions, mainly agriculture, tourism, nature, living and some industry. A new primary river dyke is required in the North Eastern corner of the Noordwaard to protect the inhabitants at Fort Steurgat. During a 1/2000 year discharge event the average water depth in the polder will be 3 meter whereby, in combination with a severe storm, waves up to 1 meter high are expected near Fort Steurgat. A first 'traditional' dyke design around Fort Steurgat resulted in a dyke height of 5.5 meter above NAP, with concrete blocks as armouring layer, leading to protests from the local population.

To create an ecodynamic design that provides safety, that provides additional values for nature and recreation and that is practical from the viewpoint of costs and durability. The construction of the wave reducing eco-dyke has a number of impacts on the dyke design. The objective of the design is to produce wave reduction in order to reduce wave overtopping on the dyke. In the final design a continuous willow tree plantation in front of the dyke provides at 80% reduction of incoming wave height at 1:2000 storm conditions. This allows the design of a dyke with a 70cm reduced crest height, without violation of maximum overtopping limitations. Furthermore, reduced wave attack allows for the design of a clay clad dyke in stead of a dyke with hard armour layer. The willow plantation is inspired by a centuries old traditional culturing of willow trees for use as brushwood in swamp areas

The construction of the wave reducing eco-dyke has a number of impacts on the dyke design. Firstly, the new dyke has a wider footprint than the 'traditional' dyke. The design includes the implementation of a willow tree plantation. This living element is outside of the expertise of traditional dyke designers and necessitates expert input of biologists. Some uncertainty remains on sensitivity of tree plantation to disease, ice-winters, forest fire, stability under extreme wave forces. Therefore some contingencies against failure are implemented in the design.

Ecological dyke reinforcement - Ellewoutsdijk

The seawall of the village of Ellewoutsdijk was in need of repairs. However, raising the dykes is not a viable option as that would mean doing away with an ancient fort. Innovative solutions are required in order to preserve safety (ComCoast). It was investigated whether it would be possible to reinforce the dyke coverings instead of raising them. That way, in extreme situations the highest waves could crash over the seaside dyke without the inward dykes failing as a result. A water retaining top layer has been added to of the armour layer. Additionally, a small (coffee cup size) hole has been made in some stones. At low tide, small puddles remain in these holes, further stimulating algae growth.

Floating marshes - IJsselmeer

Along coasts of large Dutch freshwater lakes, dykes often border the water directly, with relatively steep slopes. Shallow zones and the gradual slope from land to water are lacking. Consequently, species that inhabit these zones are decreasing. In addition, constant lake-water levels cause erosion of shores. To dampen waves and recreate gradual land-water transitions brushwood mattresses were constructed in front of the dyke. These mattresses might facilitate development of floating reed marsh in the shallow zone in front of a dyke. This marsh reduces wave impact on the dyke, enhances sedimentation and creates a clear shallow water zone with (submerged) vegetation.

The innovative application of braided brushwood mattresses aims to create floating foundations for emergence of reed vegetation. The floating mattresses locally reduce currents and waves thereby decreasing hydraulic loads on the dykes and creating valuable habitats above and below water. More benign conditions stimulate settling of suspended solids and promote the stabilisation of silty soils.

Maasvlakte 2 harde kering - Rotterdam

After the success of the first Maasvlakte harbour area in Rotterdam, a new port area, directly west of the existing port was developed as a new European location for port activities and industry, Maasvlakte 2 (MV2). The total reclaimed area will be about 2000 hectares. Half of this area will consist of commercial sites, mainly used for deep sea container handling but also for chemical industry and distribution. Another 1000 hectares will consist of infrastructure, such as sea defences, fairways, railways and port basins. The reclaimed land is protected by a partly soft and partly hard seawall.

Beach and dunes form the soft part of it, while pebbles, stone, quarry stone and concrete blocks form the hard part. Approximately 20,000 blocks from the existing Maasvlakte block dam will be reused in the new seawall. This solution is both economical and sustainable. The block dam protects the cobble beach. Waves will only pass over the block dam and attack the cobble beach in the event of a storm. During long periods a sheltered lagoon will form, promoting rich habitat diversity.

Implementing an ecologically rich dyke as hard seawall in the MV2 project contributes to the required environmental compensation, where the lost nature as a result of the construction of Maasvlakte 2 must be compensated with new nature. In this case, part of the seawall blocks are reused from the old Zuiderdam. Because these blocks already where exposed to salt water and waves, weathering already been put in motion. This provides for an appropriate material to facilitate growth of shellfish and algae.

Costs

Construction

The concept of rich revetments is too broad to provide specific costs for the different varieties. The table below sums up the costs for the construction of a new dyke optimized for ecology.

Post	eenheid	prijs (euro)	
grond ontgraven	tot 10.0000 m^3 (per m^3)	0.65	wellicht nodig als we klei gebruiken om bodems af te dichten
grond vervoeren per as	10-20km	4.75	
verwerken klei in berm	m^2	0.65	
aanbrengen geotextiel	m^2	2.25	
levering en plaatsen betonzuilen	m^2	80	nieuwe vormen van identiek materiaal zullen waarschijnlijk niet veel duurder zijn. Reefblocks vallen wellicht ook in deze prijsklasse (n.b. wel natte plaatsing!)
leveren en aanbrengen breuksteen 1-3 ton (nat)	ton	40	blijkbaar maakt de soort steen weinig uit in de prijsstelling. Prijs gebaseerd op rechtstreeks storten, niet op plaatsen van individuele steen. Overigens is deze sortering kleiner dan de grootste sortering bij Rijke Dijk ontwerpen.
leveren en aanbrengen breuksteen 60-300	ton	20	blijkbaar maakt de soort steen weinig uit in de prijsstelling
damwanden licht 7.5m	m	900	meter prijs van ontwerp 2 van rijke dijk zal tenminste dit bedrag zijn
damwanden zwaar 20m, verankering	m	4500	misschien een bovengrens voor meterprijs ontwerp 2
aanbrengen palen	m	30-150	sterk afhankelijk van de ondergrond en toegankelijkheid
verwijderen basalt	ton	4	
verwijderen asfalt	ton	10	
verwijderen basalton	ton	6.50	
verwijderen stortsteen 60-300kg	ton	6.50	
verwijderen palenrij (1.5m)	m	7.50	
onderhoudskosten dijk (indicatief)	km/jaar	75000	

*Table 1. Cost table from: '**De Rijke Dijk.** Ontwerp en benutting van harde infrastructuur in de getijzone voor ecologische en recreatieve waarden', February 2007, M. Baptist, J. van der Meer, M. de Vries. Uitgave van Port Research Centre Rotterdam-Delft. This table assumes construction of new dykes, not the adaptation of current dykes.*

Benefits

Diverse dykes have ecological as well as recreational benefits. It is also suggested that diverse dykes can serve compensation for lost nature.

Recreational value

The positive effects of a ´Diverse Dyke´ to the recreational experience can express itself in an increase of the number of visitors and / or an improvement of the quality of the landscape and nature values for the people who were visiting anyway.

There is no evidence that construction of diverse dykes will result in an increase in visitors. It is more likely that visitors who would walk or cycle on diverse dykes, will not be walking or cycling elsewhere in the region any more. So there is a regional shift in places people go to, to recreate and experience nature.

This leaves us with improved quality for regular visitors. Abma (2009) researched the willingness to pay for a more attractive dyke design on the Wadden island of Ameland. First he identified the features of a dyke exterior which were important to visitors and local people and which they found attractive for recreational purposes. He found that people preferred a green look of the dyke as opposed to a neat and taut design. Also important was the type of material the dyke is covered with, concrete columns were favourite. Least important was the location of the maintenance path (at the bottom of the dyke near the sea). Another outcome of the study was that over half of the respondents wanted extra measures to enhance the natural values of the dyke. These qualities match with the design of a diverse dyke. A dyke design was made according to the preferences of the respondents. In this design the dyke had a low bank accessible for recreational use, concrete columns, the dyke had a green appearance and extra measures were taken to create nature values. The preferred design was then presented to visitors and local people. Their willingness to pay for a green, natural (diverse) and more attractive dyke was established. Overall, tourists wanted pay an extra € 3,73 a visit and local people were willing to pay €6,70 a year for a more attractive dyke design.

Recreational fishing

Recreational fishing is, besides walking and cycling, another way to enjoy nature. It is a popular activity in the Southwest Delta. Year round, a total of 300.000 Dutch recreational fishermen try to catch fish in these waters. The true numbers of fishing trips are higher because the average fisherman fishes 8 times a year. Most of the anglers, a total of 188.000, fish from the shore as opposed to angling from a boat. An average of € 330,00 a year is spend by the Dutch recreational fishermen. Half of this amount is spend on fishing equipment in one of the 60 shops in the region. The rest of the sum is spend on boats, travel costs, accommodation and in restaurants and pubs.

Due to a decrease in nutrients in, for example the Oosterschelde, the number of fish caught is reducing. This has a negative effect on the sports fishery. Diverse dykes result in a larger area of hard substrate. This causes the different types of species living on hard substrate to increase. For certain types of fish, crabs en other mobile creatures this will result in an attractive area for foraging, reproducing and grow up in. This means an increase in the number of fish. As a result, diverse dykes are attractive places for angling. So diverse dykes can contribute to the expansion of recreational fishery.

Nature value

Diverse dykes contribute to the foraging area of fish and birds. Preservation of nature values can be a factor in the consideration between measures. This happens from the perspective of “intrinsic value” of nature as well as the prosperity that a society obtains from the preservation of nature values. It is well known that people want to contribute to these natural values. In his study on the recreational experience of the Waddensea dyke on Ameland, Abma (2009) found that the respondents wanted to pay for the creation of extra natural values on the dyke. The amount the tourists were willing to pay for these extra natural values was €1,21 a visit. Local people were willing to pay €3,00 a year for extra nature values on the dyke. Abma suggested that the willingness to pay for the extra nature values is because they think it is important to give plants and animals their habitat. This is called the non-use of the Waddensea dyke.

Saved costs due to compensation for lost nature

It is suggested that diverse dykes can serve as a measure to compensate for lost nature. The creation of nature in order to compensate for lost nature elsewhere is costly. As an example, the harbour complex 2e Maasvlakte is planned in the Dutch Voordelta which is Nature 2000 area. By constructing the harbor approximately 6.066 acres of the Nature 2000 is lost and needs to be compensated. In order to do this a sea reserve is made. By allowing less activities in this area 10% more biomass is generated. To compensate for the total area which is lost on the harbour, the sea reserve needs to be 60.660 acres. This will cost approximately 103 million euro's (PBL 2008).

In this example a large area has to be compensated but in smaller projects, diverse dykes can account for a (part of) the compensation, depending on the type of nature that needs to be compensated. If diverse dykes can contribute to compensation, costs of the construction of new nature are spared.

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C Dynamics and development of the Southwest Delta

Building with Nature aims to build hydraulic infrastructure utilizing the dynamics of the natural system and simultaneously creating opportunities for nature. In order to do this, the natural sedimentary system and its dynamics should be understood. One way to gain insight in a system is to research its geological and historical archives. Therefore we provide an overview of the geographical development of the area, which is mainly based on Vos et al. (2002).

The subsurface of the Southwest Delta consists mainly of peat, clay and sand. At the large scale the formation of these soils was controlled by the rise in sea level associated with the melting of large ice sheets after the last ice-age. The rate of sea-level rise was not constant (Figure C.1). At the beginning of the Holocene, the era after the last ice age, up to 6000 years ago, sea-level rise was about 60 to 80 cm per century. In the periods thereafter, this rise gradually decreased to 15 cm per century at about 3000 years ago to 5 to 10 cm per century during the last 2000 years, with the exception of the last 150 year. In this period the sea-level rise at the Dutch coast appears to have accelerated to 18 cm/century.

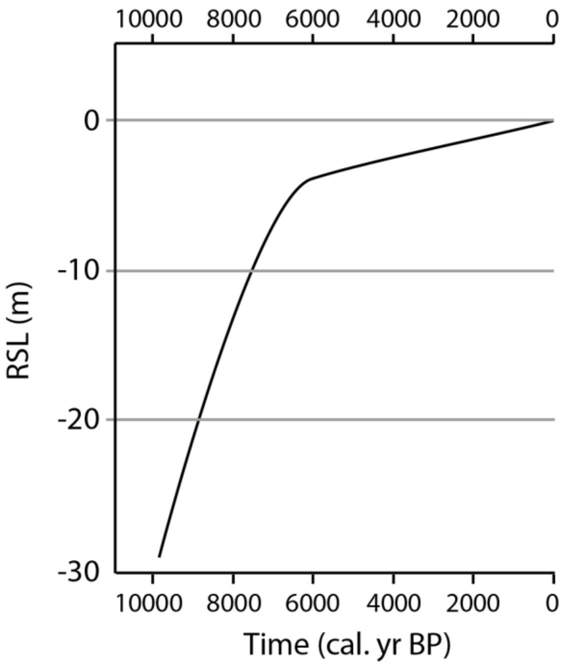


Figure C.1 Reconstructed sea-level rise for the last 10.000 calendar years Before Present (modified after Vink et al, 2007 and Kiden, 1995).

In the geographical development of the Southwest Delta, human influence became an important factor from the Iron-age and Roman age onward, and after the 11th century AD, when coastal regions were embanked on a large scale, human influence became dominant.

C.1 Start of the Holocene

At the start of the Holocene period, sea-level was still 30-45 m below NAP (Dutch Ordinance Datum), and therefore did not reach the present coastal area of Southwest Netherlands. The geometry of the Pleistocene land surface at the start of the Holocene forms the initial situation for the later marine inundation. Together with the relative sea-level rise, this initial morphology has steered the geological history of the Southwest Delta.

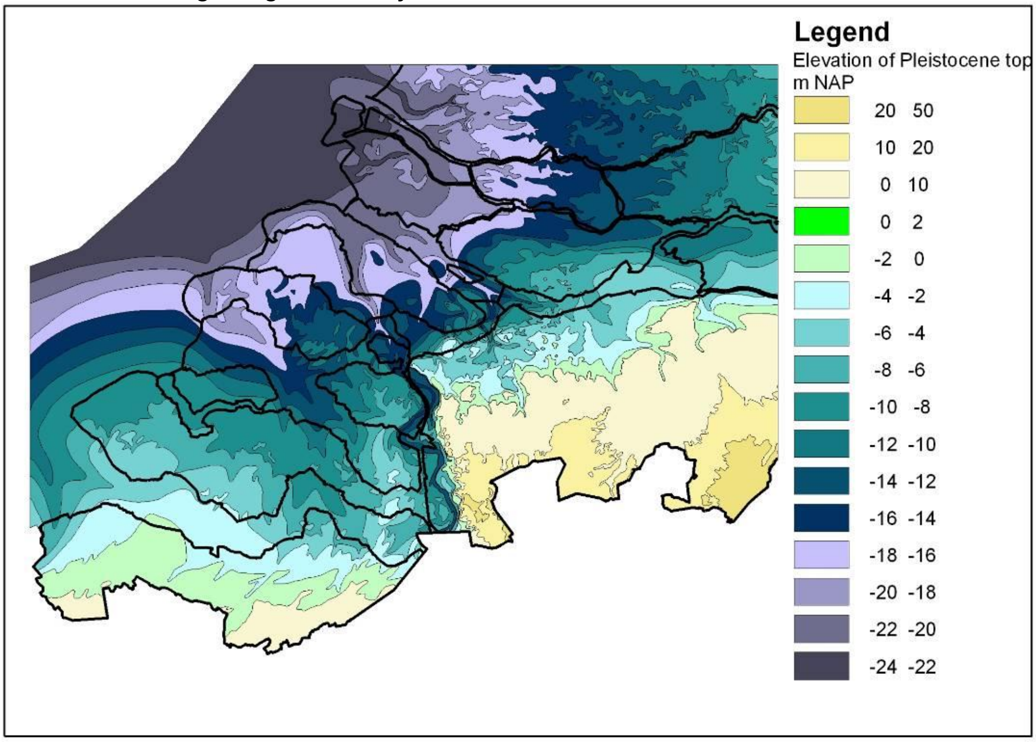


Figure C.2 Reconstruction of the Pleistocene morphology near the Southwest Delta (After Vos et al., 2002; Vos and Van Heeringen, 1997).

The Pleistocene morphology at around 11.000 years ago can be reconstructed from the present top of these deposits in corings (Figure C.2). The morphology is inherited from the end of the last Glacial period, and the sediments at the top of this surface consist mainly of windblown deposits and fluvial loams near river valleys. The map shows the pronounced paleo-Rhine –Meuse river valley where at present the Island of Goeree is situated. Also the paleo-Scheldt river drained northward into the Rhine-Meuse river Valley. In front of the present-day coast of Walcheren, a land protrusion was present. However, the Holocene sea-level rise eroded this protrusion. The eroded sedimentary material was deposited for a large part into the tidal basins of the Southwest Delta. Since this “source area” was eroded, the position, shape and size is largely hypothetical.

