PROGRAMMA NAAR EEN RIJKE WADDENZEE

Sediment solutions
Community of Understanding in prep

Combined factsheets coastal examples

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Combined factsheets of coastal examples

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Introduction

This is the combined version of the separate developed draft factsheets of trilateral Wadden Sea near-coast sediment solutions. The factsheets are work-in-progress, concerning the factsheets itself as also the overall scope of the topics and examples. The idea is the use the practical examples, documented with factsheets, as a starting point for sharing experiences and knowledge, and for further dialogue.

In this combined version draft factsheets the bold highlighted themes are presented.

1. Mud: past, present and future
2. Development of clay pits in front of and behind the dike
3. Dike reinforcement with clay
4. Managed realignment
5. Landfill with dredged sediment
6. Development of foreland salt marshes
7. Halligen
8. Varia

General introduction

Mud in the past, present and future

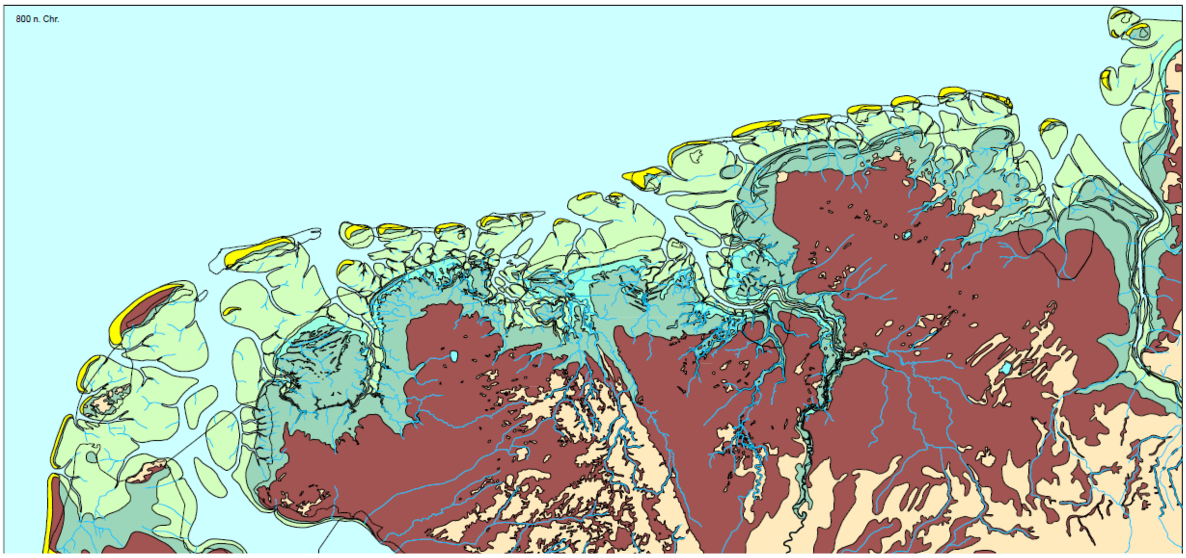
In the Wadden Sea there are two worlds: a “sand world” and a “mud world” which interact with each other. Due to their own typical sedimentary behavior, each of them cannot replace the other and provides its own natural values to the area. Compared to the natural situation, the muddy zone at the mainland has been shortened considerably by diking. At many places the clay deposits of the former muddy tidal flats are now lying tens of kilometers inland and have been subsiding relative to mean sea level, making these areas vulnerable to flooding and salt intrusion. Marine muddy embayments reaching for tens of km inland have been filled up and have disappeared. New entrances can no longer form and formation of new mud-rich environments has stopped. The mainland mudzone has changed strongly.

The first results of an inventory study indicate that at present a quite substantial part of the mud influx is deposited. As mud is transported from west to east, it is likely that mud sedimentation will decrease in that direction. For a future with accelerated sea-level rise this may prove detrimental for the resilience of the muddy systems. Wise mud management will play a major role to meet this challenge.

Two separated worlds
From measurements it has become clear that there is a relatively strong segregation between muddy sediments and sandy sediments, due to their different settling and resuspension behavior. In general, mud is deposited some 10 km from the inlets. Thus, the Wadden Sea can be thought of as consisting of a sand system and a mud system, which interact with each other. It implies that both are important for the functioning of the system and generating the natural values of the Wadden Sea area. Here we focus at mud transport and sedimentation and the role of mud management through time.

Past

The original landscape: extensive mud flats
Before humans started to influence the development of the mainland coastal zone, the Wadden Sea area was basically a flood-tide landscape. It consisted of high lying Pleistocene Boulder clays and sand deposits (Geest Grunden) surrounded by peat areas which had partially also filled in the old river valleys. This area merged into tidal marshes which gave way to higher tidal mudflats and to lower intertidal sandflats. Until the medieval dikes were built on a large scale the mud landscape formed about the half of the Wadden Sea area. Tidal marshes and tidal mudflats were up to several tens of kilometers wide.

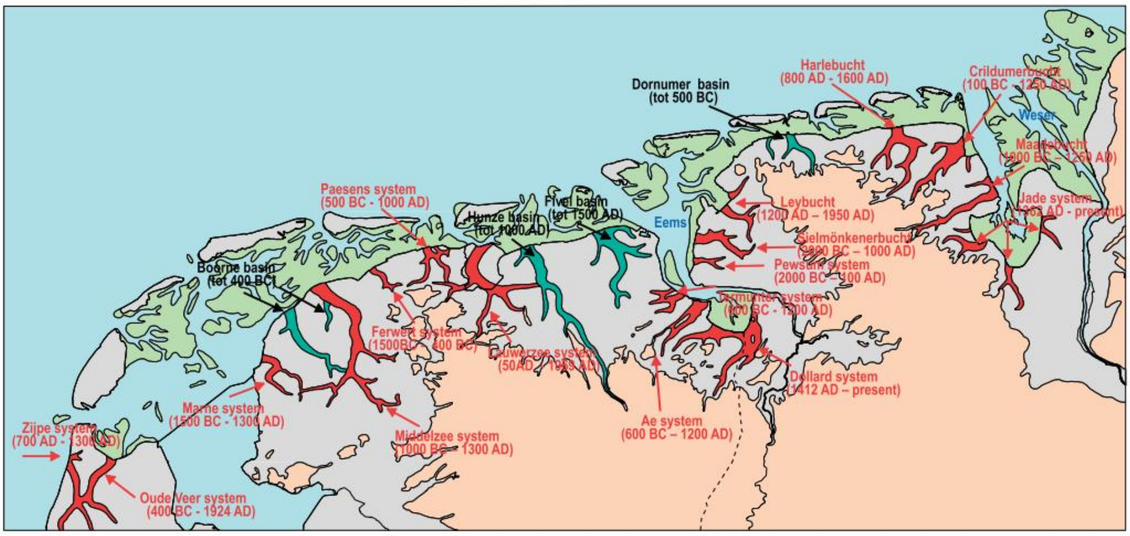


Reconstruction of the East and West Frisian Wadden Sea landscape in 800 AD. Orange = sandy areas; brown = peat; dark green = tidal marshes and mudflats; light green = mainly sandy tidal flats; yellow = sandy barrier islands (Vos & Knol, 2005).

Formation and infill of valleys: mud fills

When valleys or peat areas were flooded, the peat was eroded or compacted, and strong sedimentation of mud occurred. After the initial incursion of the sea, the area silted up and became land once again. The rapid infill of embayments such as the Dollart, the Middelzee and the Harlebay point to a very large availability of mud. For the Holocene deposits in the Dutch Wadden Sea it has been calculated that in total some 18,178*10^6 m^3 of mud was deposited. If it is assumed that the major part has been deposited during the past 5000 years that would be an average deposition of some 2.5 *10^6 m^3/yr for the Dutch Wadden Sea area up to Groningen. This is about twice as high as present-day values. The explanation is most likely two-fold:

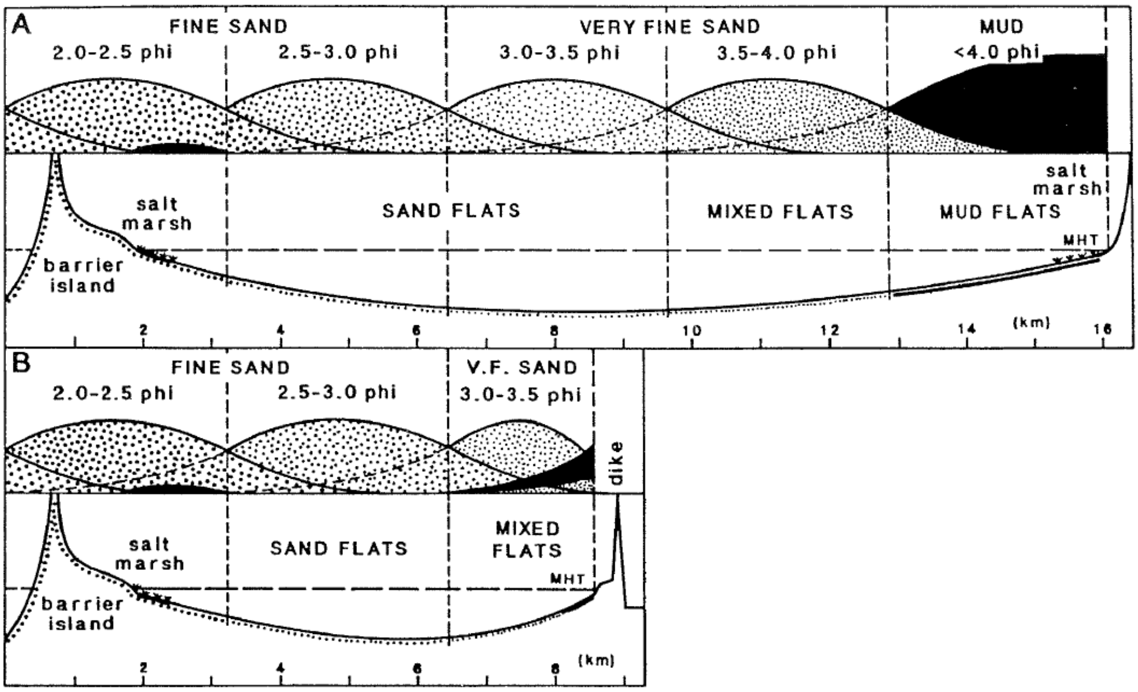
1) The incised valleys and embayments provided very quiet conditions for muds to be deposited.
2) The supply of mud might have been higher. Forest were cleared by man leading to stronger erosion and the sea bottom was still reacting on the rapid flooding after the last Ice Age, locally eroding the bottom. Also, coastal retreat has occurred over the past 5000 years in the West and East Frisian Wadden area and over the past 1000 years along the Holland coast and parts of the North Frisian Wadden area.



Locations of active tidal systems during the past 2400 years. Green: tidal channels of older tidal basins which were still active; red channels new ingressions (Vos & Knol, 2005).

Smoothening the coastline: no place for mud

On other parts, where energies became too high, the mainland coast eroded and retreated. Overall the mainland coast had a tendency to “smoothen out”, with protrusions being eroded and indentation filled up. However, from time to time new valleys and low areas would open to flooding by the sea and so the history. At the same time the barrier islands and tidal inlets retreated in a landward direction, making the energy gradient steeper and locally leading to renewed erosion.



A: Hypothetical shoreward-fining grain size model for a natural backbarrier depositional system. B: Actual shoreward-fining grain size sequence observed in the backbarrier region of Spiekeroog Island. (From Flemming & Nyandwi, 1994).

Diking the landscape: no space for mud

For the longest part of the existence of the Wadden Sea the muddy zone has been quite broad: almost fifty percent of the area consisted of mudflats and tidal marshes. This long gradient made it possible for fines to settle according to grain size. Constructions of dikes to almost the outer rim of the muddy tidal flats is thought to have shortened the energy gradient.

Where the coast extended in a seaward direction by sedimentation this was followed by farmers, which took the new land and build dwelling hills (partially consisting of mud) on the higher ridges in the landscape. There are, however, clear signs that they may have helped the natural processes somewhat. Low dikes of several decimeters were built on lower tidal marshes from at least the first century BC onwards. These may have had the same function as the brushwood fences on the present-day foreland tidal marshes: enhancing sedimentation. On the middle tidal marshes, dikes of 0.9-1 m height and up to 5 m broad were built as early as 2nd Century BC. These dikes will in general have protected the area behind it from summer storms but will have been flooded one to a few times during the winter period. Thus, winter storms would bring in nutrients and kill of the nematods, whereas during summer fresh water conditions prevailed and agriculture was possible. In the centre of the area a dwelling hill was present, protecting the inhabitants from the higher storm surges.

Although systematic building of lines of dikes became the norm around the 10th – 11th Century, these were quite low. Even in the 16th Century one could stand behind the dike and look over it. As a result, flooding and bursting of the dikes was normal and the area behind it was flooded from time to time. Where flooded land could not be reclaimed immediately (subsidence, too much erosion of peat or top soil) the area became Waddensea. In exposed areas, such as the North Frisian area, the losses were permanent. In the sheltered areas, such as the Dollard area, sedimentation was rapid (2-3*10^6 m^3/yr). Furthermore, at many places, new areas of tidal marshes heightened sufficiently to become new polders. Due to this a large part of West and East Frisia was characterized by several lines of dikes: the Dreamer, the Sleeper and the "Waker" (Guardian). Due to their low heights these will many times have functioned as a double or even triple dike system. The increase in technical possibilities led to a tendency to "straighten" the coast line reducing dike lengths. Thus, many embayments and "dents" in the coast line were removed and the possibilities for fine grained sediment to settle permanently were strongly reduced.

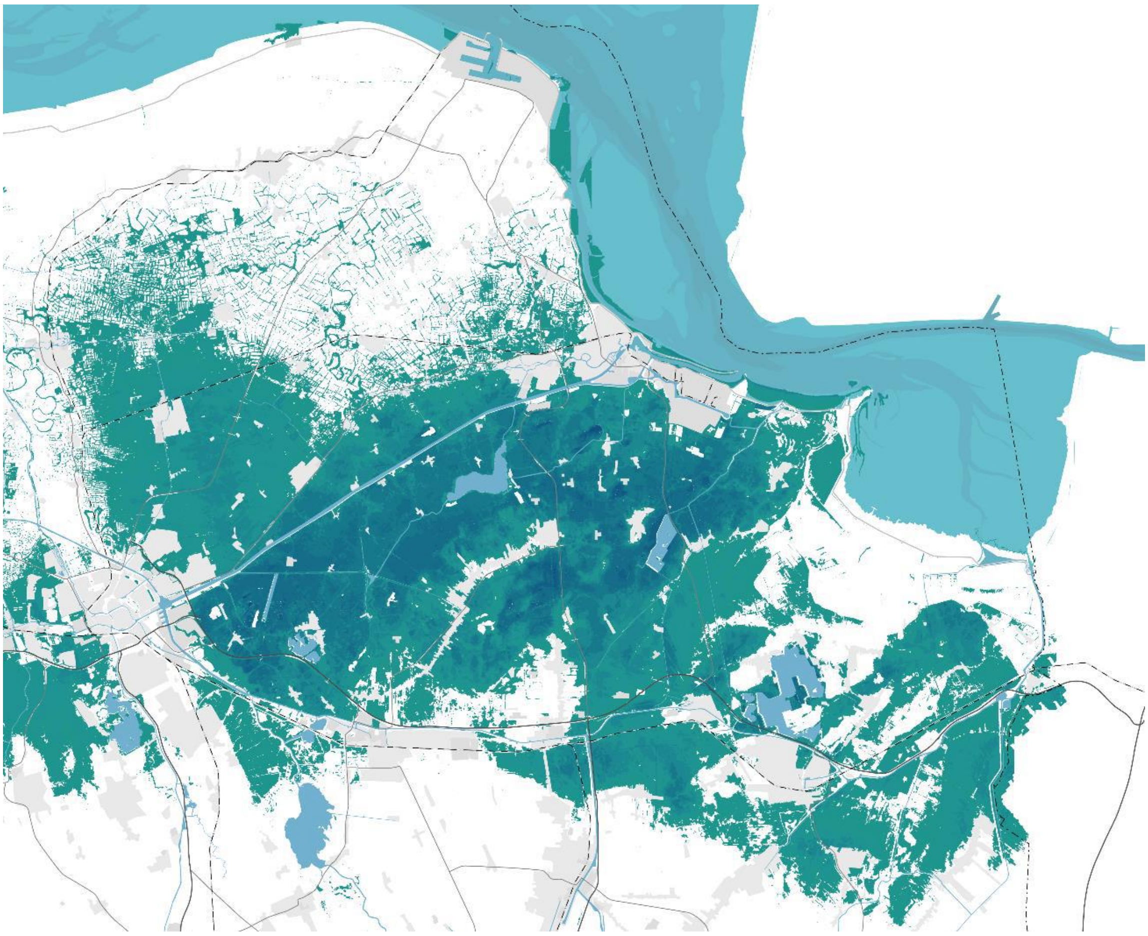
Present

Reclamation works stopped: maintaining the status quo of tidal marshes and mud flats

In the foreland tidal marshes mud deposition was furthered since at least the 16th Century via a system of ditches and brushwood groins. This practice became quite influential in the 19th and 20th century and huge areas were reclaimed. However, in the second half of the 20th Century, poldering of higher tidal marshes came gradually to an end. Centralization, the loss of natural values of tidal marsh areas and the costs to polder areas were important factors to bring expansion to a halt.

Strong separation Wadden area and mainland: former muddy flats subside

From then on, the dike line was mostly "kept". Several severe storm floods led the dike owners to increase in dike heights and widths. Dikes are nowadays up to around +10 m above MSL. Due to this heightening and the stabilization of the dike line positions, the area in front of the dike became almost completely separated from the area behind it. Ongoing sedimentation at the Wadden Sea side and subsidence at the landward side has at many locations resulted in lower elevation of the lands (below Mean Sea Level) with respect to the tidal marshes in front of the dike (above Mean High Water).



Height map with in color all areas in Groningen below Mean Sea Level (source: LAMA).

Managed realignment: restoring the mud landscape?

Locally, mainly around industrial and harbor complexes, areas were taken from the Wadden area and the estuaries for economic development. Since ca. 1990 managed realignment became important specially to compensate for loss of natural values. All in all, managed realignment resulted in some 18.5 km² of area becoming once more connected to the Wadden Sea and the major estuaries (Ems, Weser, Elbe, Varde Å). The way managed realignment was carried out differs strongly from site to site, so that -at present- strongly varying examples are present to compare.

Present-day mud sedimentation is of the same order of magnitude as the influx
The first results of ongoing research indicate that the annual influx (which does not all settle in the Wadden Sea) of mud is only slightly larger than the annual deposition including extraction. If these findings are correct, it implies that mud is a scarce commodity which should be managed with care.

Initial overview of net annual mud influx in the Trilateral Wadden Sea (Colina Alonso et al., in prep.)

Sources	Influx in 10^6 ton/yr
North Sea Continental Flow	10-14.4
Rivers	1.6
Local production & eolian dust	0,5
Subtotal:	**12.1-16.5**
East Anglia Plume (total 10-14.3*10^6 ton/year), reaching Wadden Area?	2*10^6 ton/year?

Initial overview of net mud sedimentation/year in the Trilateral Wadden Sea (Colina Alonso et al., in prep.)

		Sedimentation in 10^6 ton/yr	
Area	Period	Net mud sedimentation (= remaining sedimentation + extraction)	Extraction
Dutch Wadden Sea basins	1927-2015	1.2	- (only redistribution)
Ems Estuary	1990-2011	1.9 - 2.4	0.8
Lower Saxony	2000-2010	0.5	
Jade Bay	2000-2010	0.9	?
Weser Estuary	1998-2016	1.45	0.2
Elbe Estuary	1999-2016	1.3	0.8
Meldorf Bight	2000-2010	0.1	
Schleswig Holstein	2000-2010	1.5	
Danish Wadden Sea basins	Mainly: 1980–2003	0.2	- (only redistribution)
Tidal marshes		1.7-1.8	-
Total Trilateral Wadden Sea		**10.9-11.5**	

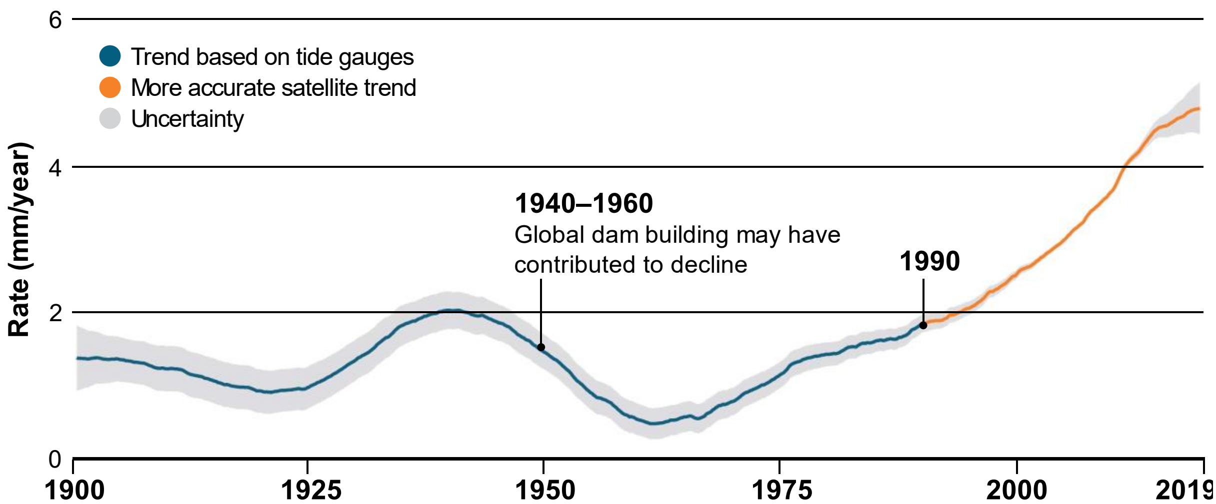
Careful mud management needed
If the initial findings of the mud balance are correct, this implies that we have to consider both the mud balance and the sand balance for the trilateral Wadden Sea and the estuaries carefully. Where the sedimentation of sand can be either limited by the supply (demand in the back-barrier basin is larger than the supply via the inlet) or limited by the demand in the basin, it is not clear if this functions in the same way with mud. Supply of mud mainly enters the area with North Sea Continental Flow from the

west. Where energy conditions and muddy sediments (which enhance mud sedimentation) make it possible, these muds may settle in relatively thick layers (locally up to several dm/yr) and suspended sediment concentrations in the water can be expected to become lower on average for the tidal basins and estuaries more to the east. What happens in terms of mud deposition in these basins is an open question: sedimentation rates might decrease with decreasing suspended sediment concentration (supply limited) or sedimentation will proceed at the same speed (demand limited). Most likely both are true: as long as suspended sediment concentrations are high enough sedimentation can proceed at its maximum rate; if it becomes too low sedimentation rates will also become lower.

Future
Climate change may complicate things further.

The role of increasing run-off: More mud available?
Already in the past century precipitation and evaporation patterns have been changing. Overall, runoff of rivers increased. However, during the summer period freshwater run-off is reduced strongly due to the increasing frequency of extremely hot periods. By contrast, during autumn/winter precipitation increased leading to strong run-off into the Wadden Sea system. At the moment it is unknown if this leads to an increase in suspended matter influx. In itself the increased outflow of fresh water will also enhance the estuarine circulation in the estuaries and the along the North Sea coast leading to a greater efficiency to trap mud in the currents. This might heighten the concentrations of mud in these waters and the availability of mud for the system.

The role of acceleration of sea-level rise: more mud needed
Global sea levels have been rising with some 1.8 mm/yr during the first half of the past century. Since 1960 global sea-level rise is accelerating. Presently, it is some 4.8 mm/yr. In large parts of the Wadden Sea sea-level rise is slower, most likely due to regional geological and glaciological effects. It is expected that global sea-level rise will continue for centuries to come and it is foreseeable that also in the Wadden Sea sea-level rise may proceed at a quicker pace. If sedimentation of the sandy flats can balance sea-level rise it would lead to a slight increase in average depth in the Wadden Sea with increasing velocity of sea level rise. The question is to what extent the hydrodynamic conditions will change and hinder sedimentation of mud? As long if that is not the case, and supply is sufficient, mud flats may keep up with sea level rise or even outgrow sea-level rise. But because more mud is needed to keep up with accelerated sea-level rise the eastward flow of mud will diminish more quickly, which might lead to deficits in the basins more to the east.



Measured rate of sea-level rise (in mm/yr) showing clear acceleration of the global rate since 1960 (after Dangendorf et al., 2019).

Above a critical limit it is expected that the sandy flats can no longer keep up with sea-level rise and start to drown gradually. Under such conditions the hydrodynamic energy will probably increase on the mudflats making lower deposition or erosion more likely. If no alternative sheltered areas are available mud flats and tidal marshes may become scarcer over time.

Saving the muddy tidal flats and marshes?
To heighten the chance of maintaining tidal muddy flats and tidal marshes in the coming centuries it is important to:

1) Develop wise mud management.

At the moment mud availability is still experienced as so high that it leads to problems. This is locally true, especially where fairways and harbors have an overdepth or where sluices are present. An example is the Ems where much effort is needed to keep shipping possible. Suspended matter concentrations within the estuary have increased leading to deteriorated conditions for primary production and fish migration. The increase of SPM is mainly attributed to the decreasing possibilities to settle permanently in the estuary. Thus, large-scale plans are currently being developed to extract the mud from the system, either by transporting dredged mud on the land or by getting it out of the local system via a "building with nature" solution. However, in the light of the likely increase in mud demand to maintain the muddy habitats in the system, a large-scale permanent retrieval might prove detrimental to the system on the long run. Prudent mud management, taking into account both spatial natural needs and mud-related problems, as well as the likely increase of mud demand in the future, will form a major challenge for this century.

2) Develop new areas for mud sedimentation

An important prerequisite for mud sedimentation is the availability of quiet hydrodynamic conditions, as present in sheltered embayments. Since the hydrodynamic energy in the present-day Wadden Sea could increase in the future, it will become increasingly important to develop new areas for mud sedimentation. Such areas might serve three goals: permanent deposition sites for uncontaminated muds; heightening the low-lying polder areas; compensating eventual losses in the future.

Double dykes as a solution?
Recently the double dike system (see factsheet) was proposed as a possible solution for the Dutch mainland coast of the Wadden Sea (Wadden Academy, WUR, Deltares). This might be extended to larger parts of the Wadden Sea coast. The central idea is that on many places the older inland dikes are still present or new inland dikes can be built in a relatively uninhabited landscape. The outer dike would serve to break the waves. The land behind it is in open connection to the Wadden Sea and will be flooded. The frequency of flooding will be determined by the height of the area. The flooding frequency will determine the exact usage of the area: nature, tourism, agriculture, mariculture, wind energy etcetera. Sedimentation in the area will heighten the area and can be used to enforce the dikes over time: a form of climate adaptation. The landward dike acts to prevent flooding but does not have to break the waves as this is already provided by the first dike. An additional benefit provided by the concept is that the double dikes give a longer time to flee an area than a single dike. What furthermore can be added to the concept are:

1) tidal marshes in front of the seaward dike, which provide nature values and breaking of waves.
2) broad green dikes which use less stone work and form a robust basis for coastal security.
3) connection with mud dredging activities in estuaries. The area can be "fed" with dredging sludge thus stimulating fast vertical sedimentation, as a way of climate adaptation.
4) seaward constructions around smaller habor towns to provide the extra dike in front of the present-day dike, taking in count not to interfere with the natural hydromorfological processes..

In this way a double dike system stimulating the development of a more diverse landscape, with larger natural values and a more diverse economy will help to enrich the mainland coast, while at the same time securing it against flooding.

Deep embayments as a solution?
Along the Dutch part of the Ems, several plans have been developed to realize the flooding and sedimentation of large areas of the former clay-rich Wadden Sea deposits which have been subsiding after diking (see factsheet managed realignment). Nature restoration, mariculture, agriculture and tourism

will all benefit from these plans. At the same time the land can grow with sea-level rise and dredged muds can find a new destination.

Outlook

Thus, perhaps in the future the circle will be round once more: the originally irregular, open and broad coastal zone with valleys incised into the mainland, will once more reappear.

Already now knowledge can be provided via the many managed realignment projects to study the feasibility of such an approach. New dedicated projects can be developed to help gain missing knowledge and built know-how. In the cause of this century larger parts of the straight coastline can thus be changed into a broad muddy coastal zone. On the longer run the broad dike zone of tidal marshes, present day dike, de-poldered zones and secondary dikes will form a sedimentation zone. It may provide the broad basis for the far future.

Lessons Learned

The typical behavior of mud differs strongly from that of sand leading to mud deposition areas which are largely separated from sand deposition areas. Under natural conditions muddy habitats such as muddy intertidal flats and tidal marshes used to constitute half of the original natural Wadden Sea landscape. Such landscapes were characterized by well-developed gradient of fines towards the coastline. Due to construction of dikes a large part of this landscape has been poldered. This part is now subsiding relative to mean sea level. The first results of the present-day mud balances learn that annual mud influx is 1-1.5 times larger than the net sedimentation. This implies that mud is a scarce commodity and that retrieval of mud may lead to unwanted effects elsewhere on the natural functioning of the muddy part of the Wadden system. For this century increases in mud demand are expected due to sea-level rise. This strengthens the need for prudent mud management. Possible solutions are found in large scale managed realignment over larger areas, such as rows of double dike systems or large-scale de-poldering measures. Such new nature, farming and tourism areas can store mud which is dredged from harbors and fairways and thus help reduce turbidity in the water column.

Stakeholder process

Locally in harbors and fairways mud causes problems and the stakeholders involved are looking for solutions which will be beneficial for man and nature. With it the discussion on wise mud management has started. For the present, the solution for local mud surpluses might be found in using these muds for nature development via the recreation of mud deposition sites via managed realignment or making the surpluses available to other stakeholders who are in need of mud for the natural functioning of the system. This can for instance be done via disposing dredged clean muds in such a way that it is taken by currents to other tidal basins. Such large-scale mud management is still in its infancy and much knowledge and know-how has to be developed, but it seems a promising way into the future.

Discussion points

- Are the initial balances correct? What are uncertainties and how can they be solved?
- How will mud sedimentation develop under conditions of higher run off and sea-level rise?
- What defines wise mud management?
- How much mud can we trap annually with realignment?
- Is it possible to use dredged mud to “feed” other tidal Wadden Sea basins?
- Is it not wiser to just heighten mainland areas with dredged mud to make the area more resilient against sea-level rise?

Literature

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http://www.lamaland.eu/projects/rijzend-land/

Seaward/Landward Solutions Development of clay pits in front of and behind the dike

Clay mining pits have been must have been in use from Roman times onwards, given the clear marsh characteristics of the sods observed in dike profiles of the Roman, medieval and postmedieval times. The system of taking sods from either inner dike areas or outer dike salt marshes to repair or built dikes has been in operation up to the 21st century.

Clay mining pits in outer dike salt marshes will fill up with new clay in due time and salt marshes can become re-established. This may result in a rejuvenation of the tidal marsh if the right conditions are met. Currently outer dike clay mining pits are no longer in use in Schleswig Holstein. The argument is that mud is part of the Wadden Sea area. There it is needed to balance sea-level rise and for the nature development of the system. In Lower Saxony the locations and the exact dimensions of outer dike clay mining are strongly determined by the interests of the National Park.

In the Netherlands clay mining has largely been stopped, because the quality constraints for sediments allowed in dike building mostly forbid the use of tidal marsh deposits. Recently, a new experiment in the Dutch part of the Eems is presently under way where clay mining in the tidal marshes of the Dollard area was combined with a bird breeding island in the center: the Nieuwe Klutenplas. At the moment monitoring is carried out.

Clay mining is as old as the earliest dikes in the Wadden area. A part of the sods visible in old dike profiles can be shown to have been taken from the tidal marshes. However, at many locations clay rich sods have also been taken from the inner dike areas as can be concluded from the many inner dike clay mining areas. Dike strengthening agreements often are written down as adding one or several sods annually on the dike profile. The inland clays were not only mined for dike building, but also to produce bricks. Large areas near the Oste river in Lower Saxony were mined for that purpose.

Cross section dike remnants at Peins 1 Cent BC given by red line. Dike built by sods in disarray taken from the middle tidal marsh various phases. Ditch visible of which clay was taken seaward of dike. (Compilation of RWS Photo's by R. Juncurt)

Where clay mining pits have been made behind the dike, they are semi-permanent although they may fill up with plant material over a prolonged time. These historic inner dike clay mining pits often provide reserves for bird life (e.g. Feddema's-plas in Groningen). At the moment it is proposed to locally allow the formation of new fresh to brackish lakes in combination with breeding areas at the landside of the Wadden Sea area to stimulate the nature functions of the Wadden Sea (Ontwerp Agenda Waddengebied 2050). These proposals have been criticized by the Nederlandse Akkerbouw Vakbond (the Dutch Agricultural Union) They state that the new approach integrates a large part of the inner dike area to manage the Natura 2000 and World Heritage area of the Wadden Sea and lead to strongly negative consequences for agriculture. One of the main objections is against proposed measures which will increase the salinity of inner dike areas, by such measures as the formation of clay pits and managed retreat.

Feddema's plas near the Ommelander Sea Dike. This inner dike lake was formed in 1924 to build dike the Julianapolder. The Waterboard Hunsingo bought the area to mine clay. Thereafter it filled with brackish water. As a result, plants are present around the lake which are characteristic for brackish to saline conditions. The lake is used by Wadden Sea birds. In 1994 the area was given to the Groninger Landschap, a provincial nature organization. (Source: https://www.groningerlandschap.nl/natuur/waddenkust/feddemas-plas/)

Where clay mining pits are formed outer dikes, it is often in the tidal marshes where clay rich sods are easily available. The strong roots in the sods made them easy to work and to use in dike building. After mining such areas might fill up relatively quickly if drainage is sufficient. Maintenance of outer dike drainage channels can be observed on maps as early as the first half of the sixteenth century. However, there are indications that drainage networks to enhance mud sedimentation on the tidal marsh may have been established much earlier, perhaps already in Roman period, as lower dikes have been observed on the lower tidal marshes and higher dikes with channels in front of them on the middle tidal marsh.

Recently, Schleswig Holstein ruled that clay mining outer dikes should be stopped as the sediments are needed for the natural functioning of the system and to keep up with sea-level rise. One question in this approach is if the present-day rather static situation with dike lines can mimic the natural rejuvenation which was originally existing. Before dikes were a dominant factor, land areas might be flooded/eroded so that new mud sedimentation or generation areas were formed[1]. This land-scape rejuvenation has largely disappeared, the only exemption being managed retreat areas and clay pits, which in scale are generally much smaller than natural formation of new embayments.

In contrast, in Holland and Lower Saxony clay mining is still allowed. On the tidal marsh of the Lower Saxony coast many clay pits have been dug. Experience learned that pits may exist for 10 to 40 years depending on the infill rates. Thus, tidal marsh area is locally lost and with it an area where insects and other organisms can life. Also, breeding area for tidal marsh birds is lost for a period of 15 to 40 years, as well as roosting space. On the positive side the large-scale clay pits generate a more natural dynamics with natural creeks and it possibly improves the quality of bird breeding, roosting and feeding area. By law, clay mining on tidal marshes is allowed when inland clay cannot be mined. However, in the National Park clay mining is in practice only by exemption allowed for individual cases, if:

- the removal does not significantly affect the protective values of the Park.
- a sustained improvement is expected of the ecological value of these areas in the sense of Natura 2000 conservation targets
- the clay removal is carried out according to nature conservation requirements.
- in the area the value-determining bird species remain in a favorable conservation status or at least their conservation status does not deteriorate.

This restricts the choice of areas where clay pits can be dug and how their form should be and makes these choices important to nature preservation. Furthermore, it was learned that large rectangular clay mining fields with only a limited connection to tidal flow need a very long regeneration time. Nowadays the clay mining takes into account the generation of extra values for nature by:

- Beveling the embankments, flat banks;
- Creating height differences;
- Undulating borders with the tidal marshes;
- Dismantling of existing anthropogenic structures;
- Connection of the creeks of the area to existing creeks;
- Initiation of the development of a creek system;
- Creation of predation-poor spaces and islands.

[1] In that period (mainly Middle Ages and direct post-medieval period) mud availability was huge due to the intense erosion of land due to deforestation. Nowadays much of the mud which is transported by rivers is trapped in artificial lakes, thus reducing mud transport to open sea. The present-day availability of mud might be considerably lower than in the past, thus reducing the possibilities for rejuvenation of the land-scape via new mud deposition.

Jadebusen embayment, Lower Saxony: At the left side and between the two new restorations: old-fashioned clay pits of the 60-ies and 70-ies, which were water-logged until 15 years ago, when they were reconnected. In between and to the right side modern clay pits with irregular borders, connectivity with creeks and height differences resulting in islands and, seaward of them, tidal marsh areas which are surrounded by water and creeks (Google Earth; pers. Information: A. Groeneveld, Nationalparkverwaltung Niedersächsisches Wattenmeer).

In Holland currently clay mining pits for dike building have become rare as the clay has to meet very strict specifications to be used for dike building. However, bird breeding islands are formed surrounded by ponds by digging out tidal marshes. Up to now the dug-out material was often used for infrastructure on the tidal marshes or the closure of ditches. In 2018 the so-called Nieuwe Klutenplas in the Dollart area, in the province of Groningen was established. This is an experiment. The clay has been used to build a containment dike for mud which should ripen to clay to be used for dike building (see Broad Dike Factsheet).

Piping
An important restriction is that the sedimentation of fine material on the tidal marsh and the older clay deposits landward of the dike results in an impermeable layer. This has an inhibiting effect on the groundwater flow. The effect is beneficial to failure mechanisms such as piping and macro-instability due to pushing up. The effect already occurs at widths >100 m. It is important that the 'impermeable layer' is not disturbed by clay pits, so that dike stability is ensured.

Research
Piping
Many dikes in the Netherlands nowadays do not meet the required safety standards; in a large part due to the perceived danger for piping. Sedimentation of thick clay layers in the front of the dike might prevent the piping process from happening, but in most cases such clay layers are not taken into account for safety calculation (one exception are the muddy deposits in the Mok-bay Texel). As far as known no research is at present carried out to evaluate the possible role of such layers or the influence of establishing outer dike clay pits.

Netherlands, Nieuwe Klutenplas

In 2018, the construction of the Nieuwe Klutenplas, an area of 3.5 ha of open water with 0.5 ha breeding island for Pied Avocets (*Recurvirostra avosetta*) created an area of open water which is much larger than those in natural tidal marshes in which pools have a maximum dimension of 0.125 ha. The Dollart tidal marshes are artificial and have an unnatural dewatering system. It is hoped that upon infill a more natural creek system will develop. However, waterboard Hunze en Aa's considers the possibility to use the mud which is deposited from time to time to let it ripen to clay which can be used for dikes. The island in the open water reduces predation by foxes and it is hoped that the breeding success of the Avocets will increase.
For the development of the Klutenplas area which is a pilot for sustainable mud production, monitoring is carried out of the development of the
1) drainage network;
2) tidal marsh erosion;
3) the sedimentary infill in the Klutenplas
4) vegetation on the breeding island.

Lower Saxony
For each potential clay pit questions which are studied on beforehand in Lower Saxony are:

- Is the mining of clay in the tidal marsh a good management action for nature conservation to further the targets in the National Park?
- Does the clay mining increase the quality of the various protected values in the National Park (tidal marshes, breeding and roosting birds)?
- To what extent does nature protection require special measures to the mining operation?

Results
In spring 2018, during the digging of the Nieuwe Klutenplas avocets were present. The first results show that the drainage channel from the Nieuwe Klutenplas towards the tidal flats initially deepened with 0.3-0.5 m. Tidal marsh erosion along the edges with the tidal flats is an autonomous process which already existed before the Klutenplas was created. The first measurement over the period 2017-2018 (-0,08 ha due to a landward retreat of 0.9 m) indicate a reduction with reference to the period 2009-2017 (resp. 0.14 ha and 1.1 m/yr). The infill of the Klutenplas is rather rapid with an initial sedimentation in the first 5 months of on average 13 cm. Vegetation on the island initially mainly consisted of annual plants and *Tripolium pannonicum.*

The findings at the Nieuwe Klutenplas are in line with the findings of Lower Saxony. The rapid sedimentation in the Klutenplas may well result from: 1) the good connectivity of the pit with the creeks so that tide water can flow in allowing for the repeated deliverance of mud; 2) the observed deepening of the drainage channel at the Nieuwe Klutenplas clearly points to the fact that the amount of tidal water is too large for the channel leading to high current velocities and hence erosion: this sediment is partially deposited in the Klutenplas. Like in the Lower Saxon case a more natural approach was followed for the formation of the clay pit. As a result, in early vegetation at some places. Like in Lower Saxony the island has proven to be a safe haven for breeding birds.

Lessons learned
From the above considerations several lessons can be learned:
1) For outer dike clay mining it is important to first have insight in the amount of mud which is needed for the nature functions of the Wadden Sea system, at present and in the future under conditions of accelerated sea-level rise. Schleswig Holstein concluded that on that basis clay mining cannot be allowed. As far as known such studies have not been carried out in other parts of the system. At te moment an appraisal study for the trilateral Wadden Sea is being conducted, aiming at getting an overview of the available knowledge.
2) If outer dike clay mining is allowed, the approach developed by Lower Saxony seems a very sensible one: nature values should increase due to the effects of the clay pit formation.
3) Allowing inland clay mining may be profitable if the sediment is meeting the requirements for use of the clays. The areas which are thus formed can provide a rich habitat for bird life and other organisms which are depending on fresh to brackish conditions.

4) In all cases, seaward and landward of the dike it is important to consider the possibility of piping and macro instability when new clay pits are made for whatever reason.

Stakeholder processes

Stakeholder processes for clay mining is mainly between dike managers such as waterboards, land owners, dike builders and nature conservationists. In Germany the state regulated management groups to a large extent determine the possibilities for clay mining. This is also true for the Netherlands, but here a growing tendency can be observed to join forces in the search of more optimal solutions for the various problems. For instance, the Nieuwe Klutenplas is the result of the experimental project which involves the following parties: Waterboard Hunze en Aa's, POV Waddenzeedijken, Eems-Dollard 2050, Province of Groningen, Groningen Seaports, Het Groninger Landschap, Ecoshape, Waddenfonds, Rijks-waterstaat, Maatschappij Onverdeelde Munnikeveen, E.H. Huisman.

Discussion points

It is clear that there are relatively large differences in the approach of formation of clay mining pits in the various countries. As such, much can be learned from each other. A main question is: is there sufficient mud available to mine clay from the tidal marshes, without negative consequences for the functioning of the trilateral Wadden Sea at large? If that is the case, the local mud availability must be considered with a similar question. Thirdly the approach of Lower Saxony seems to be an optimal choice between clay mining and nature values. But is this really the case or is the scale of clay mining too small or too large to restore natural values that were once present in a natural landscape? Or is the shift from an artificial tidal marsh towards a more natural tidal marsh so valuable that it is a justification for such measures?

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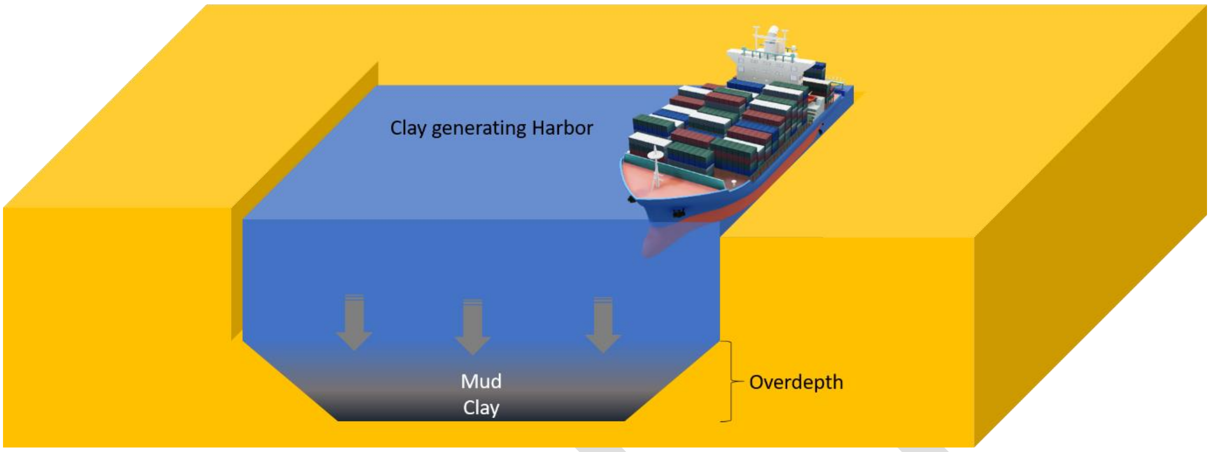
http://www.arcontor.de/_private/Referenzen.html

Seaward Solutions Clay Generating Harbor
(Idea)



The Clay Generating Harbor is a harbor with over-depth, which allows for mud deposition and compaction without influencing shipping. Dredging frequencies can be reduced and the compacted mud is a first step in clay production.

By creating an over-depth in existing harbors suspended muds can deposit. The sedimentation in the harbor is determined by:
a) the water volume water which enters from the outside into the harbor (exchange);
b) the sediment concentration in the water entering;
c) the ratio between the current velocity inside and outside the harbor;
d) settling velocity of the suspended sediment;
e) the duration of the stay of the water in the harbor.