C.2 Transgressive coastal development controlled by sea level rise (9.000 to 5.000 years BP)

Around 10.000 years ago, the rising sea starts to influence the present location of the Southwest Delta. The first indication of influence of the sea in the area is the formation of peat, that could accumulate in swamps associated with the rising groundwater table. The gradually rising sea caused a landward shift of the zone with peat swamps.

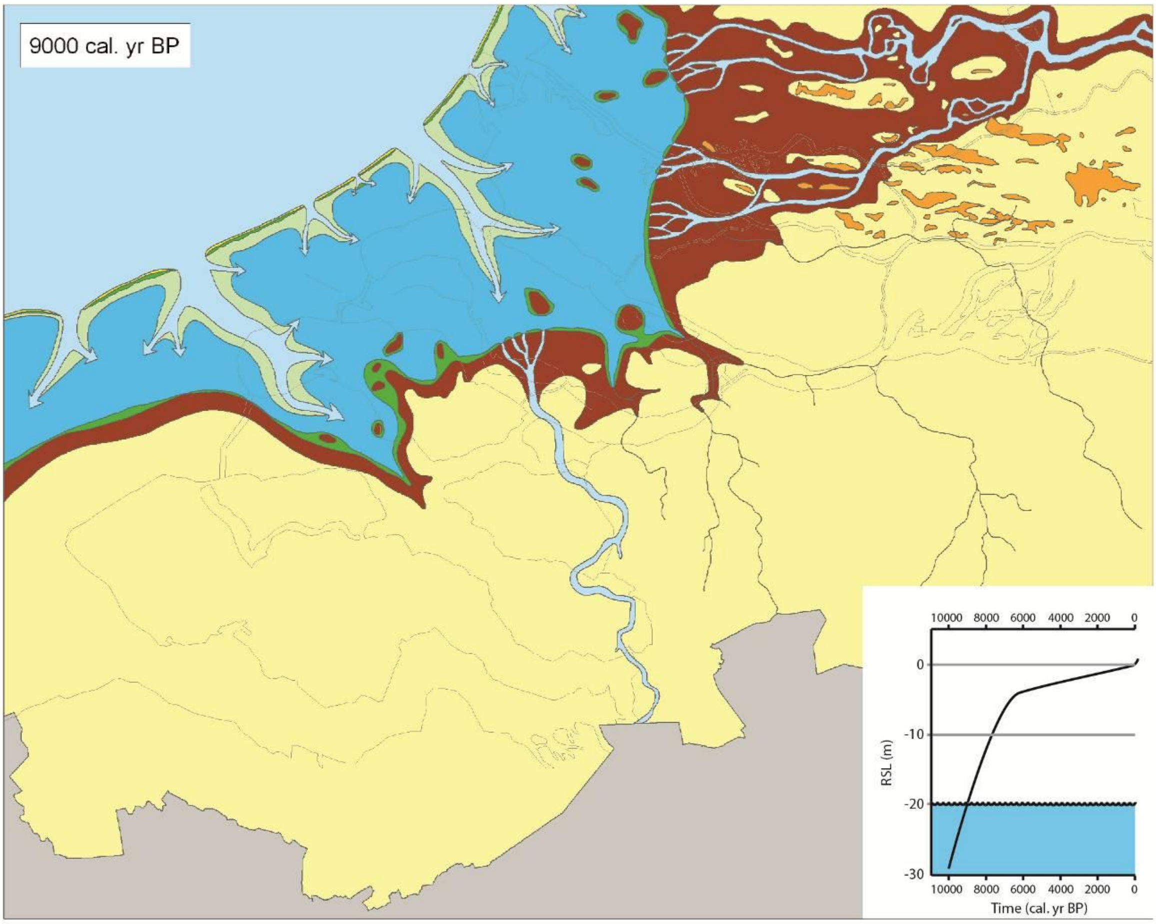


Figure C.3 Reconstruction of the geography of the Southwest Delta about 9000 years BP and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

About 9000 years ago, the sea inundated the low-lying western part of the Rhine-Meuse river-valley, the central part of the Southwest Delta and the Scheldt river-valley (Figure C.3). Due to the inundation, small tidal basins could form, in which the tidal range was limited (micro-tidal environment, with a tidal range between 1.00 – 1.25 meter; Franken, 1987; Hulsen, 1994). The fast inundation in the area combined with the limited tidal range resulted in the tidal lagoons in the area, fringed on the landward side by tidal marshes. At the seaward side, the tidal lagoon was probably protected by a series of beach ridges, and the lagoon was connected to the North Sea by tidal channels cutting through the beach ridges. Along the tidal channels, intertidal areas formed as flood tidal deltas inside the lagoon (Figure C.4).

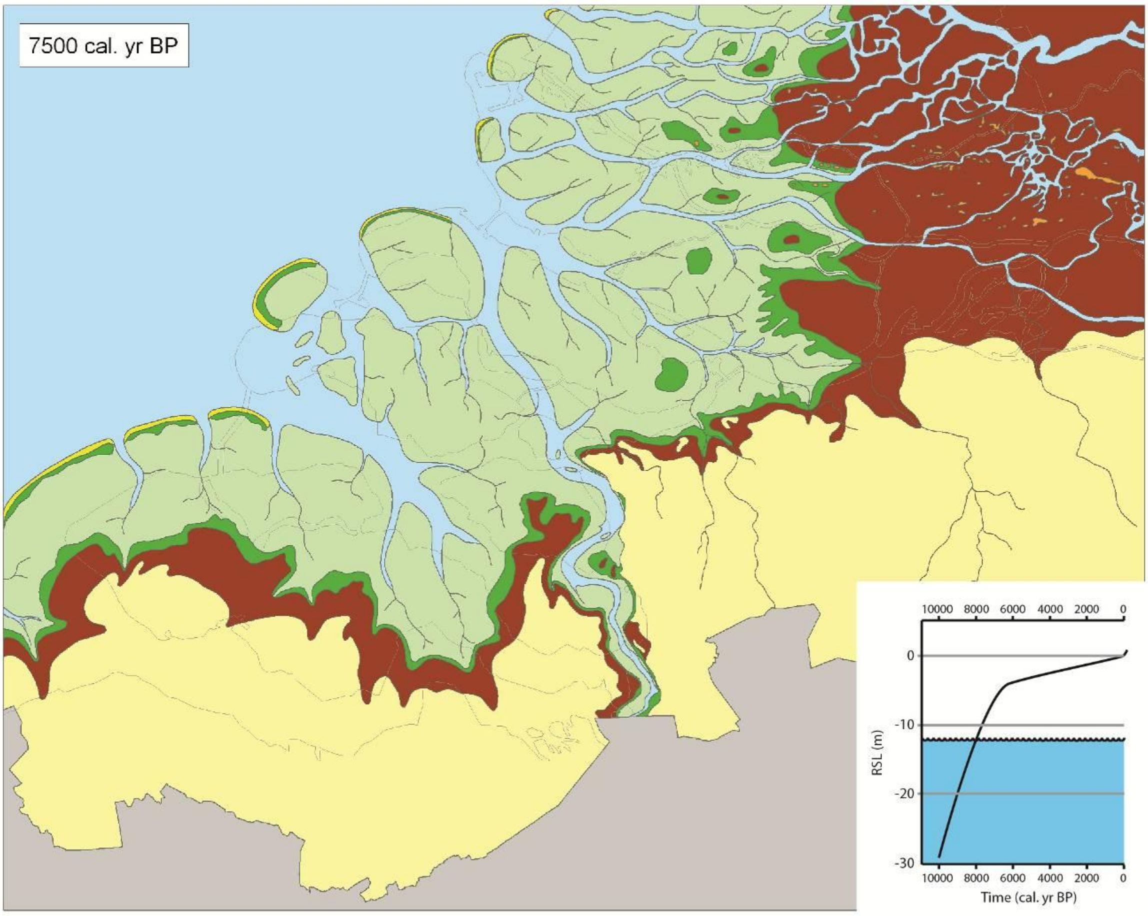


Figure C.4 Reconstruction of the geography of the Southwest Delta about 7500 years BP and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

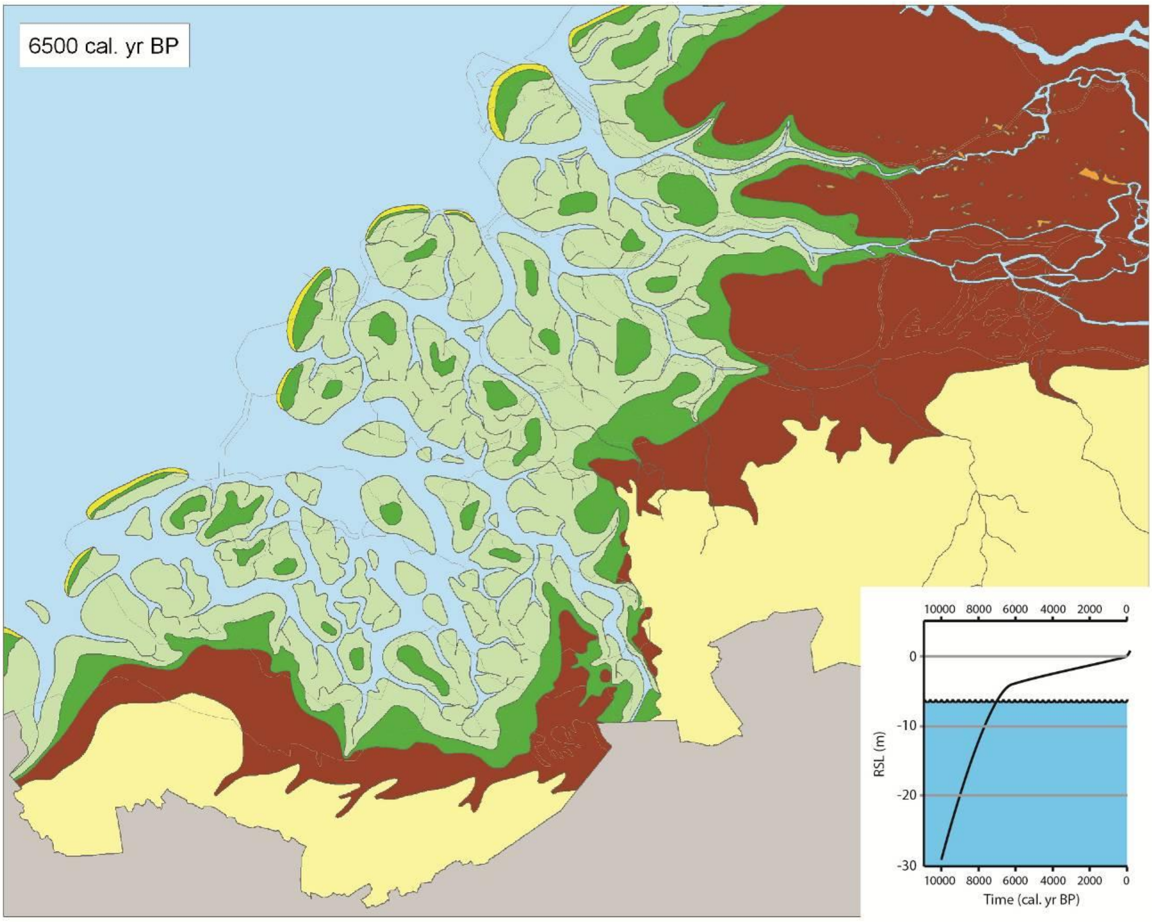


Figure C.5 Reconstruction of the geography of the Southwest Delta about 6500 years BP and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

As the North Sea deepened during the course of the Holocene, the tidal range increased. This, together with a decrease in sea-level rise around 7500 years ago, led to increased sediment transport towards the tidal basins, which gradually filled up with sediment. As a result, the lagoons disappeared and were replaced by inter-tidal areas. The Rhine-Meuse area is already expanding seaward, while the Southwest Delta is still a transgressive system at this point. The transition from a transgressive to a regressive system occurred in the Southwest Delta around 6500 years ago (Figure C.5).

The filling up of the basin resulted after 6000 years ago in a decrease in tidal volume in the area. The decrease in water flowing through the channels caused the expansion of the beach ridges. Eventually, the tidal basins were cut off from the sea (map 5000 years ago; Figure C.6).

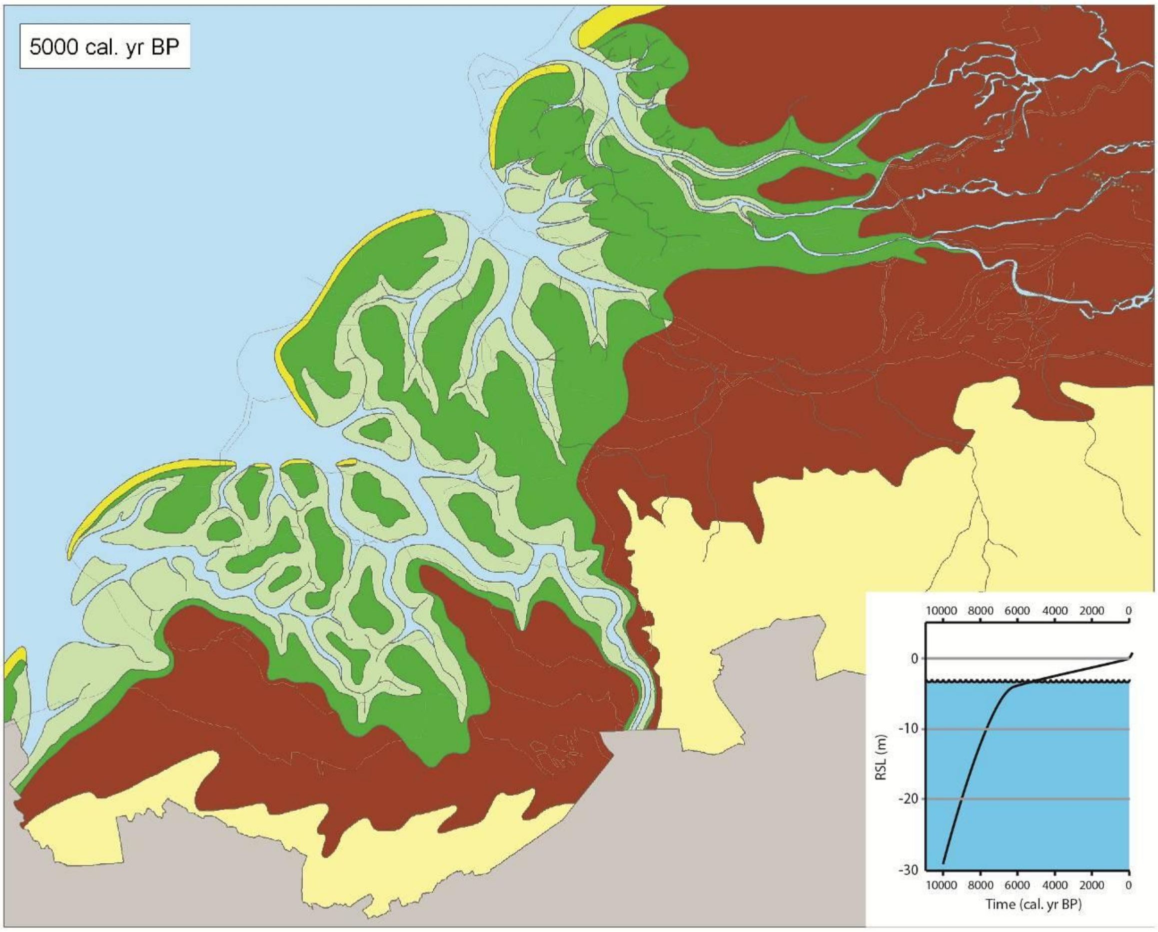


Figure C.6 Reconstruction of the geography of the Southwest Delta about 5000 years BP and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

As a result of the smaller tidal channels, the hinterland was less susceptible storm surges. Therefore, on the higher parts of the tidal marshes that became permanently dry human settlements were established.

C.3 Regressive coastal development 5.000 to 2.500 years ago

From 5000 years ago, the regressive development of the area carried through. Due to the closure of the tidal channels, drainage of the hinterland was inhibited. This led to a rise of the groundwater table. As a result, the area was progressively covered by a layer of peat. The peat formation also meant the end of Neolithic settlements in the area. Around 4000 years ago, the Southwest Delta was covered by a peat swamp (Figure C.7).