Especially the exchange rate of the water is of great importance for the sedimentation rates. In tidal situations it is determined by the tidal volume, exchange in the harbor mouth due to horizontal eddies and the exchange due to vertical eddies generated by density differences. Based on the study of the Termunterzijl harbor sedimentation of mud in the eastern part of the Dutch Wadden Sea can be estimated to be roughly 1 m^3/m^2y, or 360 kg/m^2y dry weight mud. Upon consolidation a layer of 0.3 m of clay remains (with a density of ca. 1200 kg/m^2). A typical time scale for such consolidation is months to years. If the harbor must be dredged once in 5 years, an over-depth of 4m would be needed and for 10 years an over-depth of ca. 7m.

Creating such an over-depth might be a good idea to produce clays on the spot thus reducing transport costs. Also, the formation of over-depth will produce sediments which might be marketed. However, several points will need further consideration:
1) how to avoid influx of too much sand?
2) how will creating over-depth influence stability of the harbor walls?
3) is the over-depth sufficient to avoid resuspension of muds by ship's propellors?

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Dike Solutions Sods for Dike Building

(Idea)

Using sods taken from the foreland tidal marshes to build and maintain dikes is an old technique, which is currently being re-evaluated. The technique would serve four goals: reinforcing dikes; reducing CO_2 and NO_x production for dike maintenance; rejuvenation of succession on tidal marshes; and (locally) reducing mud concentrations by enhancing sedimentation.

Taking sods from the foreland tidal marshes to build dikes is a technique which has been used for at least 2000 years in the Wadden area. The sturdy clay-rich sediments with deep root systems of the plants provided an excellent and easily available building material to form a dike. On the longer run the tidal marsh would heighten again and succession would lead once more to a sturdy sediment which might be mined again. This Building with Nature Technique thus seems very attractive for dike building. Alternatively, such sods might be used to improve the soil structure and the heightening of agricultural land, eventually after first mining the fresh clay of these areas for dike reinforcement.

Research

Recently, the technique has once again drawn the attention of researchers, and in the Living Lab Hedwige-Prosperpolder (SW Delta area) some explorative short-term and small-scale field experiments will be elaborated to adapt the dike with locally sourced salt-marsh turf and mud. However, there are still many important knowledge gaps, e.g. on:

1) reinforcing dikes;

Although sods can be an excellent building material to maintain dikes these can contain sandy sediments. The question therefore is: can functions of the foreland tidal marsh be combined with the production of clay-rich and sand-poor sods? Furthermore, dike regulations are nowadays such that a lot of sediments do not meet the current standards for use in dikes.

2) reducing CO_2 and NO_x production for dike maintenance;

Much more CO_2 and NO_x will be needed to transport clays from rivers and far-away pits to a dike, than in the case of sods taken from the tidal marshes. However: the organic content in tidal marshes will be partially stored under anaerobic conditions. This will change when the sods are used in dikes and methane might be released, potentially adding to the greenhouse gasses.

3) rejuvenation of succession on tidal marshes;
By taking the sods from the higher tidal marshes the sediment surface is lowered. Depending on that height and the drainage of the area a plant cover characteristic of the lower to middle tidal marshes might develop. The questions are: how should the 3D form of the dig be in relation to the specific goals set for the development of the vegetation? What will be the duration of infill before new sods can be taken?

4) (locally) reducing mud concentrations by enhancing sedimentation.

Approach
More insight would be gained by the following activities:
1) a. Experimental study on the impact of different management regimes of the foreland on the quality (clay content) of the sods.
   b. Exploration if and how different functions could be realigned with the aim to mine building material (sods) from the foreland
2) a. Field experiments to investigate the CO2 and NOx fluxes of application of sods
   b. System analysis to compare the CO2 and NOx footprint of local sources (sods) and transported building material from elsewhere.
3) a. Field experiments with different configuration of the clay/sods pits to investigate the impact on short-term morphologic changes in the foreland and the sedimentation pattern, and the impact on nature development
   b. Modelling of the mid-term and long-term impact under sea-level rise.
4) a. Monitoring the impact on the mud concentration of the water.
   b. Modelling of the mid-term and long-term impact om water quality.

Stakeholder processes
Important stakeholders are water boards (the users of the dike-building resources and responsible for water safety and implementing goals on sustainability), owners of the foreshores (agricultural sector and nature organizations).

Discussion points
- How can management of the foreshore affect the quality of the sods (local sourced building material), and what kind of experiments are required to gain insight and are feasible?
- How should such experiments be organized?

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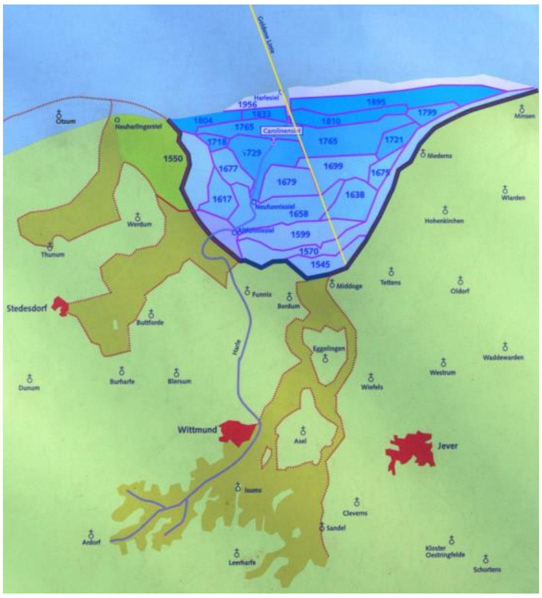
Dike Solutions Dike reinforcement with clay

Along the Wadden coast longer sea dikes exist for circa a millennium. Roughly, three types of dikes can be distinguished: those for static, eroding and static coasts. Older dikes often consist -nearly completely- out of clay. Modern dikes may have a sand core and a clay and stonework cover. Over time, sea dikes have become considerably higher and broader, as population and net values behind the dikes grew, whereas land levels dropped, and sea-levels rose. In the Netherlands, an increasing technical approach resulted in high standards for the clay that could be used in dikes and, in the 20th Century, often river clays were used. In the other Wadden Sea countries mostly local clays are used. New approaches involving different dike profiles make the use of local clays possible.

The earliest dikes in the Wadden area, which we know of, were built as early as the first Century BC. Larger continuing dikes were built since the 10th-11th Century. To understand the built up of dikes three central factors should be considered:

1) *The morphological development of the area*

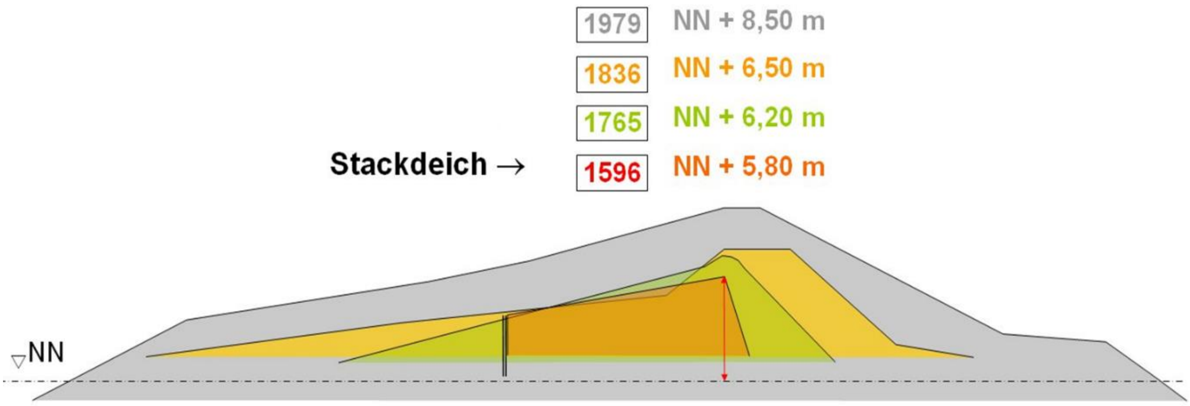
Roughly speaking: three types of morphological development can be distinguished:



Prograding coast and poldering history of the Harle Bay (Wikipedia, after Homeier, 1979). Yellow line is newly established border between Jeverland and Ostfriesland.

1a) *A prograding coast* where the deliverance of sediment outpaces sea-level rise and erosion by storm surges. In such coasts new tidal marshes may form in front of the sea dike, either fully natural or with human help. Such developments mainly occur in embayments where mud deposition is often strong but may also be encountered along straight stretches of the mainland coasts. Once the tidal marshes became high enough they were often poldered. This often happened via an upgrade of the summer dike seaward from the winter dike. In such prograding coasts mostly series of seaward increasingly younger dikes are present. Due to their young age the built-up of such dikes may be consisting of only a few “dike improvement layers”. Examples of prograding coasts can be found in embayments such as Harle Bucht, Leybucht, Jade Busen, Dollart etc. Also, where foreland tidal marshes enhancement was successful, new land could be diked, e.g. along the Groningen coast and at the Hamburger Hallig.

1b) *A static coast* where the deliverance of sediment is more or less in balance with sea-level rise and erosion by storms or where dike improvements made a static coastline possible. Depending on the period over which the coast was static, dike improvement layers may be added over a prolonged time. Examples of static coasts are large parts of the coasts of Frisia and Lower Saxony.

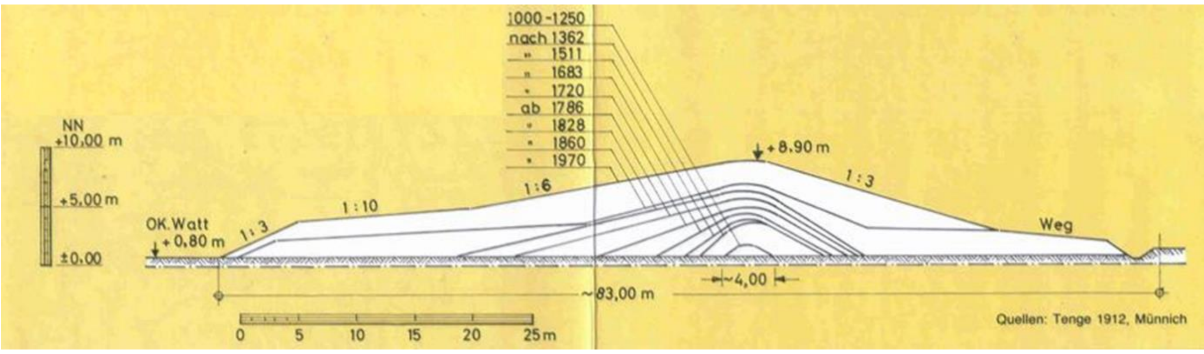


From a Stackdeich to a clay dike (after https://upload.wikimedia.org/wikipedia/commons/5/5b/Küs-teningenieurwesen_Deichverstärkung_1.jpg)

1c) *A retreating coast* where the sea-level rise and storm surges outpaces the deliverance of sediment. It should be realized that storm surges and dike failure may lead to flooding and subsequent (peat-)erosion (e.g. Dollard) of low-lying areas behind the dikes further increases the disbalance. In such coasts new dikes had to be built from time to time more inland. This continued until technical capabilities had improved enough to stop further erosion. Examples of retreating coasts can be found in Schleswig Holstein and the Land Wursten and along the former Zuiderzee area. Especially in retreating situations sediment availability was low as forelands from which clay could taken were scarce. For that reason, so-called Stackdeiche (or Holzungen) were built where the dike profile was small, and the outside was protected with woodwork and after 1731/34 with stone works. This type of dike proofed to be unsuccessful and it was decided in Denmark and Germany to go back to broader dike profiles, which was mainly done with clays taken from the tidal marshes and sometimes inland clay. In sluices and harbors stone work protection was used.

2) *<u>Relative sea-level rise</u>*

Relative sea-level rise is the relative rise of the sea with reference to the land surface. So far, as sea-level rise and MHW rise do not differ too strong along the Danish, German and Dutch Wadden coasts. Thus, the most important factor is the subsidence of the land surface. Especially in peat-rich areas subsidence may be severe up to 1m/century. This makes such diked areas vulnerable to dike failure and storm surges (e.g. the land loss in the Dollard region in the 16th Century) and forces to heighten the dikes.



Development of the dike profile at the west coast of Butjadingens (http://cuxpedia.de/images/1/19/Deichprofile.jpg)

3) <u>History of storm surges</u>

At the beginning of the large-scale dike era people lived on dwelling hills and higher patches of land, surrounded by relatively high-lying lands. Raising crops was concentrated between spring and autumn. During winter time there was no need to fully protect the agricultural areas and wave overtopping of dikes or even flooding of the land was allowed. Hence, originally dikes were mainly used to protect from summer storm surges and had small dimensions. As relative sea-level rise became more important and several severe storm surges (e.g. 1570, 1634, 1717, 1825, 1953 and 1962) showed that dike heights were too low dikes were gradually heightened and broadened in several steps.

High value industrial area behind the dike of Delfzijl https://beeldbank.rws.nl, Rijkswaterstaat / Harry van Reeken

4) <u>The value of the protected area</u>

As described in point 3, originally the agricultural areas were of low value. When population began to grow they migrated into the polders and higher dikes were needed to protect the area. During the industrial revolution investments in the area grew and better dikes were needed to protect goods and people.

Sources of clay

Originally, dikes were built from clay taken from the tidal marshes and clay layers landward of the dikes. As dike dimensions increased the volume of clay needed also grew. Where dikes were static the volume needed was relatively small. However, where new dikes had to be built the huge amounts of clay needed provided a major challenge. Newly built dikes nowadays mostly consist of a sand core which is covered by a 1 to 2 m thick layer of clay.

As the requirements for dikes became increasingly technical also the quality of the clay became more important. Also, the clay top gradually weathers and should be kept up. Marine clays from the tidal marshes or polders do not always have the right characteristics to use for dike building (too much salt, too much sand). In the Netherlands this made it sometimes necessary to use riverine clays for dike building and improvement. Experiments (for instance, double dike, broad green dike, meegroeidijk) are currently underway to test if different approaches allow the use of local clays and dredging sludge. In Bremen and Hamburg experiments were carried out to use dredged muddy sediments to build dikes. Germany and Denmark continued to use local clays. In Schleswig Holstein it was decided relatively recently to not use clay from the tidal marshes as the mud is needed to grow with (accelerated) sea-level rise.

Research Questions

1 If sea-level rise accelerates dikes have to be strengthened even more, not only due to the higher water levels but also due to the water pressure under and against the dike. At what point do the volumes of clay needed become impractical?
2 Dikes are 80 to 100 m broad. The total sea dike system is several 1000 km long (estuaries included). Thus, for every m higher dike some $80\text{-}100*10^6$ m^3 is needed. This is comparable in magnitude with sedimentation within larger areas of the Wadden Sea over a century. When does clay retrieval from the Wadden Sea system becomes a threat to the ability of the area to grow with sea-level rise?
3 Much clay can still easily be mined landward of the dikes, resulting in lower areas which are often turned into (brackish) wetlands. What is the social support for, and the added value, of such nature resorts?

Stakeholders

From the above it becomes clear that both sedimentation in the Wadden Sea and estuaries and diking with use of local clay both occur over centuries. For both huge amounts of mud (clay) are needed. Taking local clay from the Wadden Sea influences the ecosystem and might improve the quality if done right but decreases the amount of mud for natural functioning of the system. Taking local clay from the area behind the dike may improve the ecology of the area (bird breeding islands, brackish nature etc.), but will decrease the agricultural value of a highly profitable area. Thus, diking which is mainly in the hands of waterboards, municipalities and the state is also of importance for nature conservationists, tourism developers, provinces and farmers.

Literature

Top photo: https://beeldbank.rws.nl, Rijkswaterstaat / Hans Venema

Dike Solutions Broad Green Dike

A Broad Green Dike (BGD) is a gradually sloping dike with grass covering. The construction of a BGD requires a lot of clay. Only then is the dike able to absorb wave energy, without affecting the turf or underlying clay layer.

Because of the large amount of clay needed, experiments have been developed to win clay locally. This can be clay made of mud from a fresh water pond or channel or mud from the sea. The experiment also considers the use of solid clay from the present tidal marsh. It is expected that a dike reinforcement in the form of a BGD that has been made from locally produced clay, is cheaper than a traditional reinforcement with asphalt cover. A green dike (grass) also fits better in the landscape and better fits the nature reserve values. The experiment is aimed at gaining insight into:

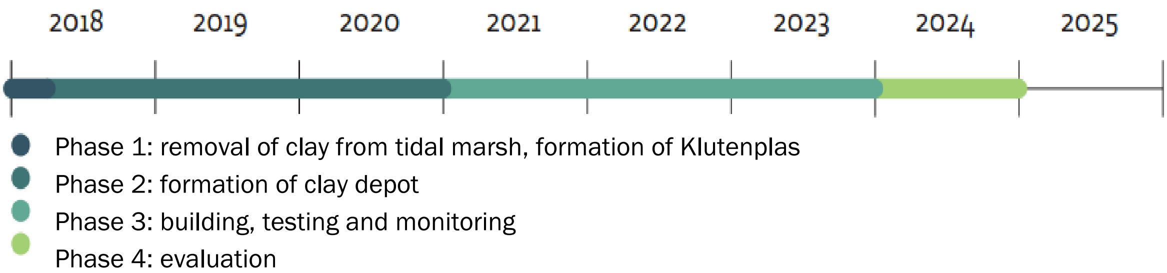
- composition and suitability of locally produced clay as a building material for sea dikes;
- clay ripening processes and strategies;
- opportunities to strengthen dikes with locally extracted clay in a sustainable and safe way;
- management processes with stakeholders needed to build a BGD;
- steps and any necessary adjustments in the legal-planological framework to make a BGD possible;
- possibilities to win clay in the Natura 2000 area of the Ems-Dollart estuary;
- possibilities to produce clay from mud on the tidal marsh in a sustainable way for future reinforcements (clay engine);
- possibilities to store mud in the Natura 2000 area Ems-Dollart in a mud depot to ripen to clay;
- possibilities to realize a BGD in Natura-2000 Ems-Dollart area;
- difference in management and maintenance for a BGD and for a traditional dike with asphalt coverings;
- financial business case, in which costs and benefits are compared to a traditional dike reinforcement;
- suitable locations in the Netherlands for the construction of a BGD in combination with sustainable (local) extraction of clay.

Research
1 Can a BGD be constructed of locally produced clay? More specifically: (a) clay from the tidal marsh in front of the dike; (b) clay produced of (brackish) mud from an inner natural polder (Breebaart); (c) clay produced of (salt) dredging mud originating from the seaport of Delfzijl.

2 Can mud from the Ems-Dollart be matured and converted into suitable clay and what is the most optimal clay maturation strategy for this?
3 Can clay be extracted and matured from the salt marshes within the Ems-Dollart?
4 Can a BGD be built in Natura 2000 area of the Ems-Dollart?
5 Can a BGD be achieved cheaper and faster than a traditional reinforcement, considering the guiding preconditions and principles, including working in the Eems-Dollard?
6 Which characteristics and preconditions a location must meet to be suitable for realization of a BGD?

Approach
Waterboard Hunze en Aa's directs the research on the BGD. Within this study, the pilot “Kleirijperij” is carried out, in which different methods of maturing mud to clay are examined. This pilot is carried out by multiple parties. In 2021 Hunze en Aa’s will build one kilometer of dike following the BGD concept for research purposes. The dike will be tested and monitored for three years.

Planning



- Phase 1, spring 2018 (finished): Digging clay from tidal marshes to construct a depot (left of dike on top photo) and to form the Klutenplas (to the far left on top photo).
- Phase 2, summer 2018 to 2021 (in progress): the construction of the clay depot (finished), in which the mud from the Breebaart polder is matured in different ways into clay.
- Phase 3, 2021 to 2024: Laying, testing and monitoring 1 km Of Brede Groene Dijk.
- Phase 4 2024: Evaluation.

Results
Phase 1 has been completed: digging out clay from the tidal marsh to construct the clay depot, in combination with the construction of the Klutenplas. As early as spring of 2018, the island in the Klutenplas was used by many Avocets as a breeding ground. In preparation for the breeding season of 2019, the island has been made suitable for breeding, by making the soil bare again. The excavated clay proved suitable for the construction of the clay depot. In 2019 the depot became partly filled with mud from polder Breebaart (Phase 2).

Stakeholders
Waterboard Hunze en Aa’s, POV Waddenzeedijken, Eems-Dollard 2050, Province of Groningen, Groningen Seaports, Het Groninger Landschap, Ecoshape, Waddenfonds, Rijkswaterstaat, Maatschappij Onverdeelde Munnikeveen, E.H. Huisman.

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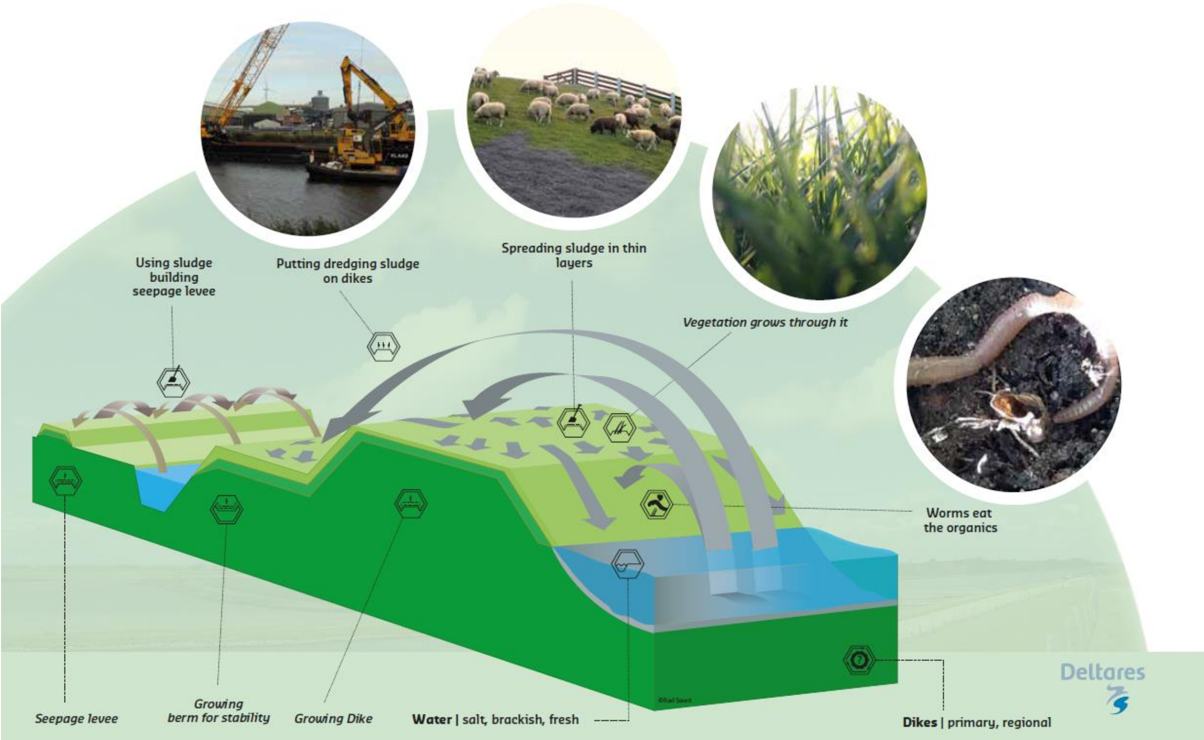
Dike Solutions Growing dike

(Idea)



On the Growing Dike thin lifts of dredge material are deposited directly on the dike and its berm, located in the immediate vicinity of the dredging location. Dredged sediment is deposited at prescribed time intervals according to a deposition scheme, such to develop controlled thin lifts that allow vegetation to survive and adapt while increasing the height and width of the dike and building eventual piping berms and seepage levees.