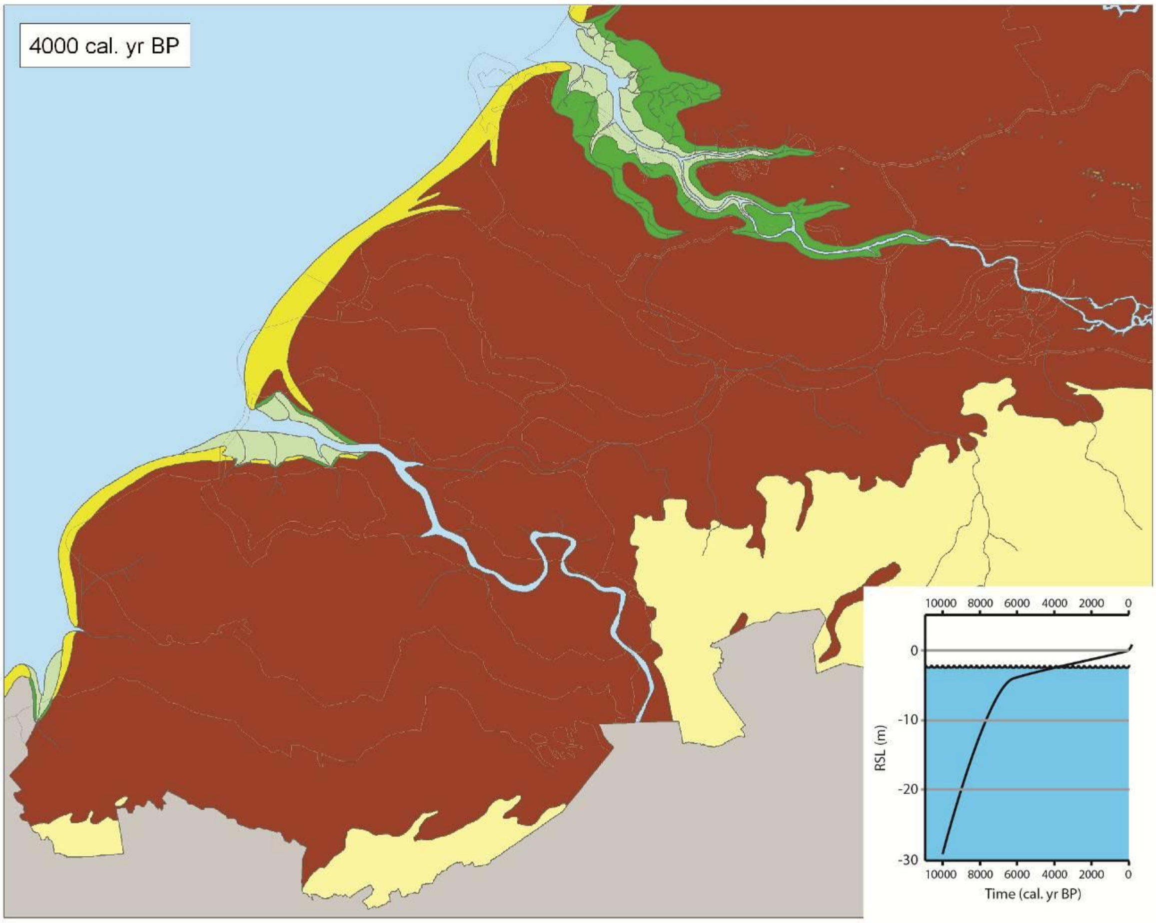


Figure C.7 Reconstruction of the geography of the Southwest Delta about 4000 years BP and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

The beach ridges build out in westward direction (map 3000 years ago; Figure C.8). Where the mouth of the present Oosterschelde is situated, the coastline was dissected by the mouth of the river Schelde. The course of the Scheldt was largely situated in the present Oosterschelde area. In the period Tidal deposits were only formed near the mouth of the river Scheldt and the Rhine-Meuse Delta.

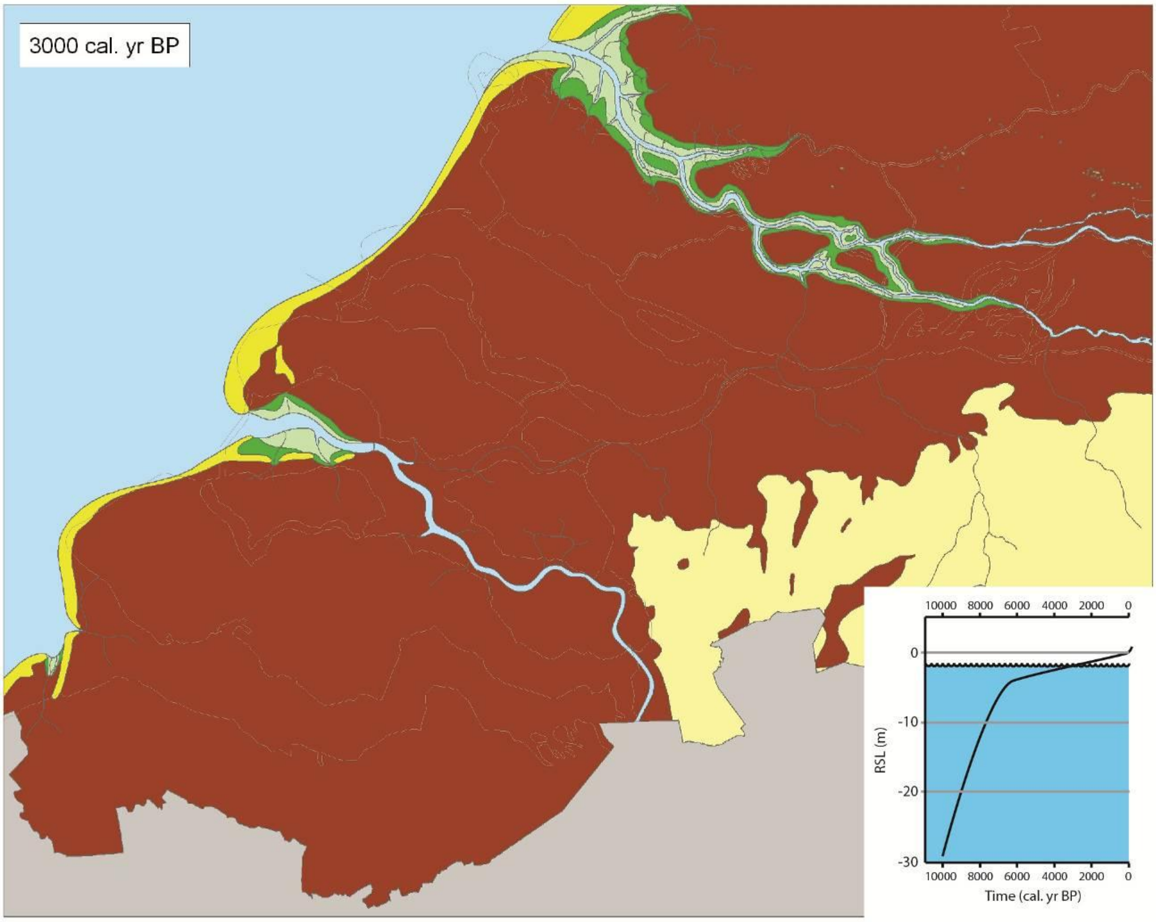


Figure C.8 Reconstruction of the geography of the Southwest Delta about 3000 years BP and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

C.4 Anthropogenically influenced transgressive coastal development (2.500 to 1.000 years ago

At the start of the Iron Age, the beach ridges start to erode again, probably as a result of a decrease of sand supply. The eroded sand from the Southwest Delta is transported and deposited along the Holland Coast where the beach ridges still build out in seaward direction.

The erosion in the Southwest Delta led to a thinner line of beach ridges, and the sea locally broke through the beach ridges, creating small tidal basins landward of the beach ridges in between the peat swamps. As a result of the dissections of the coastline, the drainage of the hinterland improved through local streams in the peat blanket.

In the late Iron Age, people started to influence the natural coastal development. The relatively elevated peat area on Walcheren was drained by ditches. Due to the high elevation and the drainage, the area became suitable for settlements. The result was that peat formation came to an end in this area.

In the Rhine-Meuse area, settlements on drained peat already took place in an earlier stage. The oldest settlements from this area date to about 2600 years ago. The settlements came to an end again later in the Iron Age as large parts of the area were inundated. This is probably due to human reclamation activity that caused lowering of the peat surface, in combination with higher river discharges from the catchments of the Rhine and Meuse.

The larger discharges also lead to an increase the channel cross-sectional area. As a result, tidal action could intrude in the estuarine systems. The tidal volumes of the basins increased, and the tidal channels increased in size. Also storm surges could intrude the hinterland again as a result of the reduced resistance of the large tidal channels. Therefore, salt marshes could expand on top of the peat cover which put an end to the human settlements from the early Iron Age. Due to the increased marine activity, estuarine sediments were deposited on top of the peat, leading to loading of the peat which caused subsidence. The subsidence on its turn, increased sedimentation and the tidal volume increased. The continuing sea-level rise also played a limited role in this process.

The transgressive process continued in the Rhine-Meuse mouth until a balance was reached between tidal volume and sedimentation. This balance was reached in Roman times. The inundation of the peat swamps occurs in different phases.

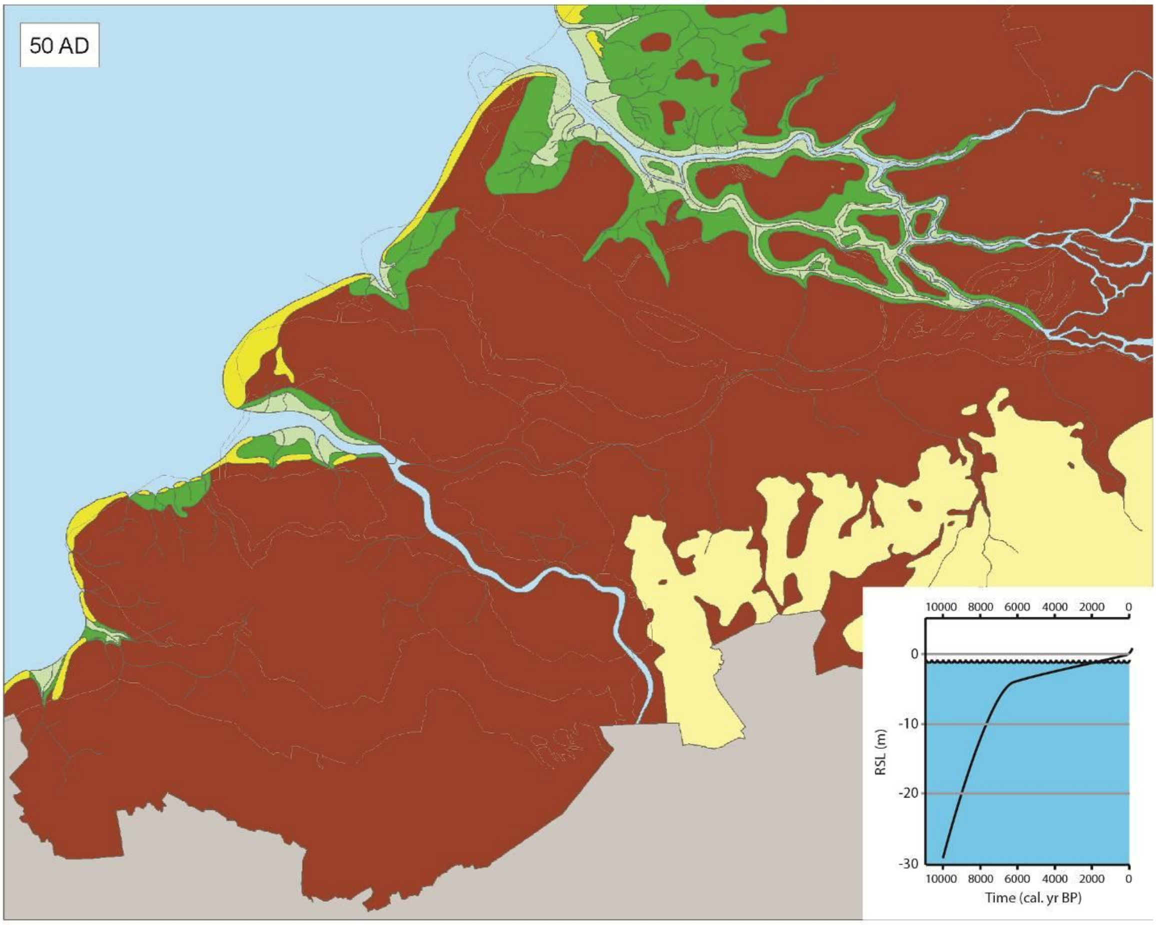


Figure C.9 Reconstruction of the geography of the Southwest Delta at about 50 AD and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

Initially, in early Roman times, the inundations in the Southwest Delta occurred on a relatively small-scale (Figure C.9). Archeological finds suggest that the peat has been used as fuel for industrial activities, such as salt extraction.

The industrial-scale peat mining and oxidation due to drainage resulted in strong subsidence in the Southwest Delta. Due to this subsidence the sea could invade the area and in early roman times the most seaward parts of the peat cover were inundated (Figure C.10). The tidal volumes and currents in the inlets dissecting the beach ridges increased. The sea could invade the area through the ditches and the peat was eroded.

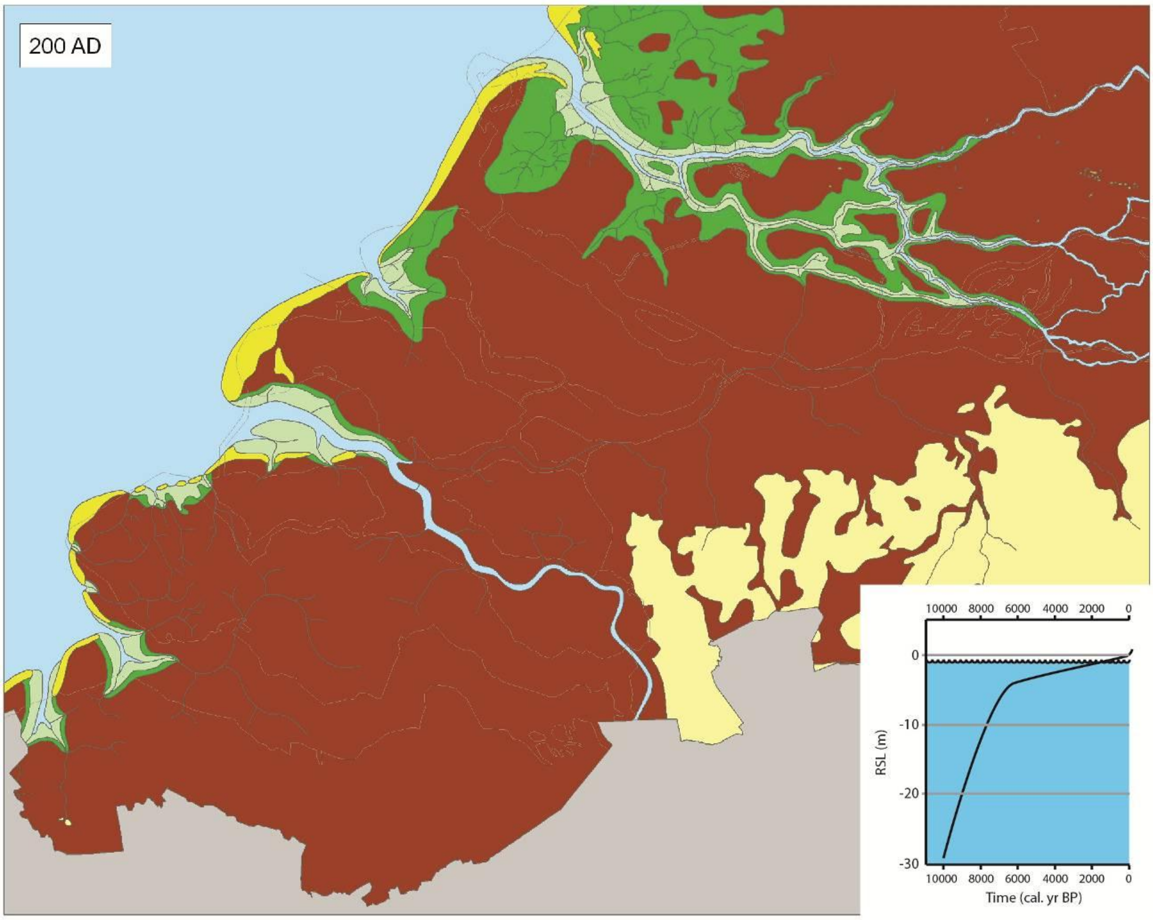


Figure C.10 Reconstruction of the geography of the Southwest Delta at about 200 AD and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

From 270 AD onward, a large-scale drowning process of the coastal area of the Southwest Delta started and around 350 AD most of the Southwest Delta had transformed into a tidal system with tidal channels, tidal flats and salt marshes (Figure C.11). People, who were the cause of the renewed drowning, disappeared from the coastal area. The process continued until after 500 AD, but the areas that were initially inundated on Walcheren, Zuid-Beveland, Schouwen and Zeeuws Vlaanderen slowly silted up and transformed into salt marshes. Around 750 AD also the proximal areas had also silted up and the drowning process start to come to an end.

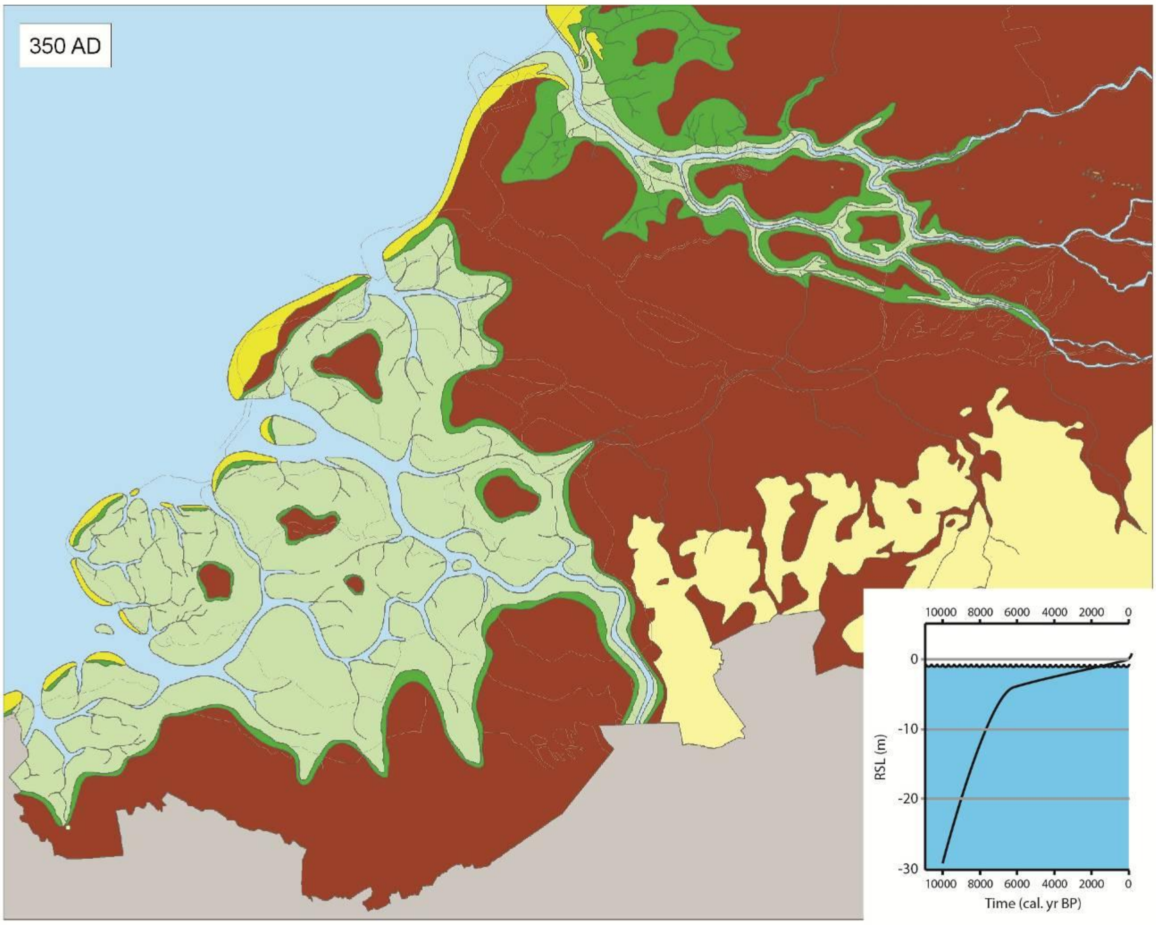


Figure C.11 Reconstruction of the geography of the Southwest Delta at about 350 AD and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

In the 10th century AD (Figure C.12) the process of silting up had made it possible to inhabit the highest salt marshes. The settlements existed on the salt marsh surface suggesting that these marshes were not flooded anymore during storm surges.

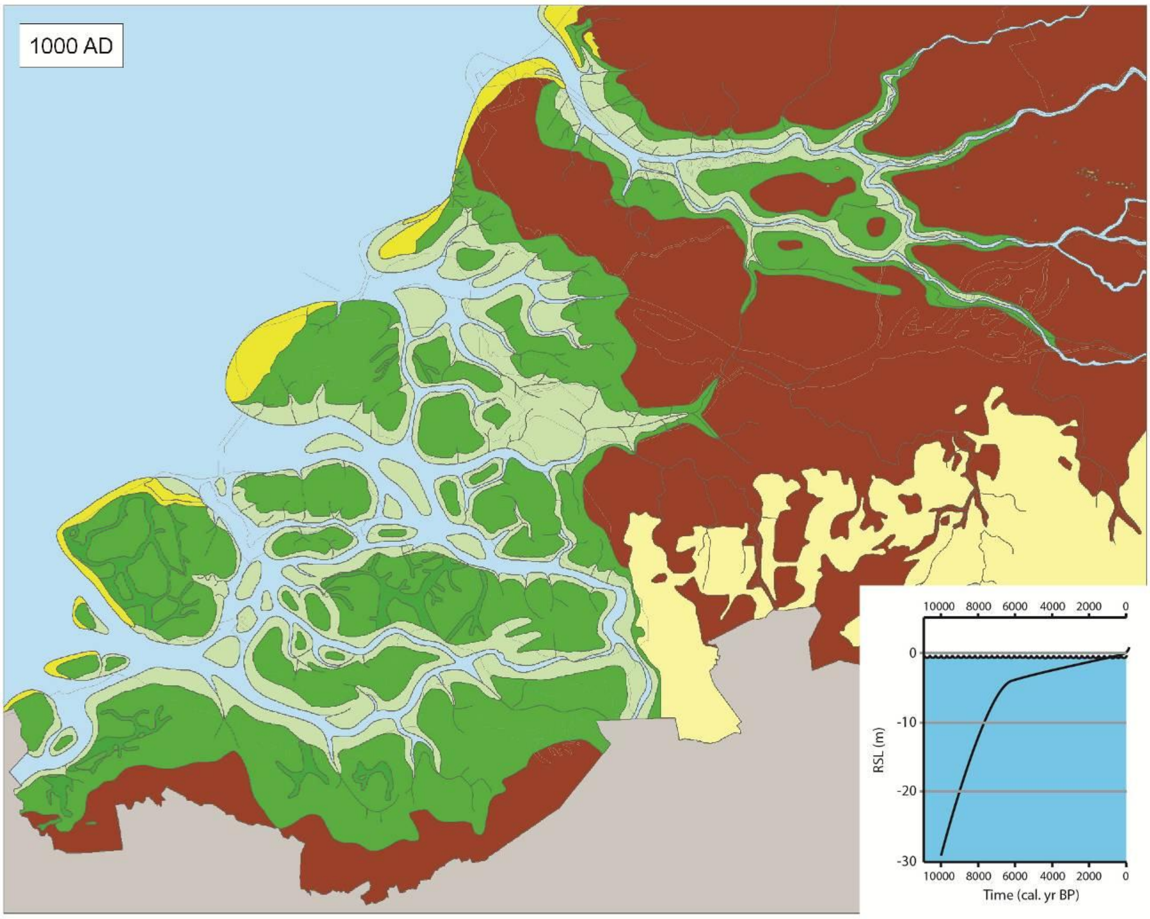


Figure C.12 Reconstruction of the geography of the Southwest Delta at about 1000 AD and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

C.5 Period of the embakmenthistory: 1.000 AD to present

After a period of relatively low storm surge heights, in the course of the 11th century the storm surge heights increased again. To protect themselves from against these floods, people started to build low dwelling mounds of about one meter high. Soon hereafter people started to protect their land by the construction of embankments. This happened opportunistically. Already around 1250 AD, the majority of the salt marsh and peat areas in the Southwest Delta was embanked.

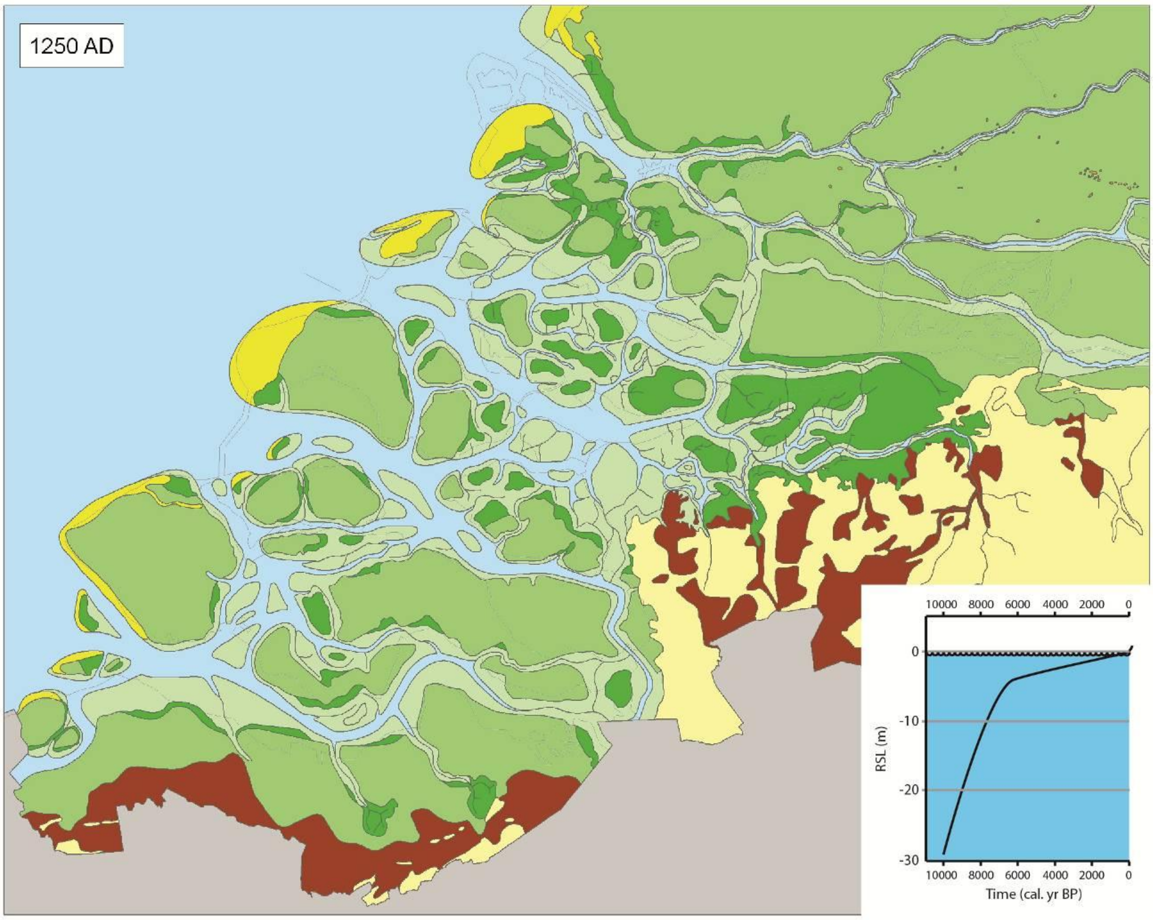


Figure C.13 Reconstruction of the geography of the Southwest Delta at about 1250 AD and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

These human interferences have influenced the tidal processes in the Netherlands considerably. The embankments decreased the storm surge accommodation space behind the tidal inlets drastically because during a storm the water couldn't flow out over the salt marshes. Instead, the water was forced up against the embankments during storms. Peat excavation and artificial drainage lowered the areas inside the embankments. As a result of the higher storm surge levels and lowering of the surface inside the embankments, floods caused by dyke breaches became catastrophic. Except for these storm surge heights, also social-economical and political factors, leading to bad maintenance, played a role in these dyke breaches.

The first long lasting land losses occurred in the oldest peat polders on the islands of South Holland. Disastrous storm surges also caused large land loss in central Zeeuws Vlaanderen (1375/1376 and 1404 AD), the Groote Waard in South Holland (1421 AD) and Het Verdronken land van Zuid-Beveland (1530 AD). The drowning of the peat polders at Saeftinghe wasn't the result of storm disasters, but were inundated on purpose as part of a military defense strategy to defend Antwerp in the Eighty Years' War.

The polders that have been lost partly or completely are mainly the polders with a peat surface, or peat covered by a thin layer of clay. In these areas, human activities had lowered the polders' surface so much that a large tidal volume became available, and as a result, large tidal channels that couldn't be repaired back in medieval times. The land loss however, was more than compensated by the reclamation of new-formed salt marshes.

The large storm surge disaster of 1530 AD in Beveland was of large impact for the course of the river Scheldt (Figure C.14). Until 1530 AD, the main course was still through the Oosterschelde. However, the tidal system of the Westerschelde came in contact with the river Scheldt and a large continuous estuary north of Saeftinghe was created. The Westerschelde took over the discharge of the river Scheldt, and the slack-water area between the Oosterschelde and the Westerschelde shifted. This shift resulted in the fast silting up of the Scheldt river channel and emergence of the slack-water area (Figure C.15).

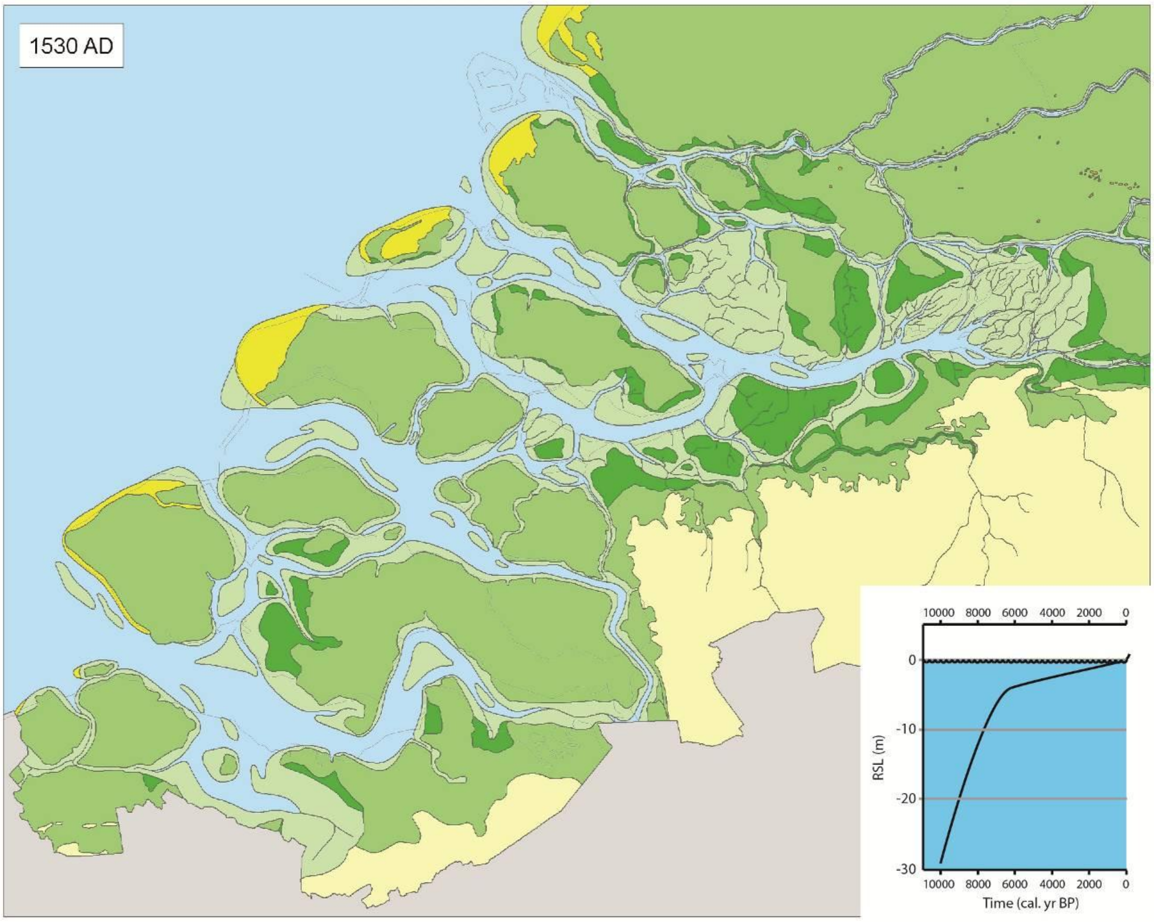


Figure C.14 Reconstruction of the geography of the Southwest Delta at about 1530 AD and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