Water authorities in the Netherlands invest significantly in water management – including the regular dredging of canals and ditches – and flood risk safety. Dredging material is often transported from the dredging location to off-site depots, while dike clay is bought and transported from elsewhere. The Growing Dike project intends to connect supply and demand by beneficially using local dredging material to strengthen nearby dikes and to build piping proof berms. The solution is thought to be applicable to both primary and secondary dikes and for salt, brackish and fresh conditions.

The Growing Dike contributes to:
1) Increasing the resilience with respect to sea-level rise and higher fresh water river discharges;
2) A circular and beneficial use of dredge sediments;
3) Climate and sustainability goals, through reducing the NO_x and CO_2 footprint (less transport);
4) Improving (budget) efficiency by applying dredge material directly near its source;
5) Reducing risks of piping.
6) Increasing biodiversity (vegetation resilience and more sustainable insects-habitats)

Research

Research is needed:

- Learn how "thick" the sludge must be: too thick will not flow out in a regular layer; too watery will result in a flow down the dike.
- Learn how the process can be brought to an industrial scale. Now it is envisaged to do this via a research scheme which allows for a gradual upscaling with clearly defined go-no-go moments.
- Learn which dredging material is suited for placement.

- Learn what influence the sludge has on the dike vegetation, biodiversity and management.
- Learn how dikes and berm develop over time.
- Understand how laws and regulations might hinder the applicability.

Overview of envisaged research

What?	Phase 1,2 (year 1)	Phase 3 (year 2-3)	Phase 4 (year 4-5)	Aim
Laboratory & Small-scale pilots (1 -10 m^2)	Fresh: secondary Salt: secondary	Fresh: secondary Salt: secondary	Fresh: secondary Salt: secondary	Quality, Quantity and density of the mud; Effect vegetation
Medium scale pilots (100-1.000 m^2)	Go-NoGo	Fresh: secondary Salt: primary	Fresh: secondary Salt: primary	Method of placement
Large scale pilots (10.000 m^2)		Go-NoGo	Fresh: secondary Salt: primary	Upscaling to ‘Full commercial application’, in relation with dredging practices
Full commercial application			Go-NoGo	Full commercial application

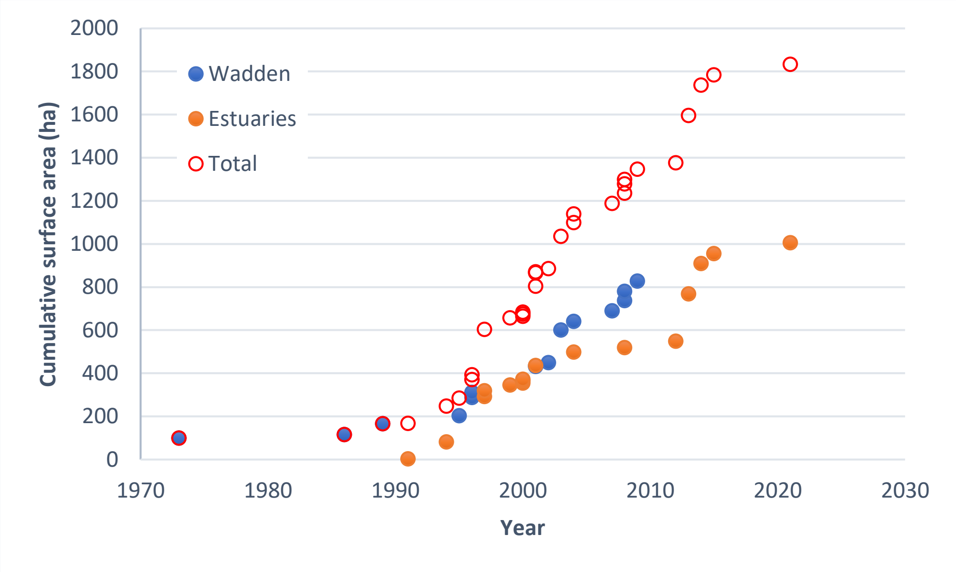
Stakeholder process

Up to now, Deltares has been discussing the idea with individual waterboards Wetterskip Fryslân, Noorderzijlvest, Delfland, Hunze en Aa’s, and Hollandse Delta; the Program to use local sediments (POV-DGG), several high school Van Hall Larenstein and the EcoShape partners: WUR, Boskalis, Arcadis, DHV, Deltares. EcoShape and waterboards have finished their first Inception Phase, which resulted in a program of demands. Based on this. they are currently working to develop a project plan which will focus on learning by doing experiments in the field. The many Dutch laws and regulations pose a major challenge and make partners prudent. At the same time there is a great strive to reduce the NO_x and CO_2 footprint which makes the idea interesting.

Landward Solutions **Managed Realignment**

Along the Wadden Sea mainland coastline, the main estuaries and on some barrier islands managed realignment has occurred. Part of it was accidental due to dike breaches; another part was planned. Plans on large-scale realignment are currently be considered.

An important estuarine and tidal habitat restoration measure is opening areas up and forming new sedimentation space via managed realignment. In the past, such realignments were often accidental when dikes were breached and had to be given up (e.g. Paesummer lannen). Nowadays, with the increased quality of the dikes, realignment is a choice. An important way to address these issues is by managed realignment (or de-embankment): the reintroduction of tidal (storm surge) influence to polders by breaching or removing dikes.

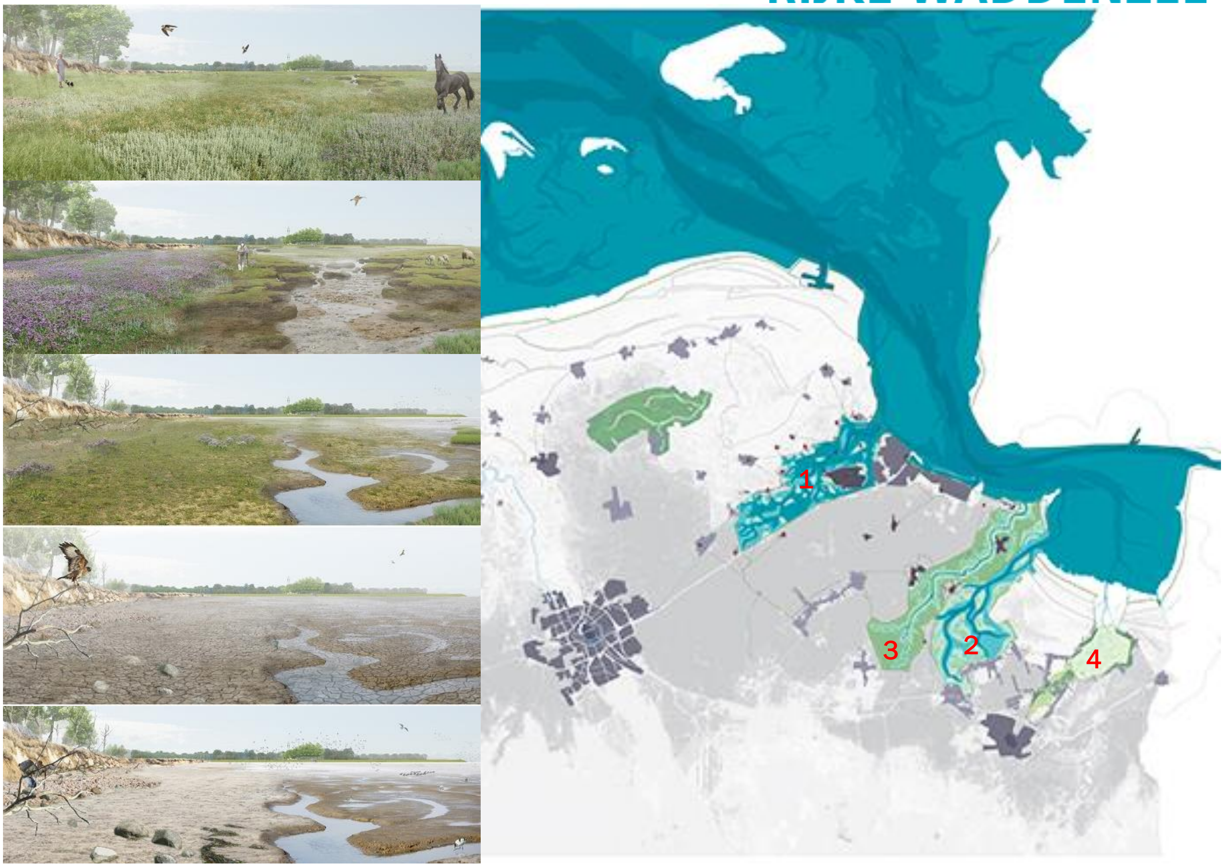


Realignment projects and cumulative area in the estuaries (Ems + Weser + Elbe) and the Wadden Sea outside the estuaries (data mainly Esselink et al., 2016, APA, 2013 and several other sources).

Since 1973 over 30 realignment projects have been implemented in the Wadden Sea Area and the estuaries, totaling to a surface area of more than 1800 ha. In areas which have been embanked during decades to centuries tides are once more introduced. A large part are summer polders previously re-claimed from artificial salt marshes. Next to that former beach plains and dune slacks have been de-poldered on the islands and former dredging dump sites and polder along the estuaries. In some cases, the whole dike was removed. In other cases, only a part of the dike was opened and sometimes (storm-surge) sluices, culverts or dams were installed. Sites with regulated tidal access (Polder Breebaart and Lütetsburger Sommerpolder) have a low success rate, due to high sedimentation rates. The Polder Breebaart must be dug out from time to time to maintain nature values.

For the Ems where turbidity is high which is considered to have detrimental effects on fish migration and primary production. The reason for the high concentration is primarily sought in the ever-smaller dimensions of the estuary, so that fine-grained sediment cannot settle anymore. Thus, there is a desire to de-polder large areas. It is hoped that in that manner sediment deposition of fines will take place on a large scale. The following benefits are expected:

- Reducing the concentration of suspended matter within the estuary;
- Heightening the de-poldered low lying areas so that vulnerability for flooding is reduced;
- Providing chances for large-scale ecological gradients between the present estuary up to the new inland dikes or beyond when streams are restored (a.o. fish migration);
- Providing opportunities for salty agriculture and fish farming;
- Providing opportunities for ecotourism;
- Reducing oxidation of local peat & storing CO_2;
- Refurbishing the water management structure: rerouting canals, heightening the land.



Sketch of subsequent depoldering of low-lying areas and re-poldering after sedimentation. Artist impression of sedimentation at left side http://www.lamaland.eu/projects/rijzend-land/

Presently, there are several possibilities are being considered: from a totally open landscape without dikes to strongly regulated tidal basins. The most comprehensive and futuristic plan is “Rijzend Land” of Bureau Lamaland. It envisages to open polders surrounded by inland dikes which function as sedimentation systems. When the area has become high enough it can be reclaimed, or if sea level rise is high: left to nature. At the same time other realignment projects are still silting up. For comparison: the silting up of a basin of 10 km^2 with 1 cm/yr, would require $0.1*10^6$ m^3/yr of mainly mud. Variants of the plan with even more futuristic approach have been brought forward by the bureau later.

More to the west also plans for double dike construction are being considered. Although reaching less inland than the Lamaland polders, they form a series of managed realignment areas. Flood safety, agriculture, tourism and nature are major drivers for these plans.

Sediment storage

Mostly the areas which have become connected to the tides of the Wadden Sea will silt up. Mostly the areas are still quite sheltered, due to the land-near location and the (partial) presence of dikes. Where storm surge barriers are present the natural erosion is largely halted. Often sedimentation rates in these areas are slightly higher or comparable to averages found in the near tidal marshes (Spadenländer Spitze: 8.8 mm/yr; Holwerder summerpolder: 10 mm/yr) However sometimes sedimentation rates are very high, especially in estuaries. An example is the Kleinsieler Plate in the Weser with a sedimentation rate of 500 mm/yr. To lower sedimentation rates an adaptation of the sill in the entrance was made. Occasionally, sedimentation rates may be very low (e.g. Bildtpollen: 1.2 mm/yr), resulting in a lag relative to mean high water level rise, but that is rare. Nowadays modelling and monitoring can prevent such effects.

The reasons for differences in sedimentation rates are the following:

- Inner dike or outer dike realignment

Whereas outer dike realignment allows full tidal action and relatively natural sediment transports and inner dike situation is often connected via a sill or smaller entrance leading to a smaller tidal range with less transport. Due to heightening of the terrain an open connection can be reduced over time, also reducing sedimentation rates.

- Suspended Particulate Matter concentrations

In general, sedimentation rates are higher at sites with a high SPM concentration. Basically, most realigned areas form a basin where all mud entering the area deposits in the high-water turn of the tides.

- Hydrodynamics of the area

Sedimentation and erosion are partially determined by the exposure of the area. For instance, if a large tidal channel is oriented towards the area, waves can be stronger leading to more erosion. Also, waves generated by ships can lead to very strong erosion. Such effects can be dampened by the design of the realignment measure.

- Elevation and inundation of the site

Differences in elevation will influence the spatial patterns of accretion and salt marsh vegetation development. There is an inverse relation between elevation and vertical accretion. Vegetation may only develop if the area is or has accreted to a few decimeters below mean high water. The vegetation will enhance the sedimentation rates during the pioneer stage and the low and middle marsh stage.

- Slope of the terrain

It has been observed that a shift from sedimentation to erosion occurs once the slope grade becomes higher than 2.5%.

- The number of breaches

If one breach is present, the area functions as a basin in which all the sediment which enters will be deposited. If several openings are present water may flow through and sedimentation rates are reduced or even erosion may occur. This was for instance the case in the Wrauster Bogen in the Elbe, where one site of a creek was closed to stop erosion and enhance habitat development.

In general, it is advised to aim at a development of the site which takes the conditions of the surrounding area into account and use, where possible, the hydrodynamic conditions to optimize the functioning of the area.

Natural values

Over many centuries, and continuing far into the 20th Century, poldering has resulted in the loss of extensive areas of salt marshes. Often, poldering proceeded in a two-step fashion by first building summer dikes resulting in summer polders which are occasionally flooded, after which they were diked more definitely to form polders. Especially along the mainland, poldering rates exceeded the development of new salt marsh, despite the artificial enhancement. Consequently, the size of the current mainland salt marshes is much smaller than the historic reference and salt marsh restoration was called for, especially now nature conservation and coastal defense issues have become increasingly important. Nowadays, the complete hydrodynamic gradient of natural wide salt marshes is only present in a limited number of cases. Thus, de-embankment of summer polders or inland polders will specifically contribute to the restoration of wide marshes. Along the estuaries many of the realignment projects are meant as compensation for the loss of values in the estuary due to shipping lane adaptations, enlarging harbors and expansion of industries. Often such plans are very local in nature and do not consider the relation with the surrounding system. An example where this has been done is the Luneburger Plate, where connectivity to inland streams is restored (see factsheet). Unrestricted tidal access and a moderate grazing regime will help to maintain high species diversity.

With realignment, sub-tidal creeks or ponds, intertidal flats, or supratidal salt marshes are added as extra habitats to the Wadden area and the estuaries. Due to the, often engineered, approach many of these projects have "extra" features which are beneficial to plant life and insects (tidal marshes), fish (connectivity, sheltered kindergarten areas), invertebrates (a.o. shell fish, spiders), specialized birds (breeding without predation). A beneficial by-product is that these areas can then be used to promote recreation and ecotourism, although this is up to now rather limited in the Wadden Sea (e.g. Noarderleeg, Wangeroog) and estuaries (e.g. Luneplate). Modelling can be used to determine if alterations to the site such as creek excavation/filling or elevation raising, can encourage formation of beneficial features. Additionally, modelling will provide information on environmental changes, such as changes to estuarine ebb/flood dominance or heights.

However, the existence of important or protected habitats behind or in front of existing coastal defenses may pose a barrier. Managed realignment can bring about detrimental impacts to many plants, animals and endangered aquatic invertebrates, which are unable to deal with tidal flooding.

Safety against flooding

In the Wadden Sea and in the estuaries managed realignment is mainly targeted at natural values. However, (when outer dikes) it may significantly reduce the cost of providing protection against coastal flooding and erosion. This goal is partially reached due to the formation of a new foreland, shortening the dike, or damping of waves by the newly established foreland. Furthermore, the it is a highly robust measure against climate change futures and generally enhances resilience to unexpected changes. Furthermore, it may locally help to reduce storm surge levels. A bonus is that it helps to mitigate carbon dioxide and methane emissions due to storage in the sediments. because the gases are stored within the sediment deposits. All these factors could be taken into consideration for future planning of new managed realignments. Preferably, managed realignment should be part of a 'strategic' shoreline management plan, which typically consider tens of kilometers of coastline in a holistic way. In this manner a variety of needs within the targeted area is addressed and can maximize benefits and overcome potential constraints.

Stakeholder processes

It requires land to be yielded to the sea, which may require the relocation of important infrastructure or buildings and giving up former functionalities. Thus, often the need of land leads to sharp political and social controversy. A lack of public acceptance is the main barrier for implementation of plans as it is often perceived as a loss of land. Furthermore, it is difficult for the general public to understand how the technology mitigates coastal flooding and erosion and furthers natural values.

The second most important barrier relates to farming communities as managed realignment is mainly implemented on agricultural land, which thus will be lost. If enough compensation is available, many farmers are willing to sell their land. Alternatively, the land may be used in other ways, such as for recreation, (shell)fish farming or salty agriculture, but also then extra investments are needed. It is interesting to notice that the higher-value future crops take up much less land and deliver the same amount of income (see table).

Overview for an area in Groningen, the Netherlands: the present-day areal extent of the crop production compared to a situation after realignment with a mix of present-day crops, shellfish farming and salty crops delivering the same income as in the current situation, leaving some 80% of the area for new nature (data Roggema, 2020). With less natural area the income can increase.

Crops	*Present day situation (ha)*	New nature (ha)	After transition present-day crop (30%)	Shellfish (20%)	Salty crops (50%)
Potatoes	*6,875*	2,750	1,203	859	2,063
Sugar beet	*2,475*	1,980	186	62	248
Wheat	*7,500*	6,750	225	150	375
Dairy cows	*9,975*	8,978	299	200	499
Grass	*9,975*	8,978	299	200	499
Carrots	*1,200*	480	210	150	360
Mais	*1,860*	1,674	56	37	91
Barley	*2,060*	1,854	62	41	103
Total	*41,920*	33,444	2,540	1,700	4,238
%	*100%*	80%	6%	4%	10%

Legal and financial difficulties, for instance concerning the responsibilities and liabilities of certain land owners or authorities, can also be a barrier to implementation for managed realignment schemes.

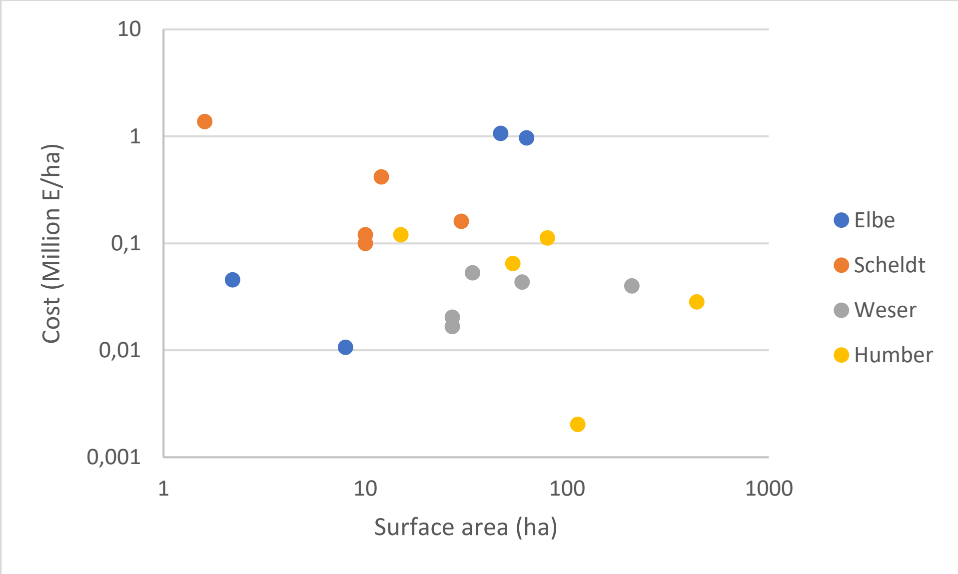
For all these reasons, it is essential that coastal managers fully engage stakeholders and the local community in the process of managed realignment for successful implementation of the schemes. Participation can help to understand legitimate concerns and interests; explain and convince stakeholders of a scheme's merits; manage expectations and develop (a feel of) ownership among stakeholders. Furthermore, care should be taken to plan strategically to avoid problems and detrimental local impacts. Better yet, planning should see to it that it improves the local situation for the surrounding area.

Financial requirements and costs

As can be observed from the 19 examples of realignment projects in estuaries the costs of vary strongly; in this case between 2000 to 1.4 million Euro per hectare. The differences are due to:

- Cost of purchasing land (mostly high)
- Compensation to occupiers
- Dismantling human-made structures to prevent marine pollution (buildings, roads, pipes, wires)
- Building/reinforcing new sea defenses to protect the hinterland
- Optional: storm surge barriers
- Optional: (restoring) connectivity to fresh water flows
- Availability and cost of human resources including expertise
- Landscaping
- Scale and frequency of monitoring

Sometimes local values lead to steep cost increases. In Germany, the cost of realignment is seen as a major barrier, since most of the North Sea defenses are in excellent condition. Monitoring and modelling in the preparation phase will help to maximize the benefits and lower the costs.



19 examples of managed realignment projects in several estuaries: x-axis: area; y-axis cost per ha; both on log scale (data from TIDE, 2013).