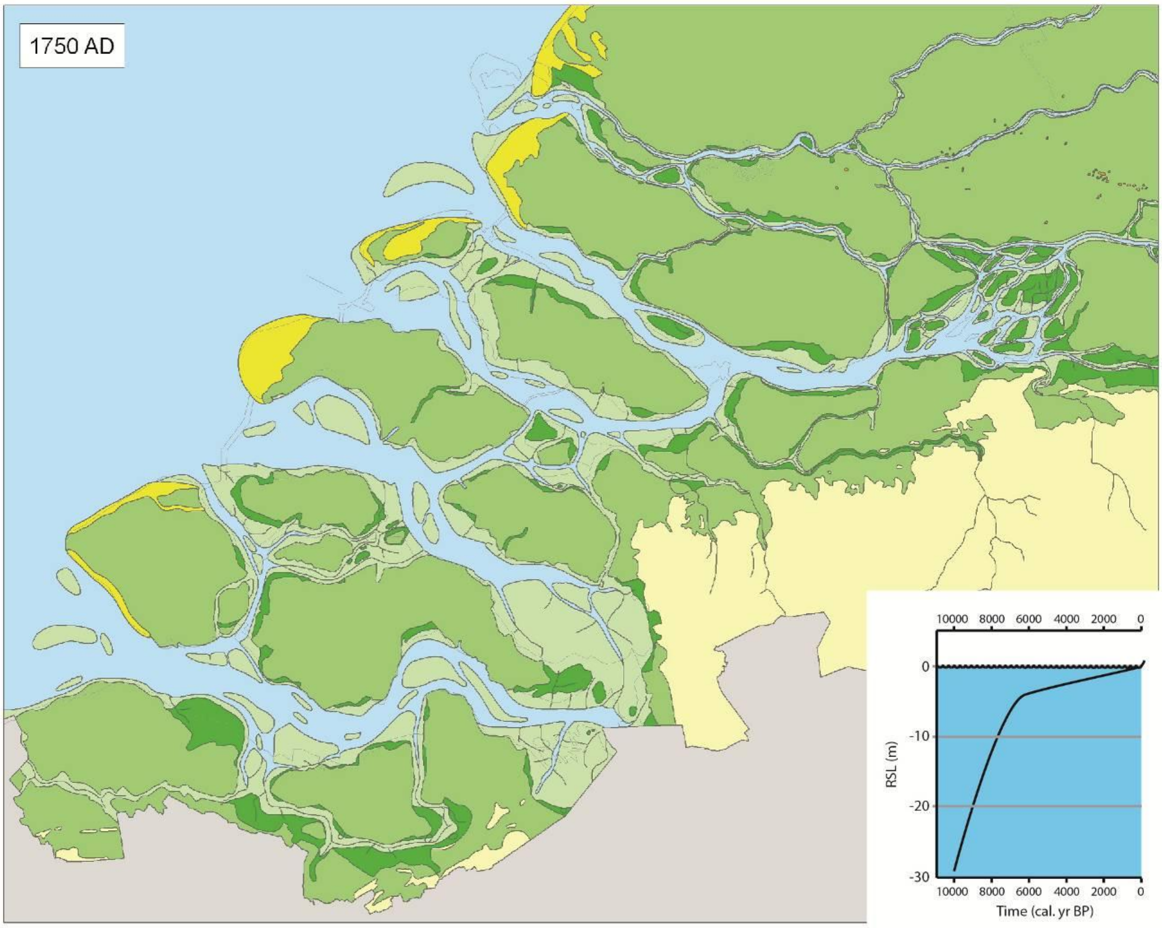


Figure C.15 Reconstruction of the geography of the Southwest Delta at about 1750 AD and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

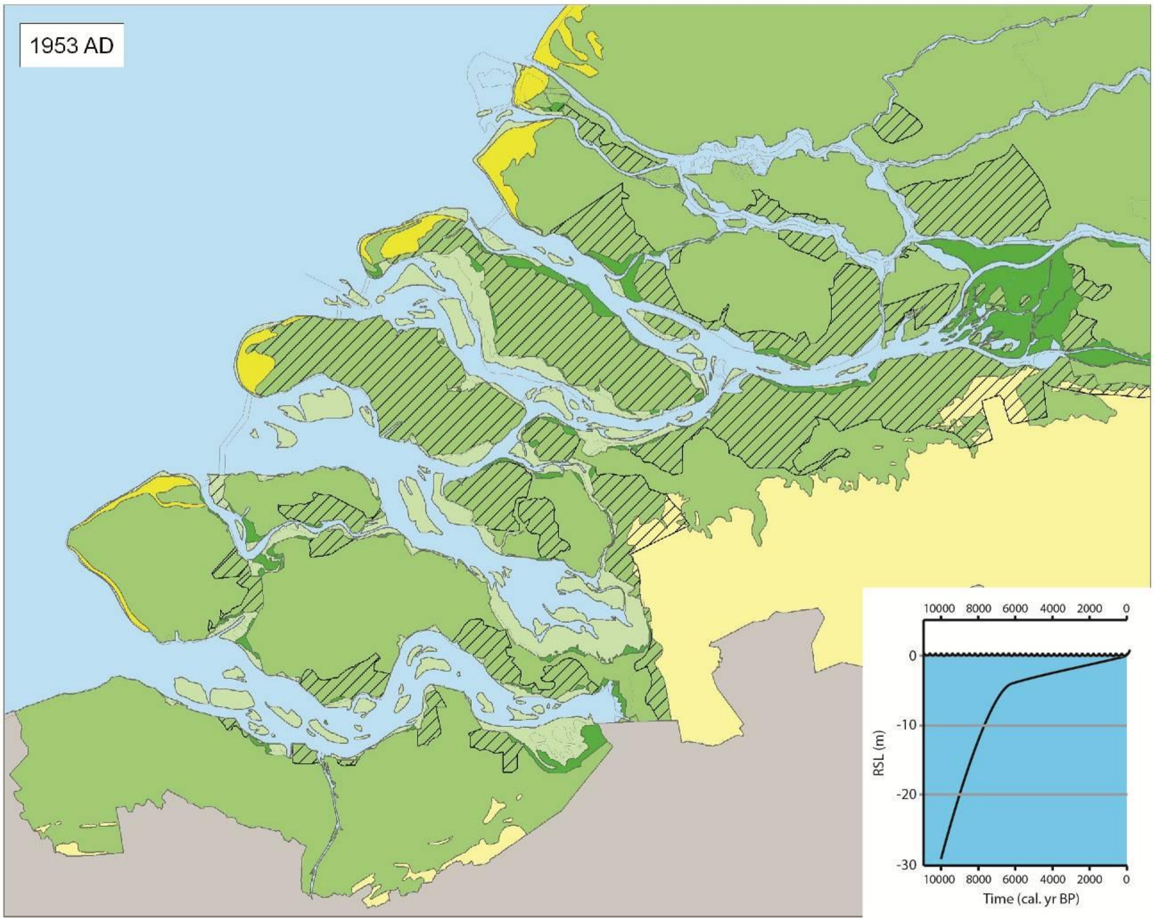


Figure C.16 Geography of the Southwest Delta at about 1953 AD showing the inundated areas and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

C.6 Lessons from the paleogeographical development of the Southwest Delta

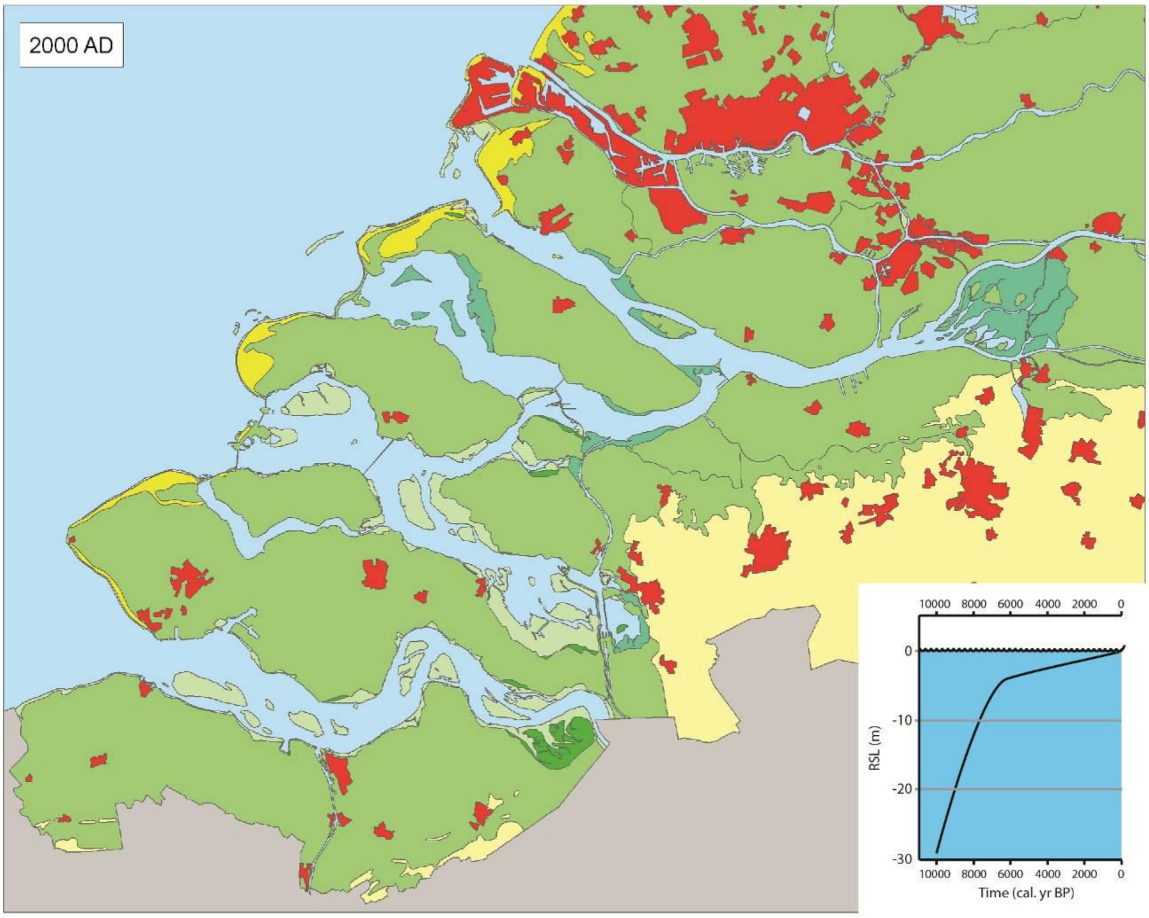


Figure C.17 Geography of the present Southwest Delta showing the inundated areas and an indication of the relative sea-level at that time (lower right panel; After Vos et al., 2002; Vos and Van Heeringen, 1997).

The paleogeographical development of the area shows that the Southwest Delta has developed as a dynamic coastal system under conditions of rising sea-level. Although the sea-level was rising, the area expanded seaward. Therefore, the paleogeographical development can provide important information about how to utilize natural processes to influence the system and create a resilient Southwest Delta under conditions of rising sea-level that is sustainable on the long term. The last centuries of land reclamation resulted in fixing the system into its present static state. Because such a static state is less resilient to high impact natural events (e.g. due to land surface subsidence), the susceptibility to a disaster increased. The last prove of which is the North Sea flood of 1953 (Figure C.16), but this flood was preceded by many others in the centuries before.

In response to the 1953 flood, the Delta Works were constructed (Figure C.17). However, outside the reclaimed land, conditions continue to change as they always have. In that respect the autonomous changes such as relative sea-level rise and changing river discharge are nothing new. In the past 50 years we have learned that the Delta Works have led to a safer Southwest Delta, but that the measures had several unanticipated side effects. Most individual basins have problems mainly resulting from loss of dynamics, which has also resulted into in a decrease in (natural) resilience of the system.

Important lessons that can be learned from the paleogeographic development are:

- The paleogeographical development of the area shows that the balance between sediment supply and sediment demand have controlled the development of the area. With a fast rising sea-level, sediment supply could not keep up with the increasing sediment demand, and the area developed transgressively. When the sea-level rise started to diminish, the sediment supply surmounted the demand, and the area developed seaward.

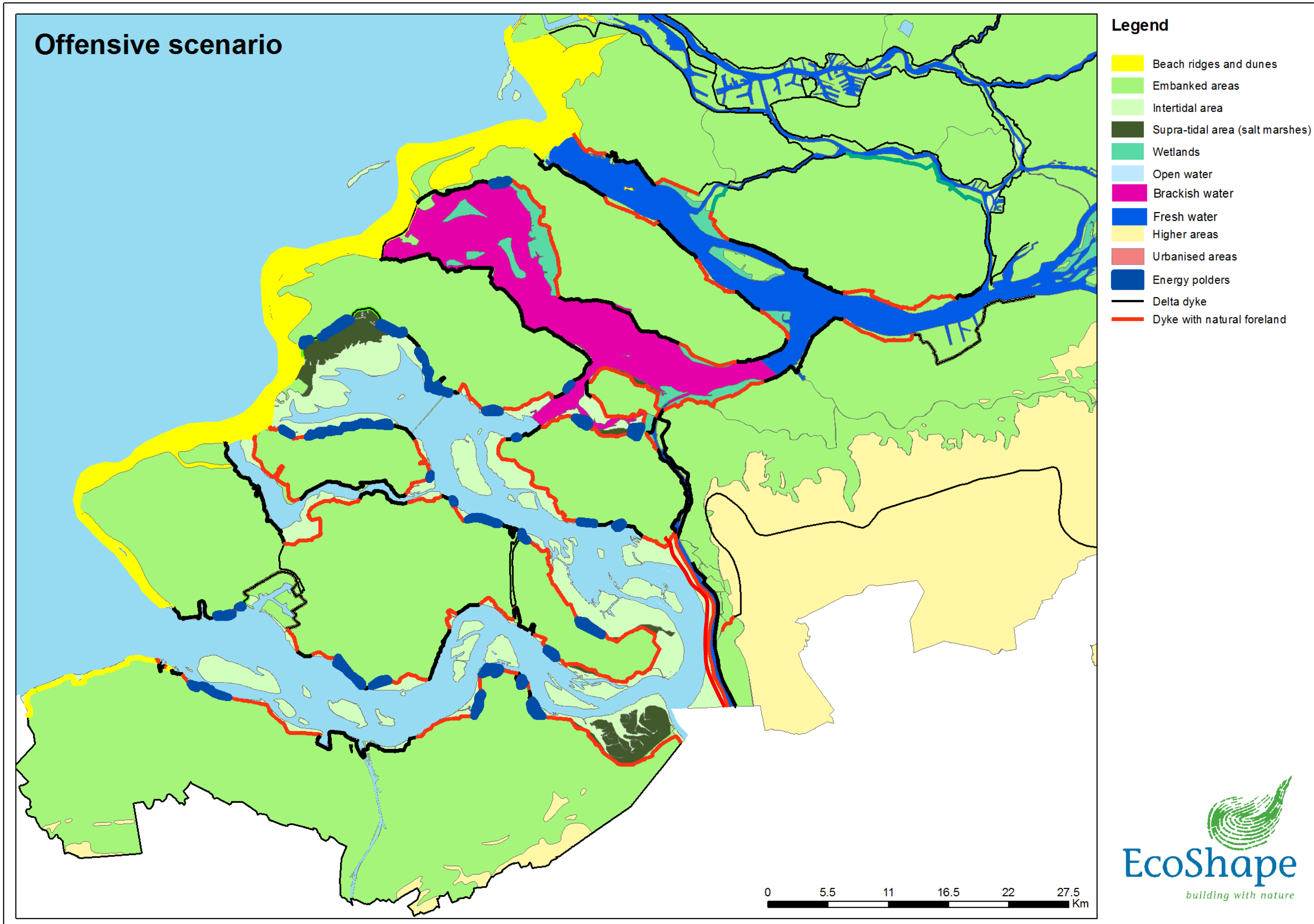
- The transgressive (landward shift) and regressive (seaward shift) phases were accompanied by feedback cycles between accommodation space, tidal prism, tidal channel flow velocities and sediment availability.

- Sediment accommodation space in fresh- and brackish water areas without sediment supply from coastal or fluvial processes was filled in by peat accumulation.

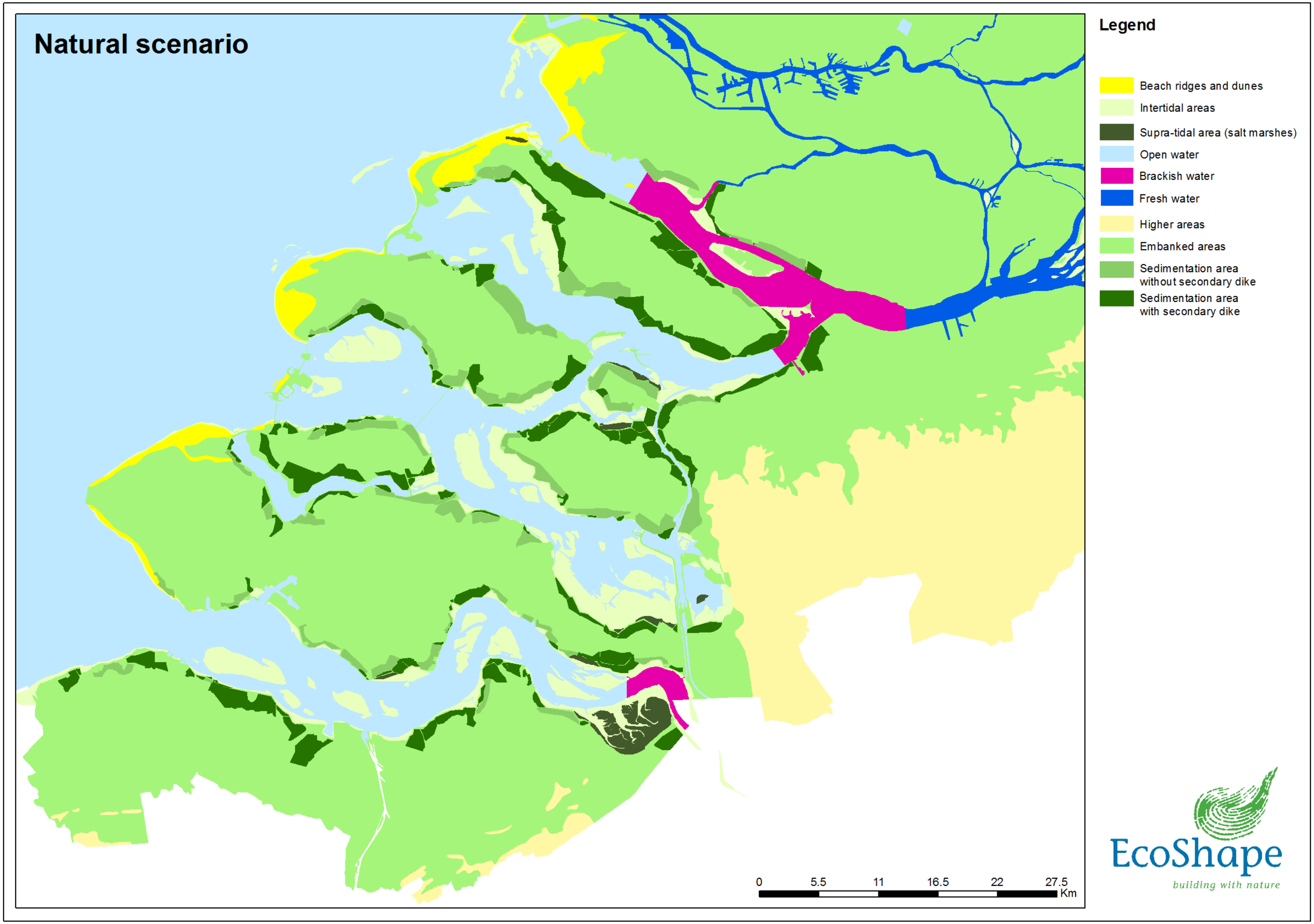
- Human interferences in the natural sedimentary system, especially ones increasing the accommodation space, can result in catastrophic floods.

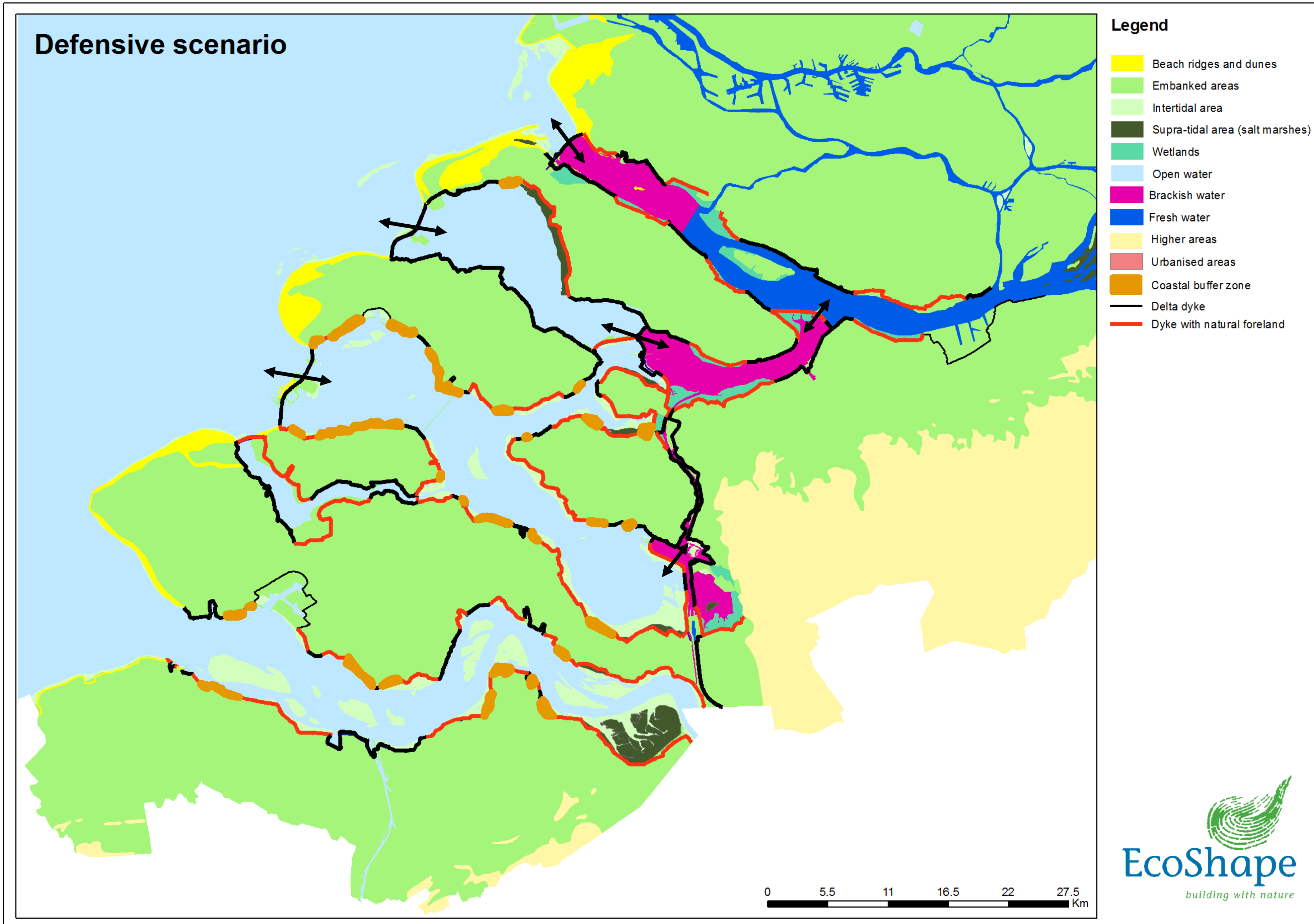
- The most valuable and largest natural areas (Biesbosch, Land van Saeftinghe) are former polders that were inundated.

D Extreme Scenarios



Offensive scenario
Legend
Beach ridges and dunes
Embanked areas
Intertidal area
Supra-tidal area (salt marshes)
Wetlands
Open water
Brackish water
Fresh water
Higher areas
Urbanised areas
Energy polders
Delta dyke
Dyke with natural foreland
0
5.5
11
16.5
22
27.5
Km
EcoShape
building with nature


Natural scenario
Legend
Beach ridges and dunes
Intertidal areas
Supra-tidal area (salt marshes)
Open water
Brackish water
Fresh water
Higher areas
Embanked areas
Sedimentation area without secondary dike
Sedimentation area with secondary dike
0
5.5
11
16.5
22
27.5
Km
EcoShape
building with nature



Defensive scenario
Legend
Beach ridges and dunes
Embanked areas
Intertidal area
Supra-tidal area (salt marshes)
Wetlands
Open water
Brackish water
Fresh water
Higher areas
Urbanised areas
Coastal buffer zone
Delta dyke
Dyke with natural foreland
0
5.5
11
16.5
22
27.5
Km
EcoShape
building with nature

E Summary sediment workshop Natural Scenario (Dutch)

De Zuidwestelijke Delta zonder dammen, oplossing voor de lange termijn?
Discussie over de hydro-morfologische haalbaarheid van een Zuidwestelijke Delta zonder dammen en met sedimentatie gebieden als oplossing voor de lange termijn veiligheid.

Delft, 8 november 2011
Aanwezig: Anneke Hibma (Ecoshape, Van Oord), Albert Oost (Deltares), Zhengbing Wang (Deltares, Thijs van Kessel (Deltares), Luca van Duren (Deltares), Laura Uunk (Ecoshape, Van Oord), Tom Ysebaert (Imares Wageningen UR), Jebbe van der Werf (Deltares), Marijn Tangelder (Imares Wageningen UR)

Inleiding
Het programma **Building with Nature** onderzoekt gebruik van dynamiek van het natuurlijke systeem bij het ontwikkelen van water-gerelateerde infrastructuur. Hierbij gaat het om het slim benutten van water stroming, getij en sedimentatie en erosie.
In de **case Zuidwestelijke Delta** onderzoeken we onder andere oplossingsrichtingen voor de lange termijn (2100) gebruik makend van “Building with Nature maatregelen” dus met name gericht op vrijgeven en benutten van natuurlijke waterbeweging en sedimentatie ten behoeve van veiligheid en gebruik. In dit kader verkennen we verschillende “extreme scenario’s” voor de Zuidwestelijke Delta met als doel uiteindelijk tot een realistische denkrichting te komen.
De workshop spitst zich toe op een van deze extreme scenario’s: het “**natuurlijke scenario**”. Dit scenario is erop gericht om in extreme mate natuurlijke dynamiek weer toe te laten, maar wel de veiligheid te blijven garanderen. Alle dammen worden verwijderd. Op plekken langs de kust waar geen voorlanden (slikken en schorren) aanwezig zijn om de golfaanval te dempen worden binnendijkse oplossingen onderzocht. Zo worden laaggelegen gebieden binnendijks ingericht als “sedimentatie gebied”. Door deze gebieden te ontpolderen ontvangen ze met elk getij sediment waardoor ze langzaam ophogen en er langs de kust een hoger gelegen zone ontstaat die meegroeit met de zeespiegel. Het natuurlijke scenario bestaat uit de volgende ingrepen:

- Alle deltawerken worden verwijderd-> volledig open verbinding tussen rivieren en zee’;
- Langs de kust worden binnendijkse zones van sedimentatie gebieden (groeilanden) aangelegd -> van kustlijn (dijken) naar kustzone (sedimentatie gebieden);
- Deltadijken op plekken waar geen binnendijkse ruimte is. Deltadijken zijn zodanig breed dat een doorbraak vrijwel uitgesloten is;
- Beschermen van buitendijkse slikken en schorren gebieden (voorlanden) voor de kust.

Tijdens de workshop geeft Marijn een korte toelichting van het natuurlijke scenario en het doel van de workshop. Hieronder volgen de belangrijkste bevindingen van de workshop.

Effecten verwijderen deltawerken en grootschalige beschouwing sedimentatiegebieden
Processen die door de aanleg van de Deltawerken in gang zijn gezet, zijn waarschijnlijk omkeerbaar, i.e. als alle Deltawerken worden verwijderd, streeft het systeem naar een nieuw evenwicht nagenoeg gelijk aan de situatie voorafgaand aan de aanleg.

- In de Oosterschelde is geen zandhonger meer, doordat het getijvolume weer maximaal is door een volledig open verbinding met de Noordzee.
- De Oosterschelde was voor de deltawerken een zand exporterend systeem, waarschijnlijk wordt het dat weer als je de deltawerken weer verwijderd.

- De Voordelta's van de verschillende getijdenbekkens beïnvloeden elkaar.
- De Voordelta's hebben over het algemeen sediment verloren door de aanleg de Deltawerken. Als deze verwijderd worden, worden ze naar alle waarschijnlijkheid weer aangevuld met sediment uit de geulen in de bekkens, maar misschien ook met zand van de kust (kusterosie).
- Het grootste deel van het sediment in de delta wordt aangevoerd vanuit zee en in mindere mate vanuit de rivieren.
- In het Haringvliet en Hollandsch Diep wordt vervuild slib gemobiliseerd wat daar in de jaren 70' op de bodem is afgezet en vervolgens geconsolideerd is. De mate van consolidatie zal bepalen hoe snel erosie optreedt van deze lagen.
- Waarschijnlijk heeft het verwijderen van de Deltawerken een grotere impact dan het aanleggen van de opslibgebieden.
- Door de aanleg van de opslibgebieden zal de komberging toenemen. Volgens de theorie van Friedrichs & Aubrey (1988) betekent dit een afname van de vloeddominantie cq. een toename van de eb-dominantie en hierdoor, mogelijkerwijs, een afname van de import cq. een toename van de export van sediment.
- Sedimentgehaltes: in de Westerschelde is dit ~50 mg/l. Bij het openen van de andere bekkens is een sedimentlading van ~20 mg/l te verwachten. Op de vooroever kan dit gauw oplopen tot ~100 mg/l. Er stroomt ~10-20 Mm^3 slib per jaar door de "kustrivier".

Effecten sedimentatie gebieden

- Minder golfoploop (rapport WUR golfreducerende werking kwelders -> Albert).
- Minder "piping" door bredere overgang tussen buitendijks-binnendijks.
- Minder zoute kwel binnendijks door langere kwelweg.

Aanbevelingen

Haalbaarheid sedimentatiegebieden: waarschijnlijk is er voldoende sediment beschikbaar om de voorgestelde sedimentatiegebieden te laten opslibben. Raadzaam is wel om niet alle gebieden tegelijk te ontpolderen vanwege de beperking in sedimentaanbod, maar stapsgewijs waardoor opslibbing relatief sneller gaat. Mogelijkheid is om een deel van de gebieden te ontpolderen en andere gebieden eerst te laten vervenen door het waterpeil te verhogen (creëren rietmoerassen) en later te ontpolderen. De verwachting is dat sedimentatie (veenvorming) sneller gaat als er al een veenpakket ligt. Bovendien ontstaat zo een luwtezone ("gekartelde oever") wat de aanslibbing versneld.
Bij selectie van sedimentatiegebieden moet bekeken worden of er een veenpakket in de ondergrond aanwezig is. Als dit gebied onderwater gezet wordt zal daarbij extra inklinking van de bodem optreden.
Zoetwaterverdeling: effecten op de zoetwaterverdeling in Nederland meenemen. Het verwijderen van de Haringvlietdam beïnvloedt de zoetwaterverdeling van de Randstad. Grote hoeveelheden zoet water worden daar heen gestuurd om "door te spoelen" om zout tegen te gaan en vanwege zoetwater voorziening (landbouw+drinkwater). Ook zou het zoet water afvoerproblemen kunnen veroorzaken in Rotterdam en Dordrecht tijdens piekafvoeren.
Binnendijkse kwel: meenemen invloed sedimentatiegebieden op binnendijkse kwel. Mogelijk vermindert de kwel door de langere kwelweg tussen de zee en de polder en minder piping onder de dijk. -> meer informatie: Gualbert Oude Essink (Deltares).
Veiligheid Biesbosch: de veiligheid van de Biesbosch is nu niet meegenomen in het natuurlijke scenario. Voor de MKBA moet hier wel rekening mee gehouden worden t.o.v. het Defensieve en Offensieve scenario. In het natuurlijke scenario zal je maatregelen moeten treffen om de Biesbosch veilig te houden en in de andere scenario's niet.

Ontwerp sedimentatiegebieden:

- Geulen/kreken:
  - uitgraven voormalige kreekpatronen
  - “voorgraven” kreekbeginselen die georiënteerd liggen in de richting van het getij zodat het zeewater gemakkelijk naar binnen stroomt.
  - Het is van belang dat er een verhang zeewaarts is zodat het water tijdens laagwater goed kan weglopen. In beoogde sedimentatie gebieden waar het gebied richting het land afloopt vereist dit dus nog graafwerkzaamheden.
- Hoogteligging: hoe lager het sedimentatiegebied ligt, hoe sneller het zal opslibben. Gebieden boven GHWS zullen niet verder opslibben.
- Instroom:
  - “slibluik” zoals in Lippenbroek
  - Eén of meerdere openingen in de zeedijk.
  - Het verlagen van de zeedijk of het maken van een overstromingsdrempel geeft geen meerwaarde voor wat betreft opslibben omdat dit de invoer van sediment belemmert.
  - Belangrijk uitgangspunt is dat je het hele sedimentatiegebied wil laten onderlopen bij hoogwater en een luwte wilt creëren zodat het sediment in het water kan neerslaan in het sedimentatiegebied.
  - er zijn verschillende mogelijkheden en maatwerk is hierbij belangrijk. De werking van verschillende vormen kan per gebied verschillen.

- Combinatie met zandmotor nabij instroom: dit zal het beste werken in een dynamisch deel waar veel transport kan plaatsvinden. Door suppletie van fijn zand nabij de instroomopening zou opslibbing sneller kunnen gaan.

  Overige opmerkingen

  - Presentatie en terminologie zijn van belang; zaken liggen gevoelig in het Zeeuwse (cf Hedwigepolder).
  - Inrichting opslibgebieden hoeft niet per se te worden geoptimaliseerd in termen van sedimentatiesnelheid; dit hangt af wat je wilt. Het kan ecologisch interessanter zijn om het juist langzamer aan te laten slibben.
  - Gebieden langs het Veerse meer zijn misschien minder interessant als opslibgebied, omdat er wellicht te weinig sediment door de smalle opening komt.

  Concrete acties

  - Bepalen waar veen ligt onder potentiële opslibgebieden (Ane Wiersma?)
  - Bepalen areaal ingetekende opslibgebieden-> Marijn
  - Literatuurstudie ervaring ontpolderingen in NL (Sieperda schor) en UK (?)

Uitvoeren enkele verkennende berekeningen naar potentie opslibgebieden, waarbij het % slib dat afgezet wordt als onzekere factor moet worden meegenomen.