Relevant conditions

Managed realignment is possible when:

- Coastal defenses are present (preferably with extra already existing defenses landward of the sea dike)
- Low-lying land is available
- Flood or coastal defense systems need to be improved
- A sustainability-oriented coastal management attitude is present
- There is a desire or need to create sub-tidal creeks or ponds, intertidal flats, or supratidal salt marshes
- There is societal awareness about the benefits of managed realignment
- Realignment brings advantages

Lessons learned

- Identify requirements for salt marsh restoration: be realistic in formulating dynamic goals with a time trajectory
- Management plan for salt marsh restoration (incl. priorities)/ Feasibility study
- Discuss with stakeholders and adapt plans
- Detailed planning: do consider terrain level heights with reference to MHW) at an early stage.
- Choose the right measures for the site (consider tides, natural hydrology, preexisting top soils and plants, terrain levels and likely sedimentation rates)
- Discuss with stakeholders and adapt plans
- Make cost calculation
- Check functionality via hydrological models in combination with local gauge data.
- Find money and sponsors
- Realize the work
- Organize long-term monitoring & evaluation
- Ensure scientific analysis
- Share results

Discussion points

- The costs of managed realignment are often high. What is a sound approach to lower the costs?

- Large-scale realignment programs which are part of a comprehensive coastal development plan may serve several goals at once, consider the regional context (and add to that) and provide more possibilities to solve local problems due to realignment. Should that be the future way forward?
- Large amounts of mud are being deposited in these newly opened areas: should such muds be primarily/temporarily used for nature development, or primarily to heighten the area and to make it more resilient to sea-level rise or both?
- Should realignment be based on a life-cycle approach or is this useless given the unknown future velocity of sea-level rise?
- Should clean mud be kept in the Wadden Sea system and estuaries or is it better to take it out and use it on land?

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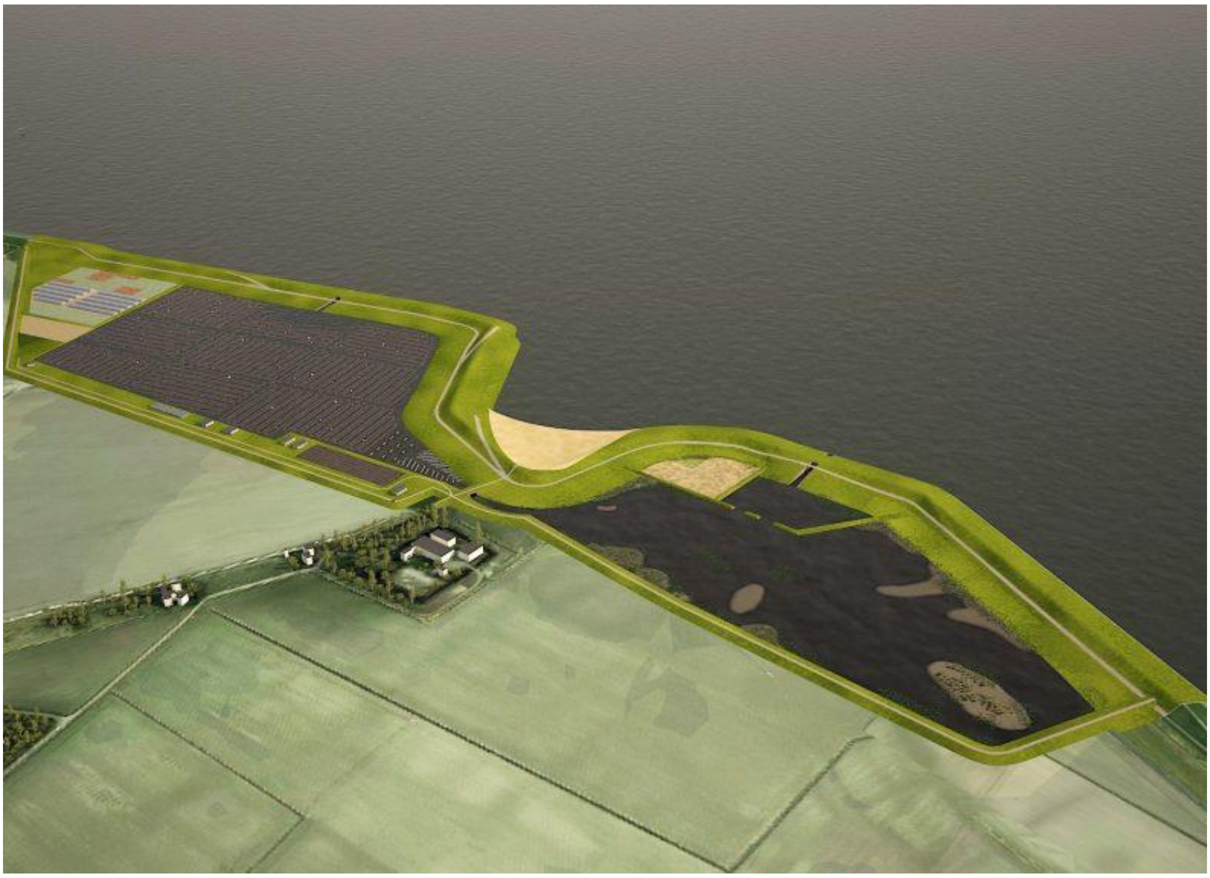
Landward Solutions The Double Dike



In a double dike not one, but two dikes provide water safety. Behind the first dike a lower dike is present in the hinterland. This creates a sustainable and climate-resistant coastal defense, aimed at growing along with sea-level rise. In addition, the combination of two dikes is also of value for nature, agriculture and recreation. Between the dikes, an area of land develops where salt water can flow freely in and out through one or more tidal culverts. In this intermediate area there is room for salty crops, nature development and mud deposition.

Water board Noorderzijlvest is currently implementing the dike improvement Eemshaven-Delfzijl. In this dike improvement project, a pilot will be carried out for the concept of a double dike to develop know-how and knowledge for such an approach.

Research Questions

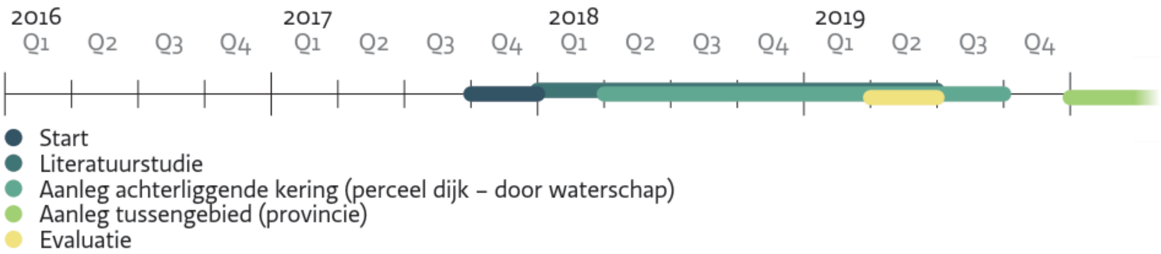
1 How can the stakeholders process around the double dike be organized?
2 What is the social support for, and the added value, of a double dike?
3 How does a double dike contribute to water safety?
4 What costs and benefits are associated with the implementation and management of a double dike?

Approach

The province of Groningen and waterboard Noorderzijlvest carry out the pilot together. In addition, the waterboard is responsible for the dikes and the province for the polder in between. The study will be based on information obtained from a desk study, interviews and the what is learned from the pilot. At Nieuwstad, N of Delfzijl, the Netherlands, waterboard Noorderzijlvest builds a second dike behind the present dike. The outer dike is reinforced and should dampen the waves. During design conditions wave overtopping of the outer dike is allowed. Under such conditions the inner lower second dike should provide protection and safety from these overtopping water volumes.

Between the two dike two polders will be present. The southern one (10 ha) will become a nature area with tides, where mud can deposit and a new tidal marsh with pioneer vegetation can form. The northern polder (27 ha) is an area where experiments can be carried out with shellfish farming and innovative salty agriculture, such as Salicornia. Now the outer dike has been reinforced and the inner dike has been built. The northern area is being prepared for agriculture.

Planning



The start was in 2016 and by 2018 the building of the pilot project started which will last up to 2022.

Results

In 2018, the new inland dike was built. The sediment used for this has been excavated from the area located between the new dike and the existing seawall. To that end the top layer of this approximately 50-hectare intermediate area was excavated. The new dike was completed in 2019 and encloses the polder. In 2021 tides will be allowed in the polder.

In 2019, the call for the exploitation has taken place and further activities were developed for the spatial planning of the polders and the construction of an in/exhaust construction in the existing sea wall.

Future ideas

At the moment, the Double Dike-concept receives a lot of attention. At many places along the Wadden Sea mainland coast of Groningen there are older dikes still present within the landscape. In the province of Frisia this is not so much the case but also there, stakeholders (waterboards, province and local interested parties) are considering the possibilities. The general idea is that the outer dike will break the wave attack during design conditions and that the inner dike will prevent flooding by storm surge levels. The polders in between will be used for tourism, salty agriculture, nature and mud entrapment. If developed on a large scale a broad sea-defense zone would form. The double dike provides safety from flooding and over a longer period the silting up of the polder will provide a heightened belt as a foundation for a sustainable sea defense. At the moment reconnaissance studies are being carried out.

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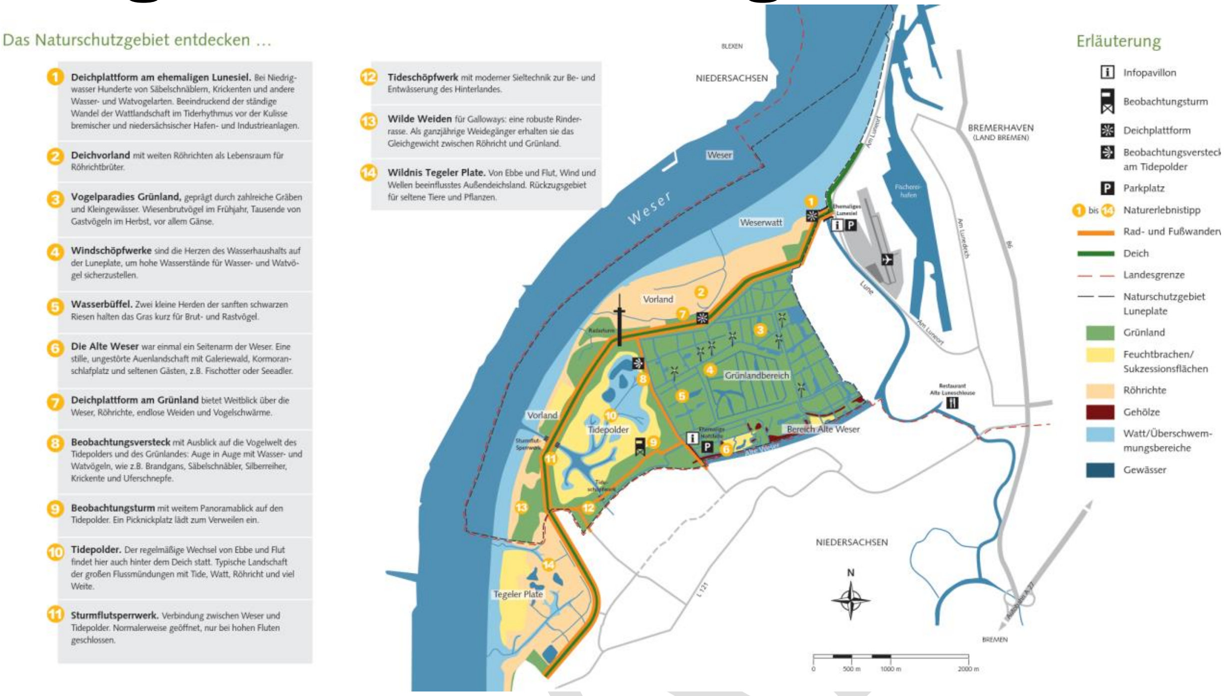
Landward Solutions Luneplate managed realignment with storm surge lock



The Luneplate nature reserve (1438 ha) has been ongoing since 1996 but was extended especially from 2003 onwards. With the realization in 2012 of the tidal polder it was completed. The latter is a remarkable form of managed retreat as tidal channels, banks and tidal flats have been constructed in a former agricultural area which is in open connection with the Weser estuary via an inlet with a storm surge lock. The area is rapidly silting up with mud.

In the 14th century the mouth of the Weser was a delta with several separate channels and was also connected to the Jade. Butjadingen was still an island at that time. Before the major Weser correction by Ludwig Franzius in 1888 the tidal channels constantly changed course. The island Luneplate formed around 1800 in the Weser estuary due to mud deposition and became covered with reeds. It was separated from the mainland by the tidal river Lune, the Weser and one branch of the Weser, the Älte Weser". It was poldered in 1922 and used for agriculture. In the 1920s, the extension of the fishery port area was under discussion. In 1939, the area was designated as a new industrial and fishery port and as a naval base. Later, in the 1960s, the plans for industrialization re-emerged and led to an agreement between the federal states of Bremen and Lower Saxony in 1979. However, all these plans were never realized. Since 1996, an area of 1438 ha of the Luneplate was in steps given a nature function as ecological compensation for the expansion of the Container Terminal Bremerhaven. The total costs for the project are around 50 MEuro. It has especially high value for bird life. Some 70 species of birds use the area during part of the year.

In 2012, as compensation for Terminal CT4 and other harbor related projects, a former 90 years old agricultural area of 215 ha called Tidepolder was changed into a tidal polder, by removing 560.000 m³ of sediments. An inlet in the Weser dike and a dug out tidal channel system allow for unhindered flow of a tidal prism of $1*10^6$ m³ (the amount of water flowing in during flood plus the amount flowing out during ebb divided by two). The tidal polder can be closed by means of a storm-surge lock during floods above +2.5m above Normalhöhennull (NHN). Since completion of the polder and the opening of the storm surge lock in autumn 2012, watercourses and banks changed, and new mudflats formed. Fish, crabs, tubifex worms, mussels and snails came in with the Weser water and have quickly colonized the new habitats. At this location the salinity of the Weser estuary is characterized as oligohaline (0.5-5 g salt per kg water). Saltwater-tolerant plants have started to grow along the banks of gullies, tidal ponds, on higher mud flats and in the grasslands. Galloway cows graze from spring to autumn to keep the landscape open.

Panorama tidepolder on the Luneplate in 9th of February 2020.

At the southern edge of the Luneplate the Alte Weser area with a size of 130 ha is present. The habitat function of the Alte Weser, a former branch of the Weser, is water fauna. The adjacent wide shore zone is used for natural succession typical of floodplain areas. The shore zone passes into temporary to regularly extensively grazed grassland biotopes. Here side arms and ponds were dug out. Construction measures were completed in 2012.

Via the tidal polder, the 28 km^2 inland Dedesdorfer marsh area to the south east of it, can be flooded during the summer season or drained from surplus rain water during the winter season. This done via a tidal pumping station, which has been placed in 2009. With two pumps in total some 5.2 m^3/s can be pumped. During pro-longed storm surges the tidal polder can serve as a catchment basin for water which is pumped out of the Dedsdorfer area

Outer dikes, to the W of the Luneplate, Galloway cows are grazing the meadows and control the development of peat area. To the S of this area the older compensation area of the Tegeler Plate is present. East of the tidal polder, in the about 209 ha area of the “Vogelparadies Grünland”, the agricultural structure of ditches has been widened and extended. The works were ended by 2010. Four polders with differing high-water levels are maintained via a series of windmills and six dams in the ditches. In this way birds can find food in a marshy environment even during a hot summer. The area is primarily developed for breeding and roosting birds. Agriculture is restricted to extensive grazing. The two herds of newly introduced water buffaloes are meant to maintain a landscape favorable to breeding and resting birds. Locally this is supplemented by mowing. During autumn the ditches are cleared to avoid filling up and clogging. More than 10.000 geese are present in winter. A 51-ha large compensation area developed in 1996 for the Terminal CT III has been integrated in this area. Also, here the water levels are regulated, and the area is used for extensive grazing.

The Luneplate has become property of the Land Bremen as recent as 1st of January 2010 when a large part was transferred by Lower Saxony (Land Oldenburg) after the buy by Bremen (30 million Euro). Bremen aims at integrating the planning of maintenance and development measures for the compensation area and of management measures for the European nature conservation area. The holistic concept is intended not only to cut costs, but also to pinpoint untapped potential for environmentally compatible local leisure uses. At present, it is the largest nature reserve of the Freie Hansestadt Bremen. On 17 February 2015, the 1438 ha Luneplate Nature Reserve was designated as part of the Natura 2000 network. A large part of the Luneplate is consisting of the EU bird sanctuary "Luneplate" (EU-Reporting No. DE2417-401, with a size 940 ha). It has outstanding importance as a resting area for Nordic Geese and Swans. As a breeding area, it is of great importance for species of birds that inhabit reed lands as well as for waterfowl. Since 2014 an information sites and a tower and observation posts to watch bird life were put in established along the walking and bicycling routes in the area to make it more accessible to the public.

Research

All areas are monitored on a regular basis on biotypes and flora. It turns out that the large part of the Tide polder developed into biotopes influenced by brackish water. Due to ongoing sedimentation the subtidal areas, which originally covered some 10% of the area have largely changed into intertidal to supratidal areas. Within the “Vogelparadies Grünland” area a species-rich mesophilic and wetland biotope developed which is brought about by the water levels and extensive grazing.

Lessons learned
This is an example of integrated management of several different areas with a wetland character. In it, the relatively large managed retreat area of the Tidepolder is the only part which receives massive volumes of mud from the estuary. The silting up is proceeding rapidly, and the question arises how long this can continue.

Stakeholder process
Originally the Luneplate was largely property of Lower Saxony, who also was interested in the development of the Ports of Bremen, as was the Freie Hansestadt Bremen and Bremenports GmbH & Co. KG. This is also visible in the compensation measures which already started in 1995/96 and were extended in the period 2003-2012, thus partially before it was official property of Bremen. The biggest push came from the discussions to establish an offshore harbor for windmill production on the Luneplate. Nature protection organizations threatened to fight this initiative up to the European Union. As the CT4 harbor extensions were needed badly it was decided to cancel these plans in 2010. At the same time the final and biggest nature compensation projects on Luneplate were carried out. The developments are largely paid for by Bremenports GmbH & Co. KG and the EU European Fund for Regional Development.

Discussion points
The area of the Tidepolder is silting up relatively fast. It implies that the areal extent of subtidal and perhaps intertidal areas will decrease, which will lead to a loss of natural diversity. The question is therefore if such costly measures are worth their money.

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https://taz.de/!426064/

Research

A development period of 15 years has been foreseen for the Luneplate area. Within the development period, different ecological success checks are carried out at different intervals on the various sub-areas (grassland area, tidal polder, old Weser area, eastern extension area) of the Luneplate. These are intended, on the one hand, to document the stock developments on the land and, on the other hand, to indicate whether the fixed compensation targets are being met with the current development on the land.

Approach

Results

Lessons learned

Stakeholder processes

Discussion points

Literature

Naturschutzgebiet

Luneplate

Schutzgebiet	Ausgewiesen als Schutzgebiet am 14.3.2015
Größe	1438 ha
Naturraum	Würdener Marsch, Unterweser mit Würdener Marsch
Lage	Bremerhaven
Lebensräume	Flussunterlauf mit Tideeinfluss, Priele und Brackwasserwatten, Röhrichte, Feuchtbrachen, salzbeeinflusste Marschengrünländer mit winterlichen Überschwemmungen, Flutrasen, Gräben und Stillgewässer, Gehölze

Eine Flussinsel wird Naturschutzgebiet

An wichtigen Vogelzugwegen und in unmittelbarer Nachbarschaft des Nationalparks Wattenmeer gelegen, ist die ehemalige Weserinsel Luneplate ein Lebensraum für Wasser- und Watvögel von internationaler Bedeutung. Bis 2010 Teil des Landes Niedersachsen, ist das Gebiet heute mit über 1400 ha Gesamtfläche das größte Naturschutzgebiet im Land Bremen und Bestandteil des europäischen Schutzgebietssystems Natura 2000.

Marschengrünland, Außendeichsflächen mit weitläufigen von Prielen durchzogenen Röhrichten, Wattflächen, ein als Kompensationsmaßnahme angelegter angelegter Tidepolder und ein alter Seitenarm der Weser, die »Alte Weser«, prägen das Landschaftsbild.

Die Luneplate war in den letzten beiden Jahrhunderten einem stetigen Wandel unterworfen: Um 1800 durch Schlickablagerungen als Insel in der Wesermündung entstanden, hat sie durch fortschreitende Eindeichung ihren Inselstatus um 1922 verloren. Zunehmend intensiv landwirtschaftlich genutzt und zur Industrieansiedlung vorgesehen, erhielt die einstige Flussinsel in den letzten Jahren durch die Gestaltung von Kompensationsflächen, die als Ausgleich und Ersatz für den Naturverlust beim Bau des Containerterminals in Bremerhaven von der bremischen Hafengesellschaft bremenports umgesetzt wurden, ihr heutiges Aussehen. Aus intensiv genutzten landwirtschaftlichen Flächen entstand wieder ein wertvoller Naturraum.

Ein Ausflug lohnt sich

Wesentlich für die Realisierung dieser Naturerlebnismaßnahmen war die Förderung im Rahmen des Europäischen Fonds für regionale Entwicklung (EFRE).

Besucher und Besucherinnen, zu Fuß oder mit dem Fahrrad, können sich auf vielen Infotafeln über den Lebensraum Luneplate informieren. Am Tidepolder bzw. am Weserdeich beeindruckt das Wechselspiel von Ebbe und Flut. Ein mehrgeschossiger Beobachtungsturm bietet einen sehr guten Überblick über den gesamten Tidepolder. Im Beobachtungsversteck kann man besonders im Frühjahr und Herbst mit etwas Geduld die Vogelwelt zum Greifen nah erleben (Bitte unbedingt ein Fernglas mitnehmen).

Containerterminal Bremerhaven

Wiesenpieper

Vogelparadies Luneplate

Auf dem von zahlreichen Wasserläufen durchzogenen ca. 300 ha großen Marschengrünland hinter dem Deich brüten im Frühjahr bis zu 500 Paare Wiesenvögel wie Kiebitz, Rotschenkel, Uferschnepfe, Wachtel, Feldlerche und Wiesenpieper. An den Gewässerufern sind Silber- und Graureiher, Löffel-, Krick- und Knäkente zuhause, im Röhricht Rohrweihe, Wasserralle, Blaukehlchen, Bartmeise und Schilfrohrsänger.

Im Frühjahr können die Brutvögel bei Balz, Nestbau und Jungenaufzucht von den Beobachtungspunkten, aber auch von Wegen und Deichen aus beobachtet werden.

Gastvögel sind Zugvögel, die den Winter in wärmeren Gegenden verbringen. Standvögel dagegen bleiben das ganze Jahr in ihrer Heimat.

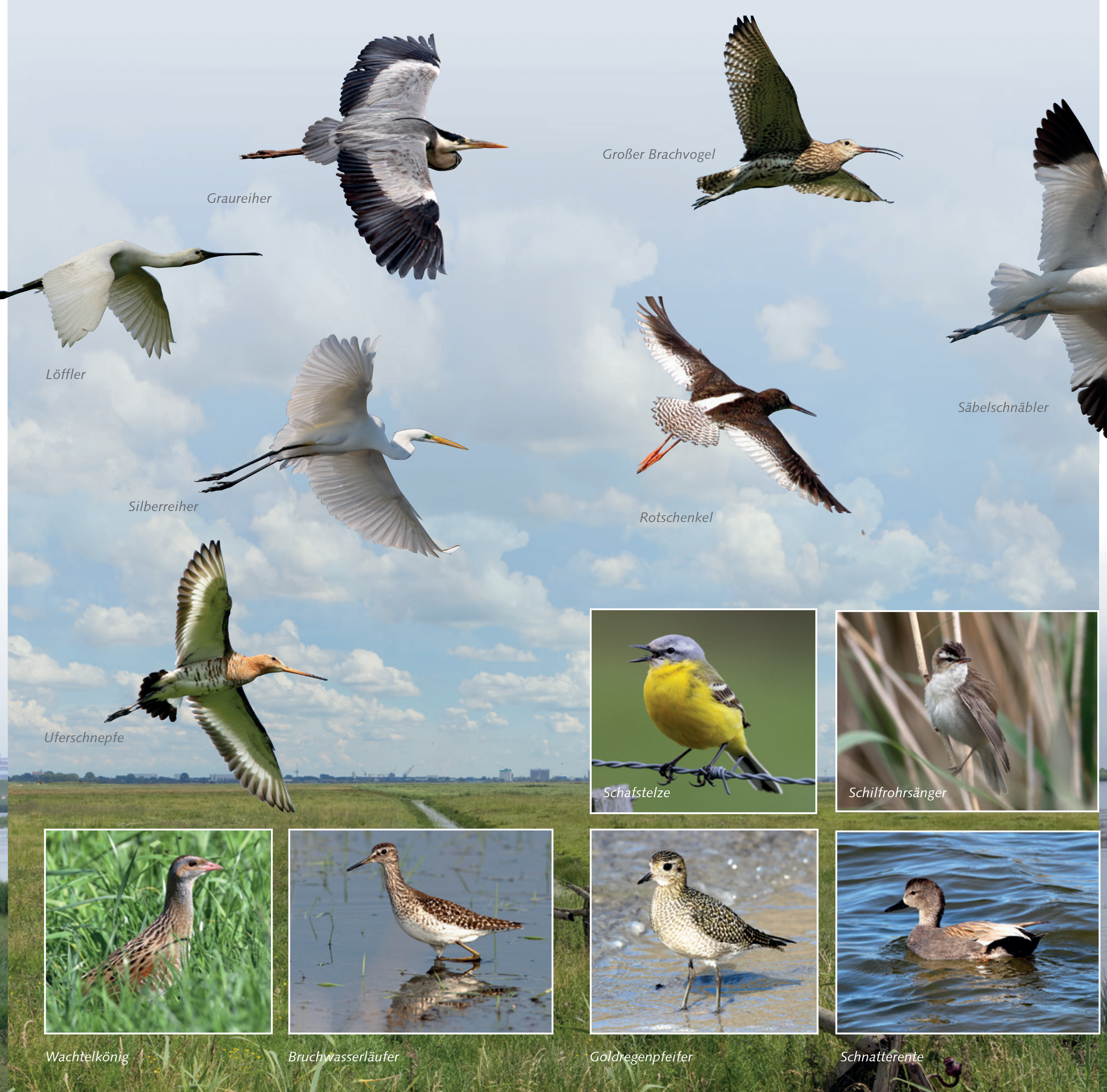
Besonders beliebt sind die Watt- und Wasserlandschaften der ehemaligen Weserinsel bei Gastvögeln. Dabei handelt es sich überwiegend um Wasser- und Watvogelarten, die hier mit bis zu 70 Arten auf dem Durchzug im Herbst und Frühjahr rasten, um Nahrung aufzunehmen.

Einige Winter- oder Mausergäste verbringen Wochen und Monate auf der Luneplate, so z.B. der Säbelschnäbler, der im Hochsommer mit bis zu 3.000 Vögeln seine Federn wechselt und auf den Wattflächen, am Weserufer und im Tidepolder Nahrung findet. Oder die Weißwangen- oder Nonnengans, die auf dem Grünland der Luneplate mit weit über 10.000 Artgenossen überwintert.

Kiebitz

Zwergsäger

Mit ein wenig Glück können Sie viele verschiedene Vogelarten auf dem Grünland oder im Tidepolder erleben.



Graureiher

Großer Brachvogel

Löffler

Silberreiher

Rotschenkel

Uferschnepfe

Säbelschnäbler

Schafstelze

Schilfrohrsänger

Wachtelkönig

Bruchwasserläufer

Goldregenpfeifer

Schnatterente

Der Säbelschnäbler – das Topmodel unter den Watvögeln

Haute Couture in schlichtem Schwarz-Weiß – das ist der Säbelschnäbler, der nicht nur für Kenner der Szene als die schönste Watvogelart gilt. Mit vielen Artgenossen bevölkert er nach der Brutzeit ab Juli die weiten Schlickwattflächen, um hier in aller Ruhe seinen Gefiederwechsel, die Mauser, durchzuführen. Das kostet viel Energie und das Flugvermögen ist in dieser Zeit eingeschränkt. Umso wichtiger ist ein sicherer Ruheplatz mit viel Futter.

Die Ruhe ist durch die Weite des Weserwatts gewährleistet. In diesen Wattflächen brodelt das Leben: Unzählige kleine Tiere leben in diesem grundlosen Matsch, auf dem nur Leichtgewichte mit großen Füßen laufen können. Schlickkrebse und Würmer sind die Nahrungsgrundlage, damit das neue Federkleid des Säbelschnäblers wieder so schick wird wie das alte.

Auch andere Wasser- und Watvogelarten nutzen die Nahrungsvielfalt des Weserwatts, z.B. Brandgans, Krickente, Pfuhlschnepfe, Dunkler Wasserläufer und Großer Brachvogel.

Das Weserwatt südlich von Bremerhaven ist nach Jadebusen und Dollart der drittgrößte Mauserplatz des Säbelschnäblers an der Deutschen Bucht.

Zu sehen ist der Säbelschnäbler im Weserwatt von Juli bis November.

Knäkente

Pfuhlschnepfe

Erhalt der Vielfalt im Grünland

Um dauerhaft die Vielfalt der Lebensräume im Grünland der Luneplate zu erhalten, sind ein ausgeklügeltes Wasserstandsmanagement und eine naturverträgliche Beweidung erforderlich.

Sechs Stauanlagen kontrollieren den Wasserstand in den Gräben, damit die Vögel auch in heißen Sommern auf feuchten Wiesen ihre Nahrung finden können.

450 Büffel und Rinder sorgen für unterschiedlich hohen Bewuchs auf den Grünlandflächen, Voraussetzung für einen guten Bruterfolg bei Wiesenvögeln. Einige Flächen werden gemäht und im Herbst werden die Gräben geräumt, um ein Zuwuchern zu verhindern.

Nicht nur für Vögel attraktiv

[1]

[2]

Charakteristische und seltene Pflanzenarten wie Wiesen-Kümmel, Wiesen-Pippau, Sumpf-Dreizack, Schwanenblume, Sumpf-Schwertlilie, Strandsimse, Laugenblume, Strand-Aster sowie die Kuckucks-Lichtnelke sind auf der Luneplate heimisch.

Auch Reh, Feldhase, Rotfuchs, Hermelin und andere Säugetiere finden hier geschützte Rückzugsräume. In den Gräben tummeln sich zur Laichzeit Amphibien wie Seefrosch, Erdkröte und Grasfrosch. An der »Alten Weser« ist die Ringelnatter zuhause. Eine Vielzahl von Insekten, wie Libellen, Heuschrecken, Laufkäfer, Zikaden und Nachtfalter sowie weitere wirbellose Arten, wie Krebse und Schnecken, vervollständigen das Bild.

Abb.: 1 Wiesenschaumkraut; 2 Sumpf-Platterbse; 3 Graugans; 4 Weißwangengans; Hintergrund: Weserwatt

Die meisten hier abgebildeten Vögel sind Zugvögel. Vögel die das ganze Jahr bei uns bleiben (Standvögel) sind mit einem gelben Punkt ● gekennzeichnet.

[3]

[4]

Der ostatlantische Zugweg

Auf der ganzen Welt gibt es Routen, auf denen Vögel im Herbst in die wärmeren Überwinterungsgebiete ziehen und im Frühjahr zurück in ihre Brutgebiete. Die Luneplate liegt auf einer solchen Route, dem Ostatlantischen Zugweg. Er beginnt in den Brutgebieten des arktischen Nordens von Sibirien, Skandinavien und Grönland, führt durch Europa an das Wattenmeer der Nordsee und weiter an Westeuropas und Westafrikas Küsten entlang bis an die Südspitze Afrikas. Mehrere tausend Kilometer legen einige Arten auf ihren Flügen zurück. Rekordhalter ist die Küstenseeschwalbe mit ca. 40.000 km Zugstrecke in einem Jahr.

Grafik: Adam Nowara

Erlebnisraum Natur

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bremenports
Bremen Bremerhaven GmbH & Co. KG

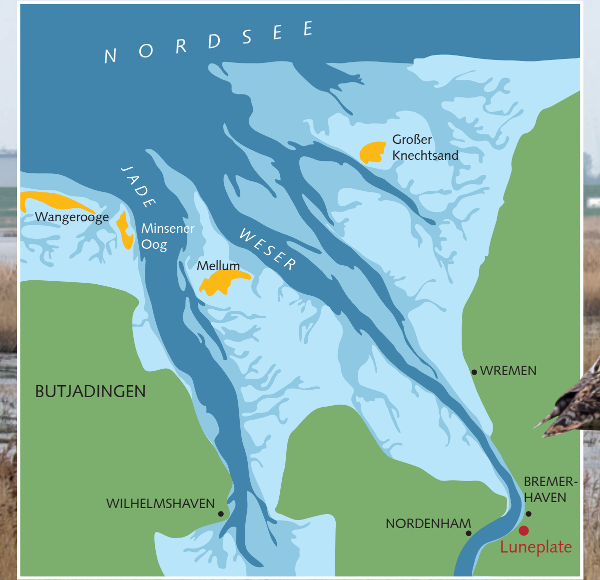
Austernfischer ●

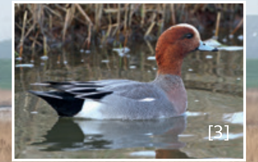
Lebensraum Weserästuar

Durch die gewaltigen Kräfte von Ebbe und Flut hat sich das Weserästuar ständig verändert. Noch im 14. Jahrhundert war die Wesermündung ein Delta mit mehreren Mündungsarmen und stand mit der Jade in Verbindung. Butjadingen war damals noch eine Insel. Erst als Ludwig Franzius die Weser 1888 begradigte und eindeichte, waren die Zeiten des stetigen, natürlichen Wandels vorbei. Geblieben ist das Überfluten und Trockenfallen von Wattflächen im Rhythmus der Gezeiten.

Ein Ästuar ist eine von Ebbe und Flut beeinflusste Flussmündung. Neben der Weser finden wir in Deutschland Ästuare an der Elbe, Ems und der Eider.

Auch heute noch zählen die Ästuare zu den Lebensräumen mit den dynamischsten natürlichen Prozessen. Überlebenskünstler im ständigen Wechsel der Gezeiten im Grenzbereich von Meer- und Süßwasser sind Muscheln, Würmer und Krebse. Diese bewohnen Wattflächen und Gewässerböden in unglaublich großer Zahl. Eine willkommene Mahlzeit für hungrige Watvögel.





Durch die vierte Ausbaustufe des Containerterminals im Norden von Bremerhaven wurden große Bereiche des wertvollen Ästuarlebensraums überbaut. Als Kompensationsmaßnahme für den Terminal CT4 sowie für weitere hafenbezogene Projekte entstand auf etwa 220 ha ehemaligen Ackerflächen der Tidepolder. Ein Sperrwerk im Weserdeich ermöglicht den ungehinderten Zu- und Abfluss des Wassers in ein weitläufiges, eingedeichtes Prielsystem. Eine Million Kubikmeter Wasser werden so zwischen jedem Hoch- und Niedrigwasser bewegt. Geschlossen wird das Sperrwerk nur bei sehr hohen Wasserständen.

Über ein Tideschöpfwerk kann die im Binnenland gelegene Dedesdorfer Marsch be- und entwässert werden.

[4]

Neue Wattflächen im Tidepolder

Seit Fertigstellung des Polders und der Öffnung des Sperrwerkes im Herbst 2012 haben sich Wasserläufe und Ufer verändert, es haben sich neue Wattflächen gebildet.

Dreistachliger Stichling

Schlickkrebse

©C. Löser / Wikipedia

[9]

Fische, Krebse, Muscheln und Schnecken sind mit dem einströmenden Weserwasser eingewandert und haben die neuen Lebensräume schnell besiedelt. Salzwassertolerante Pflanzen wie Brackwasserröhricht, Strandaster, Laugenblume und Strand-Dreizack wandern entlang der Ufer von Prielen, Tidetümpeln und Wattflächen bis ins Marschengrünland.

Von dieser Entwicklung profitieren nicht nur Wasser- und Watvögel, auch Brutvögel der Röhrichte siedeln sich an. Tausende von Enten, Gänsen und Watvögeln rasten hier auf dem Durchzug oder verbringen am Tidepolder den Winter.

[10]

[7]

[8]

© BS Thurner Hof/Wikipedia

Abb. 1 Bekassine; 2 Kiebitz; 3 Pfeifente; 4 Brandgans; 5 Blässgans; 6 Kampfläufer; 7 Großer Brachvogel; 8 Krickente; 9 Seeadler ; 10 Alpenstrandläufer

Beachten Sie bitte:

- *Viele Vögel haben große Fluchtdistanzen und reagieren sehr empfindlich auf Störungen.*
- *Bitte halten Sie sich nur auf den vorgesehenen Wegen auf und beachten Sie die Durchgangsverbote!*
- *Die Wege dürfen nicht mit Kraftfahrzeugen befahren werden. Bitte nutzen Sie die Parkplätze am ehemaligen Lunesiel und der ehemaligen Hofstelle.*
- *Hunde müssen immer angeleint sein.*
- *Die Tegeler Plate und die »Alte Weser« dürfen nicht betreten werden. Diese Bereiche können Sie auf einer der geführten Exkursionen erleben.*

Das Naturschutzgebiet entdecken …

1. **Deichplattform am ehemaligen Lunesiel.** Bei Niedrigwasser Hunderte von Säbelschnäblern, Krickenten und andere Wasser- und Watvogelarten. Beeindruckend der ständige Wandel der Wattlandschaft im Tiderhythmus vor der Kulisse bremischer und niedersächsischer Hafen- und Industrieanlagen.
2. **Deichvorland** mit weiten Röhrichten als Lebensraum für Röhrichtbrüter.
3. **Vogelparadies Grünland,** geprägt durch zahlreiche Gräben und Kleingewässer. Wiesenbrutvögel im Frühjahr, Tausende von Gastvögeln im Herbst, vor allem Gänse.
4. **Windschöpfwerke** sind die Herzen des Wasserhaushalts auf der Luneplate, um hohe Wasserstände für Wasser- und Watvögel sicherzustellen.
5. **Wasserbüffel.** Zwei kleine Herden der sanften schwarzen Riesen halten das Gras kurz für Brut- und Rastvögel.
6. **Die Alte Weser** war einmal ein Seitenarm der Weser. Eine stille, ungestörte Auenlandschaft mit Galeriewald, Kormoranschlafplatz und seltenen Gästen, z.B. Fischotter oder Seeadler.
7. **Deichplattform am Grünland** bietet Weitblick über die Weser, Röhrichte, endlose Weiden und Vogelschwärme.
8. **Beobachtungsversteck** mit Ausblick auf die Vogelwelt des Tidepolders und des Grünlandes: Auge in Auge mit Wasser- und Watvögeln, wie z.B. Brandgans, Säbelschnäbler, Silberreiher, Krickente und Uferschnepfe.
9. **Beobachtungsturm** mit weitem Panoramablick auf den Tidepolder. Ein Picknickplatz lädt zum Verweilen ein.
10. **Tidepolder.** Der regelmäßige Wechsel von Ebbe und Flut findet hier auch hinter dem Deich statt. Typische Landschaft der großen Flussmündungen mit Tide, Watt, Röhricht und viel Weite.
11. **Sturmflutsperrwerk.** Verbindung zwischen Weser und Tidepolder. Normalerweise geöffnet, nur bei hohen Fluten geschlossen.
12. **Tideschöpfwerk** mit moderner Sieltechnik zur Be- und Entwässerung des Hinterlandes.
13. **Wilde Weiden** für Galloways: eine robuste Rinderrasse. Als ganzjährige Weidegänger erhalten sie das Gleichgewicht zwischen Röhricht und Grünland.
14. **Wildnis Tegeler Plate.** Von Ebbe und Flut, Wind und Wellen beeinflusstes Außendeichsland. Rückzugsgebiet für seltene Tiere und Pflanzen.

Erläuterung

- Infopavillon
- Beobachtungsturm
- Deichplattform
- Beobachtungsversteck am Tidepolder
- Parkplatz
- 1 bis 14 Naturerlebnistipp
- Rad- und Fußwanderweg
- Deich
- Landesgrenze
- Naturschutzgebiet Luneplate
- Grünland
- Feuchtbrachen/ Sukzessionsflächen
- Röhrichte
- Gehölze
- Watt/Überschwemmungsbereiche
- Gewässer

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Luneplate

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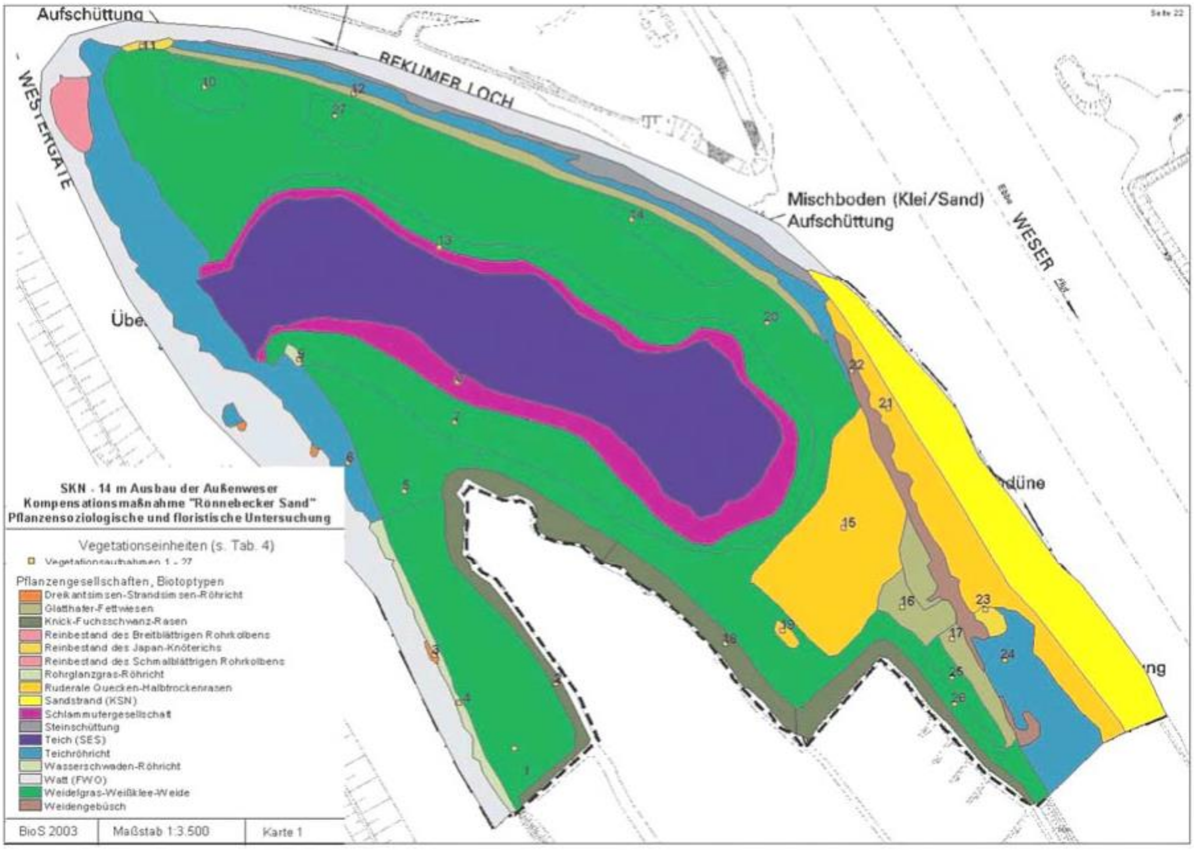
Landward Solutions Rönnebecker Sand

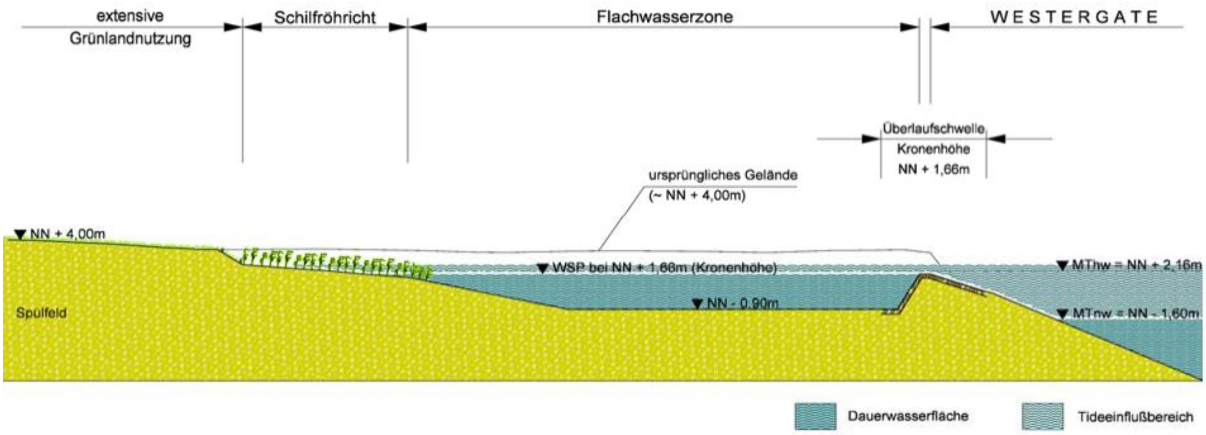


Rönnebecker Sand is an outer-dike managed realignment in the freshwater zone of the Weser estuary. The measure ‘Shallow water area Rönnebecker Sand’ aims at compensation of estuarine habitats by transforming adjacent land into freshwater marshland and subtidal moderately deep habitat. The outer dike realignment consists of a connection via a sill. Within the area some 370.000 m³ of sediments have been removed to establish a subtidal, a small intertidal and a supratidal area.

The measure was a compensation for loss of natural values due to the deepening in 1998 of the Weser to 14m below Seekartennull between km 65 and km 130. Connection to the Weser was established via Rekumer Loch to Westergate, where a sill was made with a width of 80 meters. The height of the sill was NN +1.66 m (see cross section), or 50 cm below MHW, in order to reduce fast silting of the subtidal basin. Long-term sedimentation is estimated to amount to 500 mm. The central part of the subtidal area was dug out to a depth of NN -0.90 m. Thus, an average tide is allowed of only 0.5 m, whereas the normal tides at that point in the Weser are 3.76 m. It should be emphasized however that the Rekumer Loch and Westergate are also shallow muddy channels which sit at comparable heights as the sill.

The measure was carried out in 2001 over an area of 37 ha. It was a former dredge disposal site on the isle of Weserdeicher Sände, which was dug out (see inset for details). The subtidal area is 7.5 ha and should serve aquatic life. The surrounding intertidal area (ca. 7.1 ha) consists of reed-vegetation and mud-related vegetation. Of the 22.4 ha large supratidal zone the large part is managed extensively, whereas natural succession is allowed on the remaining 2.1 ha. The total costs were 2.8 Mio €.

From disposal site to basin
Originally the site was a dredge disposal site. The site was filled up to NN +4m. It was surrounded by a summer-dike with its top on 3.9-4.2 m NN. To form the basin total ca. 370,000 m³ of sediments were removed consisting of 70,000 m³ soil, 260,000 m³ sand and 40,000 m³ clay.



Cross section of the measure (Kurth, 2007)

Research
Research was limited to functionality checks during 10 years for:

- vegetation development: species and habitats; monitoring in 2003, 2012;
- avifauna: breeding, resting and migrant birds; monitoring in 2003, 2004, 2007, 2012;
- aquatic fauna: fish, benthic invertebrate fauna, vagile epifauna, zooplankton, monitoring in 2004, 2007.

Rönnebecker Sand 8th February 2020.

Results
The measure aims at compensating considerable impacts on vegetation, avifauna and limnic fauna by:

- Construction of a tidally influenced shallow water zone
- Development of reed communities

- Creation of a buffer zone with extensive grassland use and development of succession areas

The monitoring results show that the development targets defined for the compensation measure are met at the end of the 10-year runtime of the monitoring program. At the same time, the development targets which are formulated are very unspecific, making clear evaluation difficult.

Lessons learned

Sedimentation of the deeper area will determine the functioning of the subtidal area. However, as far as known, no sedimentation rates have been measured making it unclear how long the functioning of the measure will last. Thus, investments might last longer or shorter than anticipated. It is suggested that live cycle should have been a clear target at the start of the project.

Stakeholder processes

The planning of the project was carried out by WSA Bremerhaven, who was the interested party, in cooperation with nature conservation administration and conservation groups. It was forced as nature compensation measure.

The input of nature conservationists was incorporated in the development of the plans whenever possible and adding to conservation targets. An ecosystem services (ES) assessment, shows that this measure generates overall a positive impact for 'biodiversity' and some regulating services (erosion and sedimentation regulation by water bodies, water quality regulation: reduction of excess loads coming from the catchment).

Discussion points

The area is situated in a muddy area of the Weser, with the muddy higher intertidal Westergate and Rekumer Loch as tidal connections to the Weser estuary. Hence, mud sedimentation will be important in this area. An important discussion point is: given the importance of terrain height, should sedimentation rates not be the central focus point of the monitoring?

Furthermore, what is the added value of such realignments to the trilateral of regional Wadden-ecosystem? Has this measure led to (new) habitats, which are related to the international ecosystem-demands?

In terms of mud management: clearly this is a mud trap, which reduces its life span. Is it possible to define rules to establish a live cycle for a realignment project and to compare this with the investments in order to optimize the natural value to investment ratio?

Literature

Saathoff S. & Lange J., 2012. 'Shallow water area Rönnebecker Sand' Measure analysis 25
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Kurth, R., 2006: Kompensationsmaßnahme Rönnebecker Sand (SKN - 14 m-Ausbau der Außenweser). Zwischen Weser und Ems, Heft 40, p. 12-24.

https://www.tide-toolbox.de/measures/roennebecker_sand/measure_description/

26 km kurvenreiche Vielfalt

Von der Einmündung in die Lesum bis zur Grenze des Naturschutzgebietes Borgfelder Wümmewiesen windet sich die Untere Wümme in zahlreichen Schleifen am Rande des Bremer Blocklandes entlang. Eine Rundtour, welche die niedersächsische Nordseite des Flusses mit einbezieht, ist ebenfalls möglich, verdoppelt aber die Entfernung.

1 Dammsiel – ein Fluss mäandriert

Im Garten der Gaststätte Dammsiel bietet sich ein besonders schöner Blick auf die Wümme. Der Fluss macht hier, an der Einmündung der Kleinen Wümme, einen weiten Bogen, auch Mäander genannt. Ende der 1940er Jahre sahen Ausbaupläne auch an dieser Stelle eine Laufbegradigung vor, die Gaststätte hätte ihre Lage am Fluss verloren.

2 Rechts und links am Deichfuß sind »Braken«

An einigen Stellen des Blocklander Deichs befinden sich auf der Binnenseite große Gewässer, die sogenannten Braken. Sie zeugen von ehemaligen Deichbrüchen, sind bisweilen sehr tief und erfordern am benachbarten Deich besondere Hochwassersicherung, z.B. durch Spundwände.

3 Sumpfdotterblumen und Sumpfgreiskraut

An wenigen Stellen im Vorland wird noch heute traditionell das Schilf gemäht. Hier blüht im März/April die Sumpfdotterblume besonders üppig. Im Sommer begleiten uns am Wasserrand die gelben Blüten des Sumpfgreiskrauts, eine botanische Besonderheit der Wümme.

4 Graureiherkolonie

Seit 1992 brüten im Vorland nahe der Gaststätte Gartelmanns Gasthof Dutzende Graureiher auf Bäumen am Fluss. Der Graureiherbestand hat sich seit Einstellen der Bejagung bundesweit erholt.

5 Hinein in die Wildnis – der Weg zum Fähranleger

Seit August 2014 ist er wieder in Betrieb, der romantische Weg mitten durch Schilfröhricht und vorbei an malerischen Weidenbäumen. Von Mai bis Oktober bietet der gegenüberliegende Gasthof »Zur Schleuse« einen Fährbetrieb zwischen dem bremischen und dem niedersächsischen Ufer.

6 Kuhsiel - Torfkahnstation

Bei Kuhsiel mündet der Kuhgraben in die Wümme. Wo früher mit Torf beladene Kähne aus dem Teufelsmoor die Schleuse auf dem Weg nach Bremen passierten, nutzen heutzutage vor allem Bootsfahrer die Passage zwischen Fleet und Fluss.

7 Im Reich der Weihen – Schilfröhrichte am Kreuzdeich

Ausgedehnte Röhrichte bieten hier u.a. der Rohrweihe Lebensraum. Vom Deich aus lässt sich der Vogel im Sommer gut beobachten.

Ein waches Auge

Die Stiftung NordWest Natur betreut im Auftrag des Bremischen Umweltsenators die Schutzgebiete in der Bremischen Wümmeniederung. Neben dem Naturschutzgebiet Borgfelder Wümmewiesen und den Landschaftsschutzgebieten in der Oberneulander Wümmeniederung gehört hierzu auch das Naturschutzgebiet Untere Wümme. Teil der Gebietsbetreuung ist ein umfangreiches Veranstaltungsprogramm. Informationen finden Sie unter **www.nordwest-natur.de**

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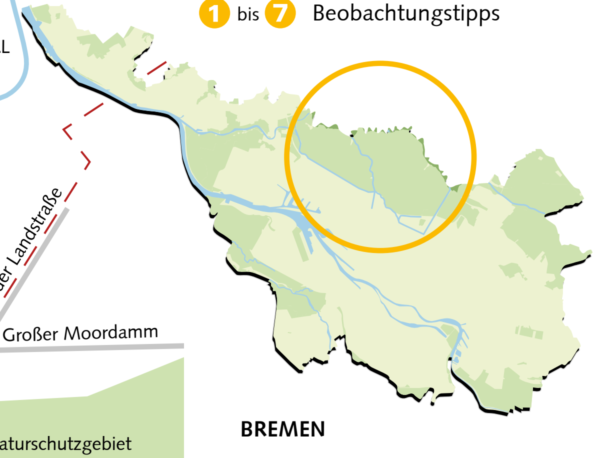

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Freie Hansestadt Bremen

Naturschutzgebiet

Untere Wümme

Schutzgebiet	Ausgewiesen am 08.10.1991 Natura 2000 – Gebiet seit 2003
Größe	148,5 ha
Naturraum	Blockland
Lage	Am Nordrand des Blocklandes
Lebensräume	Naturnaher Flusslauf, Weiden-Auwald, Schilfröhricht, Hochstaudenfluren, Süßwasserwatten
Typisch	Flussmäander, Biotopverbund von Röhricht, Weidengehölz und Gewässern, Rohrweihe, Graureiherkolonie, Sumpfdotterblume, Sumpfgreiskraut, Landschaftserlebnis von den Deichen

Etwas ganz Besonderes – der Unterlauf der Wümme

Naturnah, in weiten Schleifen, mäandriert der Unterlauf der Wümme am Nordrand des Bremer Blocklandes. Eine Rarität in Norddeutschland! Vielerorts wurden Flüsse im letzten Jahrhundert begradigt und verloren somit ihre Eigenart und ihren Reichtum an Tieren und Pflanzen.Nicht so an der Unteren Wümme: zahlreiche Wanderfische verleihen ihr den Rang eines europäischen Schutzgebietes. Der scheue Fischotter ist hier wieder genauso heimisch wie Röhrichtbrüter und Graureiher.

[1]

[2]

[3]

1 Dammsiel 1980; 2 Wümmeblick; 3 Niederblockland; ©Archiv Gunnar Oertel

Im Lauf der Jahrzehnte erlebte der Fluss dennoch Veränderungen: Das Land zwischen den Deichen wurde immer weniger landwirtschaftlich bewirtschaftet. Dies war u. a. begünstigt durch den wachsenden Tiedenhub in der Wümme. Nur wenige Wiesen und Weiden werden heute noch genutzt, an einigen Stellen wird das Schilf auch weiterhin regelmäßig gemäht. Deutlich zugenommen hat der Strauch- und Baumbestand.

Natur schützen – Natur erleben

1991 wurde die Untere Wümme Naturschutzgebiet, 2003 auch Teil des europäischen Schutzgebietssystems Natura 2000.

Die Flusslandschaft ist ein attraktives Naherholungsgebiet. Eine Fahrradtour entlang der Wümmedeiche gibt einen guten Überblick, hier bieten sich verschiedenste Einblicke in das schilfgeprägte Vorland bis hin zum Fluss.

Am Blocklander Deich laden Hofcafes und Gaststätten zum Verweilen ein. Die Fähren zu den Gasthöfen »Zur Schleuse« und »Wümmeblick« ermöglichen Radfahrern im Sommerhalbjahr bequem auf die niedersächsische Flussseite zu wechseln. Wer den Fluss hautnah erleben will, dem sei ein Ausflug mit dem Torfkahn oder dem Kanu empfohlen. Aber Vorsicht: Strömung und Tidenhub sind heute so stark, dass Kanutouren für Anfänger und Ungeübte nicht geeignet sind.

Foto ©Horst Schütze

Frühling am Fluss: Sumpfdotterblumen, Graureiher und Rohrweihe

Ein Frühlingstag an der Blocklander Wümme ist für viele Bremer eine liebgewonnene Tradition. Die am Unterlauf norddeutscher Flüsse charakteristischen Weidengehölze sorgen mit ihrem frischen Grün für wahre Frühlingsgefühle. Weidensträucher sind sehr biegsam und dadurch bestens an stark strömendes Wasser angepasst.

Rohrweihe ©Lutz Ritzel

Sumpfdotterblume ©Lothar Naumann

Vom Deich aus fällt der Blick bereits im März auf gelbe Blütenteppiche der Sumpfdotterblume.

Im April kehren die Rohrweihen aus ihren Winterquartieren am Mittelmeer bzw. in Afrika zurück. Der in typischer Flügelstellung dicht übers Schilf gleitende Greifvogel zählt zu den Charakterarten dieser Landschaft.

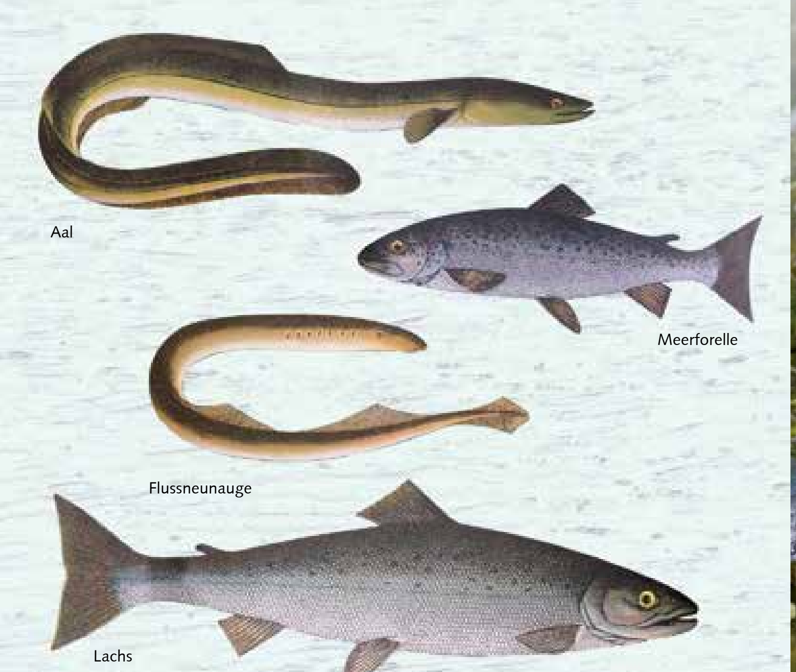
Seit 1992 gehört die Graureiherkolonie bei Gartelmanns Gasthof zu den besonderen Naturerlebnissen. Der Graureiher ernährt sich hauptsächlich von Fischen und Mäusen.

Die Rückkehr der Wanderfische...

Neunaugen sind Wanderfische, die im Meer leben und zum Laichen in Flüsse wie die Wümme aufsteigen. Die Vorkommen von Fluss- und Meerneunauge tragen wesentlich zur europäischen Bedeutung der Wümme bei. Die Neunaugenfischerei im Weser-Wümme-Revier war im Mittelalter berühmt, vor allem Flussneuaugen wurden in der Wümme viel gefangen und dann als Bremer Pricken in den Handel gebracht.

Durch Gewässerausbau, vor allem zahlreiche Stauwehre, Wasserverschmutzung und übermäßigen Fang ging der einstige Fischreichtum verloren. Mit der Renaturierung der Wümme oberhalb von Borgfeld, dem Rückbau der zahlreichen Wehre zu Sohlgleiten und verbesserter Wassergüte kam in den 1980er Jahren die Trendwende. 2011 gelang, erstmals seit 1925, wieder der Nachweis des Lachses. Für Neunaugen ist die Wümme derzeit der wertvollste norddeutsche Fluss.

Weitere Wanderfische in der Wümme sind Aal, Lachs und Meerforelle.



...und des Fischotters

Zu Gesicht bekommt man ihn selten. Er ist scheu und nachtaktiv, nur seine Spuren findet man regelmäßig an der Wümme.Der Fischotter, im 19. Jahrhundert auch an der Wümme weit verbreitet, stand hundert Jahre später vor dem Aussterben. Heute ist er dank Gewässerrenaturierung und Jagdruhe wieder zurückgekehrt.

Briefmarke mit einer Fischotterdarstellung auf dem Wappen des Fleckens Ottersberg (©Archiv Gunnar Oertel)

Fischotter bevorzugen eine intakte, vielgestaltige, naturnahe und weitläufige Flusslandschaft. Altarme, Sand- und Schlammbänke, Ried- und Röhrichtflächen liebt er besonders. Mehr als 20 km legt er auf seinen nächtlichen Erkundungszügen zurück: nicht nur im Wasser sondern auch durchaus auf dem angrenzenden Land. Mit seinem stromlinienförmigen Körper ist er dem Leben im Fluss ideal angepasst. Fische, Frösche, Bisame und Krebse sind seine Beute.

Fischotter ©Adam Nowara

Biologische Vielfalt in Gefahr: Flussbegradigung und Weservertiefung

Vor 100 Jahren waren Ebbe und Flut in der Wümme nahezu unbekannt – das änderte sich nach dem massiven Ausbau der Unterweser ab Ende des 19. Jahrhunderts: Die zunehmenden Schwankungen des Wasserspiegels zweimal täglich erhöhten die Strömungsgeschwindigkeit und führten zur Ufererosion. Zur Ufersicherung wurden vielfach Steinschüttungen verbaut. Naturnahe Schilfröhrichte nahmen ab. Dort wo Fluss und Deich unmittelbar aneinandergrenzen, sichern heute Spundwände das Flussufer.

Mit wachsendem Tidenhub haben sich vegetationsfreie Süßwasserwatten im Vorland gebildet, die bei Niedrigwasser regelmäßig trocken fallen. Die täglichen starken Wasserspiegelschwankungen haben Lebensräume von Amphibien und Libellen weitgehend zerstört. Enten und Rohrdommel sind als Brutvögel nicht mehr vertreten.

Zur Abwehr von Sturmfluten, die auf Grund des Weserausbaus mit ihren Auswirkungen immer spürbarer bis nach Bremen reichen, wurde in den 1970er Jahren an der Lesummündung ein Sperrwerk errichtet. Im gleichen Zeitraum verhinderte das Engagement von Anliegern und Naturschützern Planungen zur Flussbegradigung. Die Ausweisung als Schutzgebiet bietet trotz der genannten Einschränkungen die Grundlage für eine naturnahe Entwicklung.

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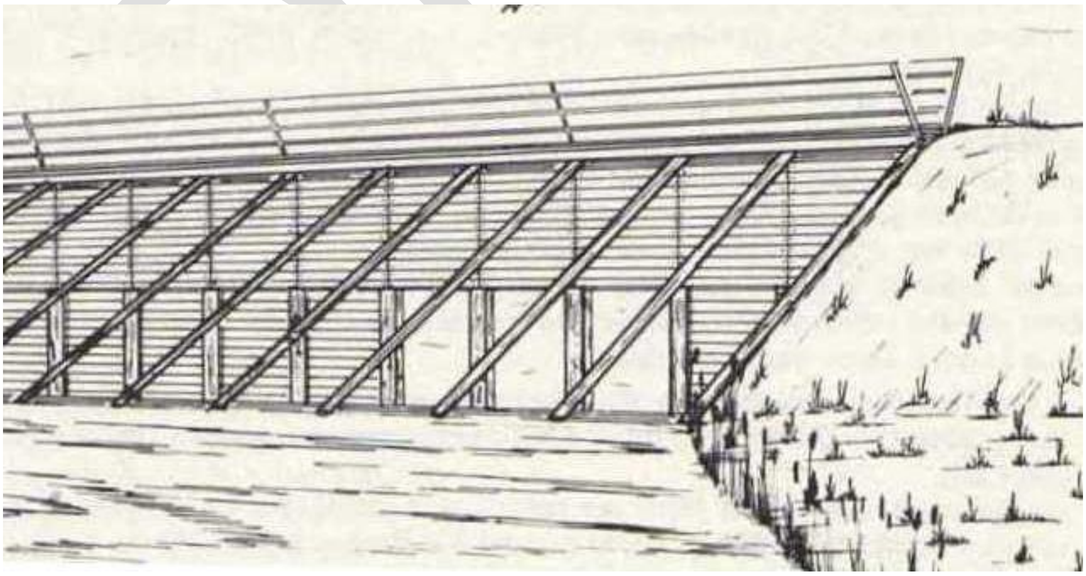
Schilfrohrsänger ©Lutz Ritzel

Landward Solutions

Landfills with dredged sediments

It is not clear when landfills started, but they took a huge flight in the 20th Century. Nowadays landfills with mud are mainly concentrated near the weirs of the estuaries. Mud is taken out to counter the infill of the fairways which occurs due to over-depths in combination with tidal pumping and locally the formation of fluid mud layers.

Enhancing sedimentation on inner-dike areas by allowing late autumn/winter-flooding of the diked lands was probably a standing practice from Roman times up to the Late Medieval period. This was done by either flooding of the low dikes or by opening sluices and such. Thereafter, diked lands had often subsided so strongly that draining the salt water became difficult; only locally flooding was still allowed. The main goal was probably to bring nutrients into the soil.



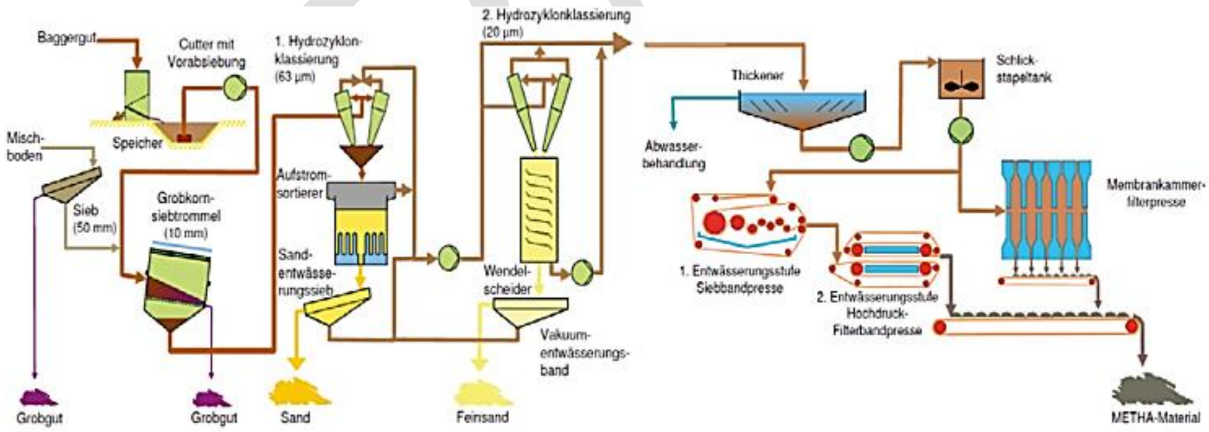
Sketch of one of the inlet systems for the Bewässerungsfelder in the dike at the Oste (Fischer, 2011).

However, in the 19th Century and up to the early 20th Century farmers along the Oste tidal river (brackish) in Lower Saxony strived to heighten their lands. They developed so-called “Bewässerungsfelder”, which could be flooded each high tide during wintertime by opening some special inlet devices. In in the Blumenthal polder resulted in sedimentation 4 1- cm/yr.

The above described examples are based on temporal flooding of the mainland area. One of the earliest known examples of actively transporting mud to the land comes from farming practices. In the early 20th Century (and probably earlier) farmers living near the Wadden Sea, spent their spare time to dredge mud from the Wadden Sea and to spread it over their lands. Most likely this was mainly to bring nutrients on the fields and not so much to heighten the lands.

Starting in the late 19th Century landfills with mud have taken a flight in the 20th Century as harbors were extended and fairways were deepened. This is especially true for the three big estuaries of the Ems, Weser and Elbe, each showing their own developments. Especially the riverine sediments from the Elbe and Weser are heavily contaminated (although concentrations are going down). Environmental considerations made storage on land unavoidable.

Traditionally, the dredging material from the Port of Hamburg is stored on land, to heighten areas. At the end of the 1970s, the environmental impacts of this practice became clear. A small part is relatively clean and will be dewatered in the Moorburg Entwässerungsfeldern. The rest is strongly contaminated. For these sediments a dredging material treatment was developed and implemented in the 1980s, the so-called METHA-Anlage (Mechanische Anlage zur Trennung von Hafensedimenten). The METHA-Anlage, an industrial separation operation, processes some $1*10^6$ m^3/y of the most contaminated dredging sludge (Figure). Annually some 550 000 ton of dredged material (after drying 1 000 000 m^3) is processed. The sand is separated from the mud fraction (silt and clay). The sediment is flushed to remove the salts and is subsequently dewatered.



Overview of the production process METHA Anlage Hamburg (Hamburg Port Authority, NY).

The possibilities to use the sediments of the METHA Anlage are limited due to the high costs and the ecological limitations. Sand can be used among others as drainage sand. The mud fraction is mostly contaminated and must be stored in two depots which are especially adapted to that end. The fine fraction which is not contaminated is used for clay cover of dikes and such.

In harbors of Bremen and Bremerhaven produce dredged sediments, mainly consisting of clayey mud which is contaminated with heavy minerals and the antifouling agent tributyltin (TBT). Before 1994 contaminated fine-grained material from the harbors was deposited on disposal sites on land and on a placement site in the Wurster Arm (Outer Weser). Since 1994 Bremen stores on land at the integrated dredged material disposal site in Bremen-Seehausen (Figure). Since 2001 also Bremerhaven uses the site. First, the sediment is being pre-processed in 16 dredging depots of 100*200 m each (max sediment depth: 2.6 m). In the process the sludge will dewater and ripen. On a regular basis the sediment will be turned over by means of a “Mietenumsetzer”. After about one year, the most contaminated mud is placed in a specially adapted landfill of Bremen-Seehausen. The part of the sediment which meets environmental standards is used for various purposes.

Dredging depots Bremen-Seehausen (www.Bremenports.de)

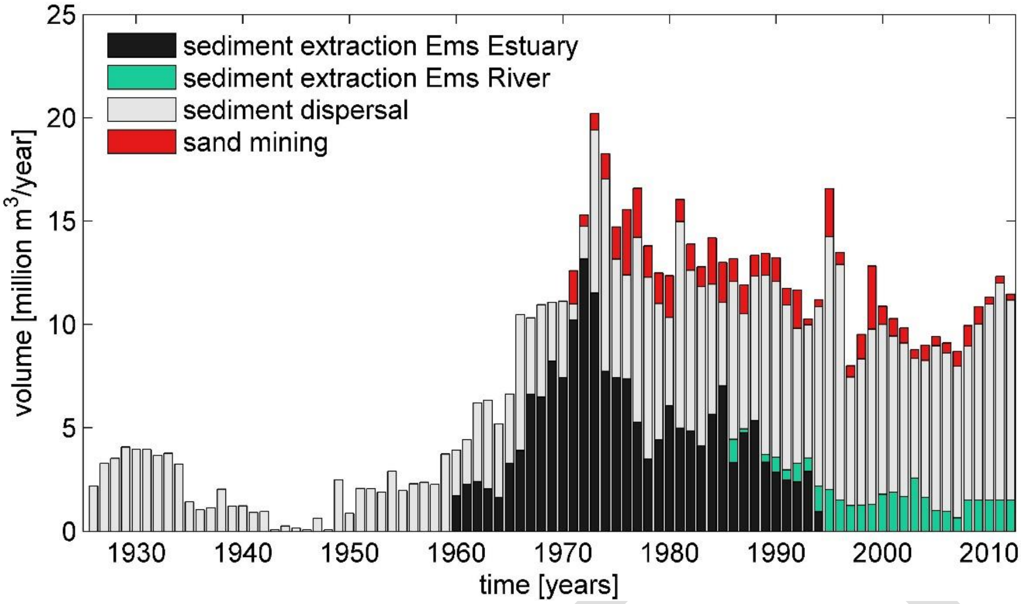
At the Ems, dredging and land storage started probably at the end of the 19th Century. Already in the 1930-ies substantial amounts of mud were stored in landfills. Quantities of sediment extracted before 1960 are not exactly known. Between 1960 and 1994, $5.1*10^6$ m^3/y was dredged from the port of Emden ($1.5*10^6$ m^3/y) and fairway (3.6 10^6 m^3/y) and brought on land (Figure). Another $5*10^6$ m^3 of sediment was dredged from the estuarine approach channels and ports, and subsequently dispersed within the estuary. Approximately $1.5*10^6$ m^3 of the extracted sediment was sand: the remaining $3.6*10^6$ m^3/y (or $1.8*10^6$ tons/y) was mud. On many sites east of the Ems landfills were developed heightening the land and improving the agricultural quality. Furthermore, sediment was used to heighten tidal marshlands which were formed behind dams, such as the Rysumer Nacken over the period 1949-1995.

The Niederung Eden Riepe is being filled via a 13 km long pipe transporting the dredging sludge over the Ems-Jade channel (period 1946-1989). (Source: Creative Commons Attribution 4.0 International License Photo HB01395.jpg)

Since 1994, sediment is no longer dredged from the port of Emden, but regularly re-aerated, thereby preventing consolidation. The resulting poorly consolidated bed remains navigable, and consequently the port no longer requires maintenance dredging. At the same time, sediment dredged from the approach channel to Emden is no longer extracted but dispersed in the estuary. No dredged sediment is disposed in marine waters outside of the estuary.

Since its last major deepening in 1994, the lower Ems River requires regular dredging. Around $1.5*10^6$ m^3/y ($0.8*10^6$ ton/y) of fine sediment are extracted annually from the lower Ems River and brought on land. These are clean sediments. They are deposited in the landfills near Ihrhove (top figure), which are relatively quickly filled up. Just below the top soil peat layers of 2 to 3 m thick are sometimes present and care should be taken not to compact these peats. Furthermore, it appeared that the drainage of the newly established fields is not sufficient, leading to negative changes in plant species composition, slower nutrient release in spring and slower soil-ripening processes. The landowners press currently for subsurface drainage pipes.

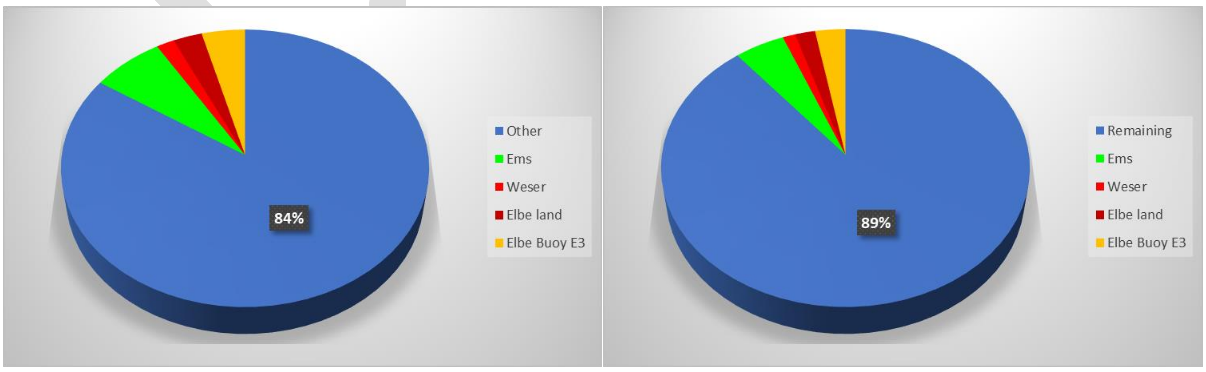
Plans are being developed for the Ems estuary to reduce the suspended matter concentrations by artificially enhancing sedimentation over larger areas which will be opened to deposit sediment (managed retreat), using it for diking, or withdrawing muddy sediment to heighten inner dike polders. The last two approaches are already used in Lower Saxony (see above and factsheet on clay pits). The first approach envisages managed retreat on a very large scale of the order of 10 km^2 (see factsheet on managed retreat).



Dredging volumes for the Ems estuary since 1925: sediment extraction (mainly mud) in the Ems estuary and the lower Ems River, sediment dispersal, and sand mining (from van Maren et al. (2016). Total dredging volumes before 1960 are from de Jonge (1983); dredging volumes after 1960 are from Mulder (2013) for the Ems estuary and from Krebs (2006) in the lower Ems River (until 2006; after 2006 a constant value of $1.5*10^6$ m^3 is assumed).

Lessons learned

All old harbors in the three big estuaries were medieval in age and were founded when these locations were the cross points between roads and sea-going ships at that time which had much smaller dimensions. As dimensions of ships increased, especially during the past 100 years, fairways had to be deepened and harbors had to expand. This led to a massive increase in maintenance dredging. Storage on land of the dredged material seemed like a good idea and due to this, large amounts of mud and sand were retrieved from the harbor. As a result, large areas around the estuaries were heightened considerably, which made them less vulnerable to flooding. In the 70-ies the realization came that part of especially the muds were heavily contaminated and had to be stored under controlled conditions. Another part of it is clear mud which could also be left in the estuary.



Comparison of landfill volumes as part of total sedimentation (left) and total influx of suspended matter (right; excluding supply by the East Anglia Plume)

Some $3000*10^6$ m^3 of mud must have thus been stored on land along the Ems in the past 120 years: this is comparable to the total net sedimentation in the western part of the Dutch Wadden Sea area in the same period. How this is for the Weser and Elbe is not well known. Recently it became clear that especially the long-term (over a century) and large-scale retrieval of mud from the Ems estuary is significant if compared to the estimated 8-20 $*10^6$ ton of mud which is annually transported from the West into the Wadden area. Given the large internal buffers in the Wadden Sea possible effects will probably go unnoticed for a long time. At the moment, it is unclear whether such extraction influences the sedimentary and ecological development of the Wadden Sea area more to the east of the estuary.

Stakeholder process

Two of the three estuaries are largely part of two German States (Bundesland): Freie und Hanzestadt Hamburg and Freie Hansestadt Bremen. As these sea harbors are important to Germany the influence of the harbors and industry on the development and management of the area is large. For the Elbe the stakeholders are Hamburg and to some extent Schleswig Holstein and Lower Saxony on a state level. Next to that the Harbors of Hamburg, Cuxhaven and Brünsbuttel have a strong say in the development. Furthermore, environmental groups influence the discours. The ever-continuing deepening of the fairway meets with stiff resistance of the environmentalists. Furthermore, part of the estuary is part of nature protection areas which also leads to discussions considering the development of the harbors and fairways. In the Weser estuary the land of Bremen and the harbors of Bremen and Bremerhaven are quite influential. Another stakeholder is Lower Saxony which has also to take care of the National Park of the Lower Saxon Wadden Sea. During the past decennia much effort has been given to managed realignment measures to compensate the effects of the harbor and fairway measures. As for the contaminated mud retrieval there seems to be no objection from environmental groups to take this out of the estuary.

The Ems Estuary is bordering both the Netherlands and Germany and is an important local motor for the economy of the surrounding region. Also here, the influence of the economics and industry is considerable. States and harbors and the shipyard of Papenburg have a relatively large influence in the development of the estuary. Environmental groups are pushing to improve the quality of the estuary via measures such as restoring connectivity for fish migration, managed realignment and decreasing the turbidity of the water to enhance primary production and fish migration. The turbidity is thought to have increased considerably due to the lack of permanent sedimentation sites and the ending of landfills from the dredging of the main part of the estuary and harbors by Germany since 1994. A part of the plans aims at annually retrieving large amounts of mud either via land storage, dike clay production or deposition in tidal marsh areas (ED2050 projects).

Discussion points

Clearly a part of the mud stored on the mainland is so contaminated that it cannot remain in the estuaries of Elbe and Weser. The question arises: are the current contaminated landfills sea-level rise proof enough for the coming centuries?

The amount of uncontaminated fine sediments which is taken from the Ems is significant when compared to the annual import in the Wadden Sea. At the moment it is not known if there are any adverse effects for the Wadden area east of the Estuary from retrieval of such amounts of mud over such an extended period. The question arises: is it not more prudent to keep these dredged sediments in the system and for instance to dump it east of the estuary? Or should we instead take out more material to improve the water quality (reducing turbidity) and heighten the landscape so that it becomes more resilient against sea-level rise?

By the same token: $1.5*10^6$ m^3/y ($0.8*10^6$ ton/y) of fine sediment could allow an area of $150*10^6$ m^2 to keep up with 1 cm/yr of sea-level rise, rates foreseen for the end of the century. Extra tidal marshes and mudflats could be created, either via Foreland Tidal Marsh creation in the Wadden Sea or via managed realignment. Would it be more interesting to choose for helping to establish extra tidal marsh where it is absent in front of existing dikes and adding to their safety (wave breaking), or to create more tidal marshes on a large scale by managed realignment to create natural values and add to the touristic appeal than to concentrate on land-fills with uncontaminated muds?

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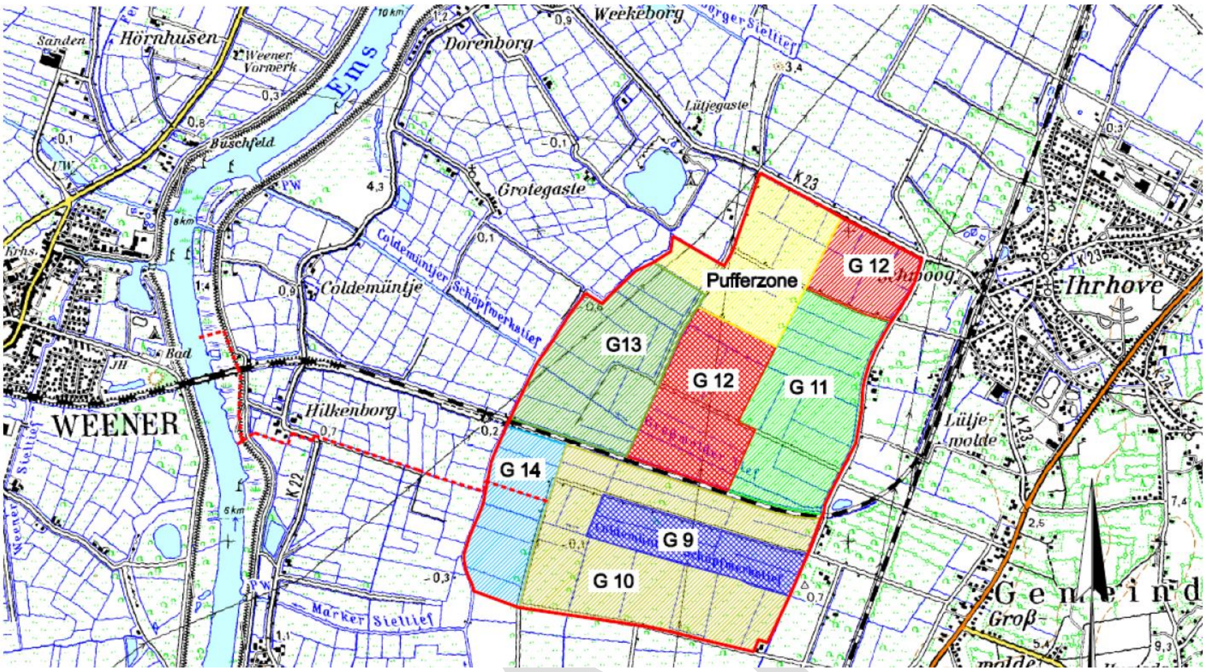
Landward Solutions Ihrhove landfill



Dredging sludge taken from the Ems river is used near Ihrhove and Großwolde in the municipality of West-Overledingen to heighten and improve some 530 ha of agricultural land. Up to 1.5 million m³ is annually stored. The benefits for the dredging operations of the Lower Ems river are that transport distances for the dredgers are reduced considerably, reducing the costs. Furthermore, the heightening of the land should facilitate water management in the area.

20.000 m³ dredging sludge per ha can be deposited. At the start, an annual amount of up to 500.000 m³ dredging sludge was deposited annually requiring an area of 15 - 20 ha. Later, these amounts were heightened to up to at maximum 1.5 million m³. As a result, some 500 ha of the 530 ha in total had already been covered with mud in the period 2006-2015, shortening the original project time considerably (2006-2031). Currently a placement of a second layer on top of the current layer is considered.

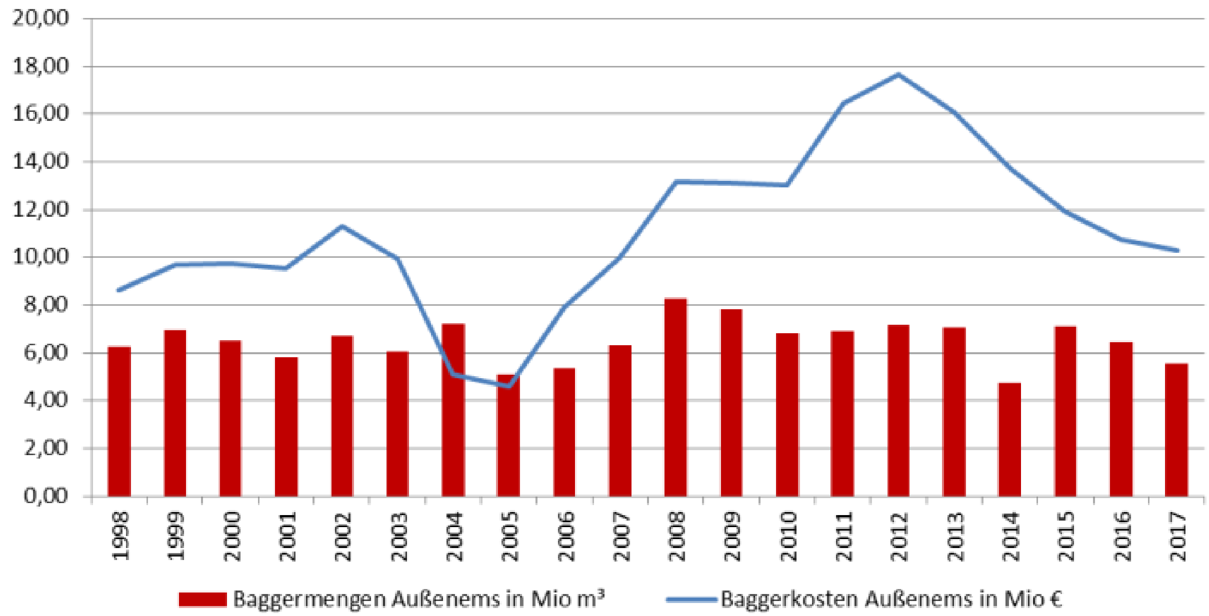
The sludge is transported by pipes over a total distance of some 5 km from the Ems. The profit of the landfill approach is that the transport time for the dredging boats will decrease considerably compared to the dumping of the sediments in the outer Ems reaches (lower Figure). The sludge dredged is mainly from the brackish water zone between Leer and Papenburg. As other landfill sites, such as clay mining pits, along this area are almost not available (anymore) the new approach offers a welcome alternative. Over the period 1996-2017 on average some 7.9 million m³ was dredged from the lower Ems river including 2.5 million m³ from the harbor at Emden. The costs vary from less than 5 million Euros to almost 18 million. Over the period 1996-2017 of the sludge thus dredged some 1.8 (1.5-2.0) million m³ is annually stored of which 1.3 million m³/yr on land.

Research

Without research such landfills are not possible. The following research is needed:

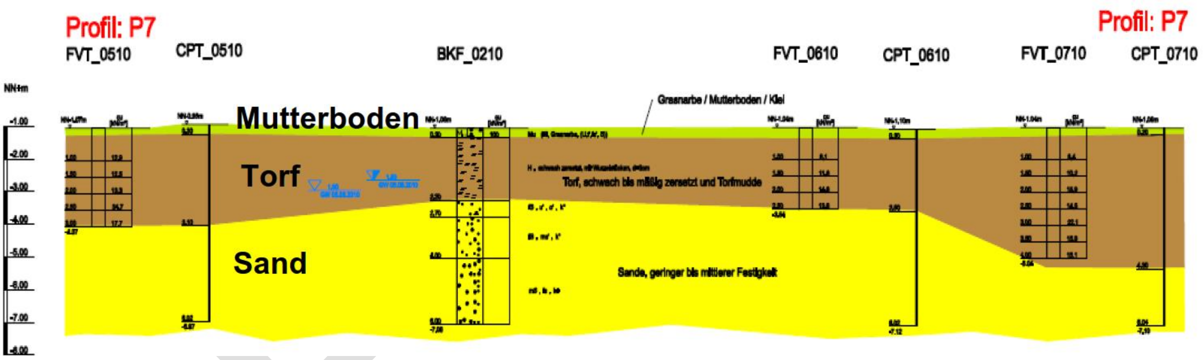
- An intensive coring and cone penetration testing are needed (every 50-100m) to establish an overview of the sedimentary built up (see below).
- Determination of the height of electric power poles.
- Assessment of archeological values
- Continuous control of the chemical composition of the dredged sediments, applying very strict quality standards.
- The landfill requires vegetation monitoring which is currently carried out by bureau Diekmann & Mosebach.

- Furthermore, ecological compensation areas have to be located outside the landfill areas.
- Water-related research for the affluent waters and ground waters (Bureau de Vries).



Dredging volumes and costs for the lower Ems (Meyer, 2018).

Approach
The start of the project was in 2006, SW of Ihrhove when in total circa 30 ha were surrounded with a 4 km long dam which should retain the sludge. This is less trivial than it might look at first sight. The subsurface sediments on which the mud is deposited consist of a thick peat layer which is not very strong (see Figure cross-section). After establishment of the sedimentary built-up of the area, dikes would be built on the weak subsurface in such a manner that they are able to withstand the filling of the basins behind them.



Representative cross section of the area (F.P. Eißfeldt, 2011).

The layer deposited is some 2 m thick. The weight of the mud should not be too much as it compacts the underlying peats and will lead to subsidence. After 3 years of ripening only a 1m thick layer will remain. After the ripening, a period of 2 years is needed to cultivate the soil. From the start of the landfill works it takes 7 years before farming is possible again.

Results
It turned