F Sedimentation areas: measures, salinity elevation and accretion rate

Name	Basin code	Second dike?	Salinity	Perimeter (m)	Area (ha)	Mean elevation (m-NAP)	Accreation rate (cm/yr)
Polder Zuiderland	Grevelingen East	ja	zout	8853	226.3	0.583	1
Polder Battenoord	Grevelingen East	ja	zout	9077	358.2	0.256	1
Sir Jansland	Grevelingen East	nee	zout	5566	149.2	0.133	1
Herkingen2	Grevelingen East	nee	zout	10940	491.7	0.183	1
Phlip1	Grevelingen East	nee	zout	13185	424.6	1.1	1
Nieuw Bommenend	Grevelingen West	ja	zout	6842	264.7	0.525	1
Polder Kijkuit	Grevelingen West	ja	zout	4116	84.4	0.4	1
Brouwerhaven2	Grevelingen West	ja	zout	736	1.5	0.067	1
Grabiëllina	Grevelingen West	ja	zout	3887	60.2	0.8	1
Ouddorp	Grevelingen West	ja	zout	5596	15.8	0.2	1
Brouwerhaven	Grevelingen West	ja	zout	2198	19.6	0.267	1
Polder Nieuw-Stelle	Grevelingen West	ja	zout	9917	195.0	1.233	1
Polder Diederik	Grevelingen West	ja	zout	10463	283.0	1.07	1
Kleine Zuiderpolder	Grevelingen West	ja	zout	3656	45.7	0.65	1
Polder Roxenisse	Grevelingen West	ja	zout	5695	192.7	0.633	1
Preekhilpolder	Grevelingen West	ja	zout	2652	30.2	1.367	1
Ouddorp3	Grevelingen West	nee	zout	5085	147.3	0.256	1
Polder Oud Westerl	Grevelingen West	nee	zout	5824	177.0	0.533	1
Brouwershaven	Grevelingen West	nee	zout	2073	14.5	0.4	1
Scharendijke	Grevelingen West	nee	zout	5263	91.7	-1.6	1
Herkingen	Grevelingen West	nee	zout	8820	391.9	0.267	1
Ouddorp2	Grevelingen West	nee	zout	1784	18.5	0.933	1
Ouddorp0	Grevelingen West	nee	zout	4207	61.3	0.9	1
Dreischor	Grevelingen West	nee	zout	15539	869.0	0.033	1
Schuilhoek	Haringvliet	ja	brak	4740	94.9	0.156	1
Polder Oude Stad	Haringvliet	ja	brak	7903	304.5	0.311	1
Leenherenpolder	Haringvliet	ja	brak	13775	274.1	0.1	1
Polder het Rietveld	Haringvliet	ja	brak	6257	91.1	0.344	1
St Antoniegorzen	Haringvliet	ja	brak	4416	100.5	0.656	1
Polder Nieuwe Stad	Haringvliet	ja	brak	4527	102.8	0.044	1
Oostplaat Flakkee	Haringvliet	ja	brak	11498	469.1	0.8	1

Name	Basin code	Second dike?	Salinity	Perimeter (m)	Area (ha)	Mean elevation (m-NAP)	Accreation rate (cm/yr)
Hv3	Haringvliet	ja	brak	5238	147.5	0.344	1
Zuiderdiep	Haringvliet	ja	zout	9619	133.1	1.188	1
Scheelhoek	Haringvliet	ja	zout	18508	924.3	0.633	1
HV1	Haringvliet	nee	brak	11831	366.3	-0.144	1
HV2	Haringvliet	nee	brak	6423	82.5	-0.344	1
den bommel	Haringvliet	nee	brak	6675	128.9	-0.667	1
Oudenhoorn	Haringvliet	nee	zout	13744	470.8	-0.23	1
vzm	Krammer-Volkerak	ja	brak	10621	489.4	0.467	1
Drievriendenpolder	Krammer-Volkerak	ja	zout	9320	205.7	0.933	1
Heerenpolder3	Krammer-Volkerak	ja	zout	2349	32.0	0.91	1
Leguit	Krammer-Volkerak	ja	zout	5953	138.0	0.5	1
Hikkepolder	Krammer-Volkerak	ja	zout	6338	233.0	0.533	1
Eendrachtspolder	Krammer-Volkerak	ja	zout	9663	258.4	0.55	1
Hendrikpolder	Krammer-Volkerak	ja	zout	7511	252.2	2.175	1
Dintelpolder	Krammer-Volkerak	ja	zout	5043	91.0	0.633	1
Heerenpolder2	Krammer-Volkerak	ja	zout	3485	53.1	4.4	1
Groote Adriane The	Krammer-Volkerak	ja	zout	12843	521.7	0.456	1
Anna Wilhelminapo	Krammer-Volkerak	ja	zout	12720	561.6	0.956	1
Oud Vossemeer	Krammer-Volkerak	ja	zout	2970	38.7	0.6	1
Eendrachtpolder	Krammer-Volkerak	ja	zout	6886	172.5	1.233	1
Hollare polder	Krammer-Volkerak	ja	zout	9544	287.0	1.167	1
Joanna Maria	Krammer-Volkerak	ja	zout	6934	143.6	1.3	1
Van Haaftenpolder	Krammer-Volkerak	ja	zout	4002	111.1	1.283	1
Rammegors	Krammer-Volkerak	ja	zout	4866	146.1	1.517	1
tholen	Krammer-Volkerak	ja	zout	4407	63.8	1.6	1
tholen	Krammer-Volkerak	nee	zout	8870	184.2	-0.383	1
Wemeldinge	Oosterschelde East	ja	zout	5705	45.3	-0.233	1
Mosselhoek	Oosterschelde East	ja	zout	4232	77.6	0.225	1
Tholen1	Oosterschelde East	ja	zout	1924	11.0	-1.367	1
Stroodorpepolder	Oosterschelde East	ja	zout	2481	35.3	0.967	1
Bathpolderweg	Oosterschelde East	ja	zout	2105	21.4	4.2	1

Name	Basin code	Second dike?	Salinity	Perimeter (m)	Area (ha)	Mean elevation (m-NAP)	Accreation rate (cm/yr)
Muijepolder	Oosterschelde East	ja	zout	4522	52.6	1	1
Tweede Bathpolder	Oosterschelde East	ja	zout	9273	274.7	1.167	1
Nieuwelandepolder	Oosterschelde East	ja	zout	4802	99.3	0.838	1
Kanaal door ZB	Oosterschelde East	ja	zout	2290	15.3	0.867	1
Sint Pieterpolder	Oosterschelde East	ja	zout	5084	82.3	0.767	1
Het Sas	Oosterschelde East	ja	zout	4056	81.2	1.1	1
Tholen2	Oosterschelde East	ja	zout	1944	22.4	-0.275	1
Roelshoek	Oosterschelde East	ja	zout	2462	32.0	0.667	1
Reimerswaal	Oosterschelde East	ja	zout	7372	228.3	1	1
Halsteren	Oosterschelde East	nee	zout	10867	499.7	0.817	1
Tholen	Oosterschelde East	nee	zout	5873	162.3	1.117	1
Tholen3	Oosterschelde East	nee	zout	7735	232.8	-0.967	1
Kattendijke	Oosterschelde East	nee	zout	6776	193.8	-0.233	1
Het Sas	Oosterschelde East	nee	zout	5083	59.1	1.2	1
Goes	Oosterschelde East	nee	zout	8251	331.8	1.1	1
Kanaal door ZB	Oosterschelde East	nee	zout	6733	161.3	0.225	1
Gorishoek	Oosterschelde East	nee	zout	3753	64.6	-0.65	1
Sint-maartensdijk	Oosterschelde East	nee	zout	13592	390.2	0.033	1
Poortvliet	Oosterschelde East	nee	zout	10244	277.0	-1.267	1
vm	Oosterschelde East	nee	zout	9303	248.9	2.267	1
Westbout	Oosterschelde West	ja	zout	1551	10.1	0.533	1
Katse Heule	Oosterschelde West	ja	zout	2335	31.7	0.8	1
Wevers- en Flaauwe	Oosterschelde West	ja	zout	4713	64.4	-0.933	1
Roompot	Oosterschelde West	ja	zout	2272	12.0	1.667	1
Kisters inlaag	Oosterschelde West	ja	zout	2037	15.0	-1.6	1
Zierikzee2	Oosterschelde West	ja	zout	3676	70.7	-1.1	1
Burghsluis-Schelper	Oosterschelde West	ja	zout	5832	83.3	-1.4	1
Wissenkerke2	Oosterschelde West	ja	zout	1569	10.3	0.7	1
Colijnsplaat2	Oosterschelde West	ja	zout	3244	25.9	0.85	1
Katse Heule 2	Oosterschelde West	ja	zout	5125	65.8	1.133	1
Bruinisse1	Oosterschelde West	ja	zout	1712	8.8	-0.133	1

Name	Basin code	Second dike?	Salinity	Perimeter (m)	Area (ha)	Mean elevation (m-NAP)	Accreation rate (cm/yr)
Colijnsplaat1	Oosterschelde West	ja	zout	2655	22.0	0.3	1
Ouwerkerk	Oosterschelde West	ja	zout	3117	35.5	-1.133	1
Zeelandbrug 1	Oosterschelde West	ja	zout	633	2.1	-1.3	1
Stavenisse2	Oosterschelde West	ja	zout	991	5.3	0.6	1
Stavenisse1	Oosterschelde West	ja	zout	3108	39.4	1	1
Wissekerke3	Oosterschelde West	ja	zout	5422	130.4	0.833	1
Anna vosdijk polder	Oosterschelde West	ja	zout	7383	260.1	0.65	1
Suzannapolder	Oosterschelde West	ja	zout	3548	56.1	0.667	1
Anna Vosdijk polder	Oosterschelde West	ja	zout	3556	44.7	0.967	1
Kats2	Oosterschelde West	ja	zout	4827	101.6	1.067	1
Oud Kempershofste	Oosterschelde West	ja	zout	6747	242.4	0.751	1
Zierikzee 3	Oosterschelde West	ja	zout	3399	38.6	1.033	1
Bruinisse2	Oosterschelde West	ja	zout	10239	408.0	0.429	1
Zierikzee1	Oosterschelde West	ja	zout	1410	10.8	-1.5	1
StPhillipsland	Oosterschelde West	ja	zout	3090	55.0	1.133	1
Roompot2	Oosterschelde West	ja	zout	3684	67.8	1.4	1
Kats1	Oosterschelde West	ja	zout	1066	4.8	1.25	1
Roompot	Oosterschelde West	ja	zout	4009	64.5	0.933	1
Wissenkerke1	Oosterschelde West	ja	zout	1411	10.5	0.8	1
Roompot2	Oosterschelde West	ja	zout	556	1.1	2.3	1
Colijnsplaat3	Oosterschelde West	ja	zout	1818	9.8	0.4	1
Ouwerkerk2	Oosterschelde West	ja	zout	7104	238.8	0.433	1
Schelphoek	Oosterschelde West	ja	zout	7329	242.9	-0.64	1
vm1	Oosterschelde West	ja	zout	4811	87.5	1.067	1
vm2	Oosterschelde West	ja	zout	5996	117.1	1.233	1
vm3	Oosterschelde West	ja	zout	3186	36.0	0.87	1
vm4	Oosterschelde West	ja	zout	2764	31.1	1.6	1
vm5	Oosterschelde West	ja	zout	12245	157.4	0.533	1
vm6	Oosterschelde West	ja	zout	3588	54.8	0.9	1
Vm	Oosterschelde West	ja	zout	8402	228.1	1.333	1
vm1	Oosterschelde West	ja	zout	19771	926.9	0.7	1

Name	Basin code	Second dike?	Salinity	Perimeter (m)	Area (ha)	Mean elevation (m-NAP)	Accreation rate (cm/yr)
vm2	Oosterschelde West	ja	zout	8376	238.3	0.9	1
Wissekerke	Oosterschelde West	nee	zout	4366	102.6	0.833	1
Wolphaartsdijk	Oosterschelde West	nee	zout	4765	95.1	0.467	1
Kleverskerke	Oosterschelde West	nee	zout	4085	95.3	-0.24	1
Veere	Oosterschelde West	nee	zout	7685	121.6	0.667	1
Westerschenge	Oosterschelde West	nee	zout	5565	149.1	0.8	1
Oranjeplaat	Oosterschelde West	nee	zout	3734	62.1	0.967	1
Burghsluis2	Oosterschelde West	nee	zout	1937	20.2	0.233	1
Zierikzee2	Oosterschelde West	nee	zout	4605	90.4	-1.267	1
Westerschouwen 2	Oosterschelde West	nee	zout	5825	115.3	-1.03	1
Westerschouwen 3	Oosterschelde West	nee	zout	6127	174.8	-1.133	1
Westerschouwen_1	Oosterschelde West	nee	zout	3284	52.5	-0.26	1
Kerwerve	Oosterschelde West	nee	zout	7315	136.1	-1.133	1
Phlip2	Oosterschelde West	nee	zout	6046	193.1	1.15	1
Phlip3	Oosterschelde West	nee	zout	8226	223.1	0.733	1
Zierikzee 3	Oosterschelde West	nee	zout	6797	225.9	-0.733	1
Wissekerke2	Oosterschelde West	nee	zout	4651	106.3	0.825	1
Ouwerkerk	Oosterschelde West	nee	zout	10618	332.1	-0.3	1
SintPhillipsland	Oosterschelde West	nee	zout	3107	29.3	1.067	1
Stavenisse	Oosterschelde West	nee	zout	8340	153.1	0.867	1
Oosterland	Oosterschelde West	nee	zout	8733	240.2	-0.367	1
colijnsplaat1	Oosterschelde West	nee	zout	8154	240.1	1.267	1
Colijnsplaat2	Oosterschelde West	nee	zout	8603	208.5	0.9	1
Burghsluis	Oosterschelde West	nee	zout	5274	66.7	-0.73	1
Bath	Westerschelde Oost	ja	brak	3224	40.1	-0.3	1.5
Oude Doel	Westerschelde Oost	ja	brak	7131	304.0	1.567	1.5
Rilland	Westerschelde Oost	ja	brak	9517	233.8	1.5	1.5
Rilland2	Westerschelde Oost	ja	brak	7482	313.7	1.333	1.5
nisse	Westerschelde Oost	ja	zout	4990	115.5	0.925	1.5
Veer Walsoorden	Westerschelde Oost	ja	zout	1851	19.6	0.5	1.5
Gawege	Westerschelde Oost	ja	zout	5658	99.1	1.367	1.5

Name	Basin code	Second dike?	Salinity	Perimeter (m)	Area (ha)	Mean elevation (m-NAP)	Accreation rate (cm/yr)
Kreverhille	Westerschelde Oost	ja	zout	1996	22.6	0.95	1.5
Molenpolder	Westerschelde Oost	ja	zout	3035	47.3	0.867	1.5
Kleine huissenspolc	Westerschelde Oost	ja	zout	5284	154.2	1.175	1.5
Waarde	Westerschelde Oost	ja	zout	2542	28.2	0.2	1.5
Walsoorden	Westerschelde Oost	ja	zout	2779	30.1	0.607	1.5
Eversdijk	Westerschelde Oost	ja	zout	8330	289.1	0.5	1.5
Margarethapolder	Westerschelde Oost	ja	zout	6397	235.8	0.833	1.5
s'Gravenpolder1	Westerschelde Oost	ja	zout	1050	6.7	1	1.5
s'Gravenpolder2	Westerschelde Oost	ja	zout	1452	11.3	0.85	1.5
Ellewoutsdijk3	Westerschelde Oost	ja	zout	706	2.5	0.033	1.5
Tienhonderdpolder	Westerschelde Oost	ja	zout	6633	205.7	1.167	1.5
Nieuwvliet-bad	Westerschelde Oost	ja	zout	1891	18.9	1.6	1.5
Hoedekenskerke	Westerschelde Oost	ja	zout	2511	8.9	-1.25	1.5
Ellewoutsdijk	Westerschelde Oost	ja	zout	3390	29.3	1.8	1.5
Zuidpolder	Westerschelde Oost	ja	zout	4585	87.1	1.033	1.5
knuitershoek	Westerschelde Oost	ja	zout	1915	16.1	1.4	1.5
Ellewoutsdijk2	Westerschelde Oost	ja	zout	2303	21.2	1.2	1.5
Wilhelmuspolder	Westerschelde Oost	ja	zout	4054	73.0	0.667	1.5
Westdijk	Westerschelde Oost	ja	zout	4751	50.7	1.25	1.5
Everingepolder	Westerschelde Oost	ja	zout	4332	108.5	1.433	1.5
Knuitershoek	Westerschelde Oost	ja	zout	6616	248.7	0.15	1.5
Paal	Westerschelde Oost	ja	zout	2234	25.6	1.7	1.5
Hoedekenskerke	Westerschelde Oost	ja	zout	2350	18.4	-0.555	1.5
Hellegatpolder	Westerschelde Oost	ja	zout	5532	133.1	1.6	1.5
Karelpolder	Westerschelde Oost	ja	zout	5465	71.3	0.9	1.5
Rilland	Westerschelde Oost	nee	brak	7338	115.8	1.333	1.5
Hoedekenskerke	Westerschelde Oost	nee	zout	4586	40.4	0.666	1.5
Biezelinge	Westerschelde Oost	nee	zout	4957	76.3	0.367	1.5
Hoedekenskerke2	Westerschelde Oost	nee	zout	8645	206.0	0.075	1.5
Waarde	Westerschelde Oost	nee	zout	7340	126.6	0.1	1.5
Nieuwvliet	Westerschelde Oost	nee	zout	10602	241.5	0.733	1.5

G Cost – Benefit Analysis Spreadsheet

This appendix elaborates on the economic values or social benefits of the three sustainable scenarios for the Southwest Delta and describes how these benefits are determined in this study. Some benefits are described in the factsheets of the Building with Nature solutions (building blocks) which can be found in appendix B These costs and benefits are not separately discussed in this chapter.

G.1 Costs

G.1.1 Removal of dams

In the Natural scenario all dams and the Oosterscheldekering are removed to regain estuarine dynamics and natural processes. The costs of removing the Oosterscheldekering are calculated between the 1 and 2 billion euro's. For the cost-benefit calculations of the Natural scenario the average, 1,5 billion is used (RWS, 2008).

For the removal of the dams no costs were available. The costs of removal of the dams are therefore estimated by using the costs of creating an 800 meter culvert in the Brouwersdam (Witteveen + Bos (2008). Based on the available detailed report of the Brouwersdam average costs of € 40.000.000 are estimated for total removal of 1 kilometre dam.
The length and estimated costs of removal (in Million Euro) of the dams in the Southwest Delta are:

Oosterscheldekering	8 km	320
Oesterdam	10,5 km	420
Grevelingendam	6,0 km	240
Philipsdam	6,0 km	240
Brouwersdam	6,5 km	260
Zandkreekdam	0,8 km	32
Volkerakdam	4,5 km	180

G.1.2 Creation passage Overschelde and storm surge barrier at Zijpe

In the Offensive scenario, the delta basins serve as a long and broad estuary in which a gradual salt – fresh water transition takes place. The coastline is largely closed off, with the exception of the Westerschelde. To make sure all the basins are sufficiently connected to create such an estuary the Overschelde is created. The costs of this 4 x 4 km wide passage with an average depth of 5 meters are calculated1.570 million Euro (bron: De Nocker et al. (2004). Kosten en baten van de Overschelde, price level 2004).

The large amount of sediment that comes available by creating the Overschelde, approximately 80 Mm^3, is used for nourishments in the Offensive scenario. It is assumed that it takes about 5 years to create the Overschelde and in those years an average of 16Mm^3 is used for nourishments. This means a reduction in nourishment costs the first 5 years.

In periods with combined high river discharges and storm conditions a storm surge barrier is needed in the Offensive scenario. This barrier will be located at Zijpe. The construction costs of this barrier equal the investment costs of the Maeslantkering (EUR 450 million). The costs for maintenance of this storm surge barrier is about 1,5% of the investment costs annually.

G.1.3 Construction and maintenance Managed realignment

The factsheet managed realignment gives several examples of the costs of managed realignment (source: De Nocker et al, 2010). From this data it is clear that the costs of managed realignment depend on the scale of the project. Also the costs and maintenance of realizing managed realignment in polders with a secondary dyke differ from polders without such a dyke. To estimate the costs for realigning all polders in the entire Delta 6 different average costs were calculated.

- managed realignment of polders less than 75 ha with a secondary dyke
  - construction 369.249 € / ha
  - maintenance 5.044 € / ha / year
- managed realignment of polders less than 75 ha without a secondary dyke
  - construction 342.667 € /ha
  - maintenance 4.778 € / ha / year
- managed realignment of polders between 75 and 400 ha with a secondary dyke
  - construction 216.432 € / ha
  - maintenance 2.770 € / ha / year
- managed realignment of polders between 75 and 400 ha without a secondary dyke
  - construction 205.286 € / ha
  - maintenance 2.658 € / ha / year
- managed realignment of polders more than 400 ha with a secondary dyke
  - construction 196.605 € / ha
  - maintenance 1.981 € / ha / year
- managed realignment of polders more than 400 ha without a secondary dyke
  - construction 188.920 € / ha
  - maintenance 1.904 € / ha / year

The Natural scenario has 205 polders that are to be transformed into managed realignment. For each of these polders the area is determined and the cost categorization that it fits in (scale and secondary dyke).

G.1.4 Construction and maintenance Energy Polder

Examples of construction costs of energy polders are mentioned in the factsheet (bron: Haskoning 2009). The average costs for construction of energy polders are calculated from these examples. The average costs of €121.364 per hectare are used in the cost benefit analyses. Maintenance costs are 1,5% of the construction costs.

G.1.5 Loss of agricultural yields due to Managed Realignment or Energy Polders

In the factsheet Managed Realignment agricultural production loss is described based on the study from De Nocker et al (2010). The same loss also occurs when coastal buffer zones are used as energy polders.

G.1.6 Nourishments

There are no nourishments of the Delta in the Natural scenario, in the Defensive scenario ‘normal’ yearly sand nourishments are done and in the Offensive scenario the Delta is overly nourished. The Voordelta is nourished in all three scenarios. In the Defensive scenario normal nourishment of the Voordelta takes place, as in the Natural scenario. The volume of nourished sand (m^3 / year) of the Natural scenario is therefore taken from the calculations for the Defensive scenario. The Voordelta is also over-nourished in the Offensive scenario. In this scenario the Oosterscheldekering and Brouwersdam are turned into large dunes). For regular nourishments a sand price of 5,2 euro/ m3 is used (Witteveen+Bos, 2010). For the overly nourishments in the Offensive scenario the sand has to come from the North Sea and needs long transport. The costs of this sand is EUR 13,70/ m3 (Witteveen+Bos, 2010). In the next tables the sand volumes of the Offensive and Defensive scenario are presented.

Offensive scenario	**Volume per year (m3)**		
Climate scenario	35cm	50cm	85cm
Oosterschelde	1.850.000	2.000.000	2.350.000
Grevelingen	500.000	715.000	1.215.500
Volkerak/markiezaat	330.000	470.000	800.000
Haringvliet/Hollandsch diep	860.000	1.230.000	2.100.000
Veerse Meer	150.000	210.000	355.000
Voordelta + Westerschelde	12.200.000	17.400.000	29.800.000
Total	**15.890.000**	**22.025.000**	**36.620.500**

Defensive scenario	**Volume per year (m3)**		
Climate scenario	35cm	50cm	85cm
Oosterschelde	23.800	34.000	57.800
Grevelingen	3.920	5.600	9.520
Volkerak/markiezaat	0	0	0
Haringvliet/Hollandsch diep	0	0	0
Veerse Meer	6.440	9.200	15.640
Voordelta + Westerschelde	6.100.000	8.700.000	14.900.000
Total	**6.134.160**	**8.748.800**	**14.982.960**

G.1.7 Construction and maintenance Delta Dykes

In the factsheet Delta Dykes two studies are mentioned in which estimates are given for the construction of Delta Dykes. In the cost-benefit analysis the average between the two studies, 6.300.000 € / km, is used. Maintenance of Delta Dykes is set on 1% of the construction costs a year.

G.1.8 Regular dyke raising

Improvement of the dykes takes place in the natural and Defensive scenario. However, how much a dyke needs to be raised as a result of the sea-level rise varies between the climate scenarios and between the scenarios.
In the Defensive scenario, where there is no foreland in front of the dyke and where there is no secondary dyke (coastal buffer zones) present, dykes are raised in a regular manner. In this scenario dyke raising runs parallel to the sea-level rise which is assumed linear. Dyke reinforcements should last at least 50 years. So, when the sea level is expected to rise 50 cm in the next 100 years (middle climate scenario), dykes will be raised 25 cm now and another 25 cm in 50 years from now. The costs are discounted over those periods.
In the Natural scenario, nourishment strategies to maintain the tidal flats and the use of shellfish reefs can reduce the wave energy. The effect hereof is a reduction in dyke reinforcement costs. Unfortunately more research has to be done to predict the size of this effect. Because this lack of knowledge, we assumed that in the Natural scenario dykes are raised as high as in the Defensive scenario. This might imply an overestimate of the costs of regular dyke raising in the Natural scenario.

The actual costs of dyke raising used in the scenarios are 8.100.000 €/km per meter increase of the dyke. This figure is an average of costs of dyke raising in rural areas found in several studies (e.g. Arcadis and Fugro, 2006, Eijgenraam, 2006 and Kok et al., 2008).

G.1.9 Construction and maintenance of rich revetments

In Yerseke, a town in the Southwest Delta, a pilot project has taken place. In this project rich revetments were constructed on the dyke. This is done over a length of 1 kilometre. The costs for this project were €100.000. In the absence of other information about the costs of constructing rich revetments on an existing dyke, the number of 100.000 € /km is used in the cost - benefit analyses.

G.1.10 Construction and maintenance overtopping resistant dyke to create an coastal buffer zone

To create a coastal buffer zone the primary dyke is made overtopping resistant and the secondary dyke needs to be strengthened. The costs of creating a coastal buffer zone are 4.000.000 € / km, the maintenance costs are 3.500 €/km/year (Witteveen + Bos, 2007). Contrary to regular dyke rising, the primary dyke of an coastal buffer zone does not need to be raised every 50 years. If the sea-level rises, the coastal buffer zone is flooded more often but the level of safety behind the secondary dyke stays the same so no raising is necessary.

G.2 Benefits

G.2.1 Saved maintenance costs civil engineering works

In the Offensive scenario most of the dams that were constructed for the Delta Works are removed (Oesterdam, Zandkreekdam, Philipsdam, Grevelingendam, Volkerakdam) and the Haringvlietdam, Brouwersdam and Oosterschelde storm surge barrier will be gradually covered by dunes. This means that there are no maintenance costs any more. The saved maintenance costs are approximately 1,5% of the building costs of the dams (standard maintenance for large civil engineering works). The building costs of all dams are approximately 5 billion euro. Also in the Natural scenario all dams and the Oosterscheldekering are removed. The saved maintenance costs for civil engineering works count also for this scenario.

G.2.2 Revenues reed

Reed can have several uses. It can be harvested and sold for thatched roofs, it can be used for biofuel production or, when left to grow, it can be a means of carbon sequestration In the Defensive scenario half of the reed is harvested for biofuel production and half is left to grow. It is assumed the biofuel is sold for commercial purposes. The market price for biofuel which is made from 1 hectare reed is €750,- (harvest rate of eighty percent and twenty percent on-year reed; Grandiek et al (2007)). In the Offensive scenario the reed is harvested and sold in sheaves. The price for a sheave reed is €2,-. One hectare of reed produces about 250 sheaves of reed.

G.2.3 Revenues of saline crops

Known yields of salicornia and aster are respectively 84,000 and 35,000 euros / ha / year. These yields are based on (extensive) cultivation. The wild harvest of these plants is very labour intensive because they grow very scattered in marshes. Accordingly, revenues of harvesting salicornia or sea aster in the wild are considerably less. The assumption made is that inter-tidal areas created by managed realignment produce 80% less yield of salicornia and sea aster. Coastal buffer zones are less suitable for growth salicornia because the area is rarely over-flowing, so the assumption is 90% less revenue in a coastal buffer zone.

G.2.4 Revenues bouchot mussels and pacific oysters

In the Natural scenario, the first 50 meters of sedimentation areas bordering the coast are used for cultivation of mussels on poles (bouchot) and cultivation of oysters (on tables). Under the assumption that this area will be flooded throughout the whole period (coming 100 years), half of the area is used for the mussels, half of it for oysters. The yield of bouchot mussels is 41.920 € / ha / year and the yield of the pacific oysters is 25.000 € / ha / year.

G.2.5 Clean surface water

Salt marshes, reed lands and foreland have the ability to contribute to clean surface water by sequestration of N, P, and C and sometimes heavy metals. This is describes in detail in the factsheet Ecosystem engineers.

G.2.6 Protection against climate change

Protection of climate change is described in detail in the factsheet Ecosystem engineers.

G.2.7 Generation of tidal energy

This is described in detail in the factsheet ‘Energy Polder’.

G.2.8 Nature value

The non-use of nature value, as quantified in willingness to pay studies, applies only if the project or measures taken lead to an increase or decrease of the amount of nature. People are only willing to pay for extra nature or are willing to pay to preserve nature when it is threatened to disappear.

In the Natural scenario the area salt marshes grows in the next 100 years. The assumption is made that almost the entire coastal line will slowly be transformed into a salt marsh nature park. In the Offensive scenario salt marshes and tidal flats stay approximately the same but the amount of dunes on the North sea coastline is doubled. In the Offensive scenario the area In the Defensive scenario the area of salt marshes and tidal flats drastically diminish in the next century.

If there are relatively small changes in nature area, only people living close by (less than 10 km’s) are willing to pay for the extra nature or to prevent it from disappearing. When nature areas are large and rare, for example national parks like the Wadden Sea or the Veluwe, the entire nation is willing to pay for this kind of nature.
In the Natural scenario the coastal line of the Southwest Delta changes into a nature area of national importance. The assumption is that the entire nation is willing to pay for nature on such a large scale. The benefit ‘non-use of nature’ is therefore calculated by multiplying the amount of households in the Netherlands by the non-use value for salt marshes and mudflats. The average willingness to pay for salt marshes and mudflats should be EUR 15,7 per household per year (average of Ruijgrok and Lorenz, 2004 and ter Haar, 2011).

In the Offensive scenario the dunes on the North Sea coast are created. In contrast to the Natural scenario, this doesn’t mean that a natural area of national importance is created. This is because the increase in dune-area is not large enough and because the entire coastal line of the Netherlands consists of dunes, so the area is not especially rare. But to the inhabitants of the province Zeeland the extra dunes are worth something. This is because these people now have large sand dunes relatively nearby. The rest of the inhabitants do not live close by enough to have extra value for them. The non-use of nature in the offensive area is therefore calculated by multiplying the amount of households in Zeeland by the non-use value of

coastal nature. The average willingness to pay for dunes should be about EUR 20/ household per year (Ruijgrok et al, 2006).
In the Offensive scenario the area of reed lands is also significantly increased but not to the status of national park. People who live less than 10 kilometres from the reed lands are probably willing to pay for the extra reed lands. Since almost everybody in the Southwest Delta lives near the banks of a basin, we assume that all inhabitants of the Delta are willing to pay for nature value of reed lands. The average willingness to pay for reed lands should be EUR 11/ household per year (Ruijgrok et al, 2006).

In the Defensive scenario the area of salt marshes and tidal flats is diminished by 40% in the next 100 years. The deterioration of nature values in this scenario counts as a negative benefit. This is calculated by multiplying all households in the Southwest Delta by the willingness to pay for the preservation of intertidal nature.

G.2.9 Recreation

An increase in use of leisure accommodation is expected in the Natural and Offensive scenario. This is due to the changing landscape. In the Natural scenario salt marshes and tidal flats increase in surface area compared to the current situation. Large parts of the coastal zone become intertidal areas with wet nature in former coastal buffer zones and salt marshes and mud flats before the coast. The appearance of Southwest Delta will thus resemble the Wadden Sea area. The assumption is that the Southwest delta could have the same potential for overnight stays by tourists as the Wadden Sea.

In the Offensive scenario the attractiveness of the Southwest Delta as a place to spend your holidays increases because there will be more nature (in the form of reed lands) and mainly because of the increased area of dunes. Because of this increase in dune area the coast of Zeeland becomes an attractive alternative to coastal area in Zuid- en Noord Holland. The same reasoning as in the Natural scenario however does not apply to the Offensive scenario. Because of the different tourist function of the Delta compared to the coastal area of the Holland.
Where the delta in the Natural scenario has the same appearance as the Wadden Sea and thus will attract the same types of tourists (nature-lovers, people who come for rest and tranquillity, cyclists and walkers), the Holland coastline and bathing places attract other types of tourists. This is because the beach resorts in Noord- en Zuid Holland are all relatively close to large (r) cities. Tourists therefore, visit not just for the beach and the dunes but also for the cultural activities in cities like The Hague, Leiden, Haarlem and Alkmaar in the hinterland areas.

Research (Noord Holland Bezoekersprofiel (2009)) shows that most tourists come to the Noord Holland coastal area to enjoy cultural activities and to go out. If however visitors are asked why they visit the coast of Noord Holland, 58% states that they come for the beach, nature and the tranquillity. 42% visits the coastal region for other purposes.
The Southwest Delta does not have large cities and the range of cultural activities is less. This is why we cannot compare the Southwest Delta in the Offensive scenario one on one to the Noord- en Zuid-Holland coast. To make an assumption about the potential tourism of the Delta in the Offensive scenario with a larger area of nature and dunes, the number of overnight stays in the North Holland is taken and corrected by 42% (the proportion of tourist who visit to enjoy nature, tranquillity and the beach).

G.3 References

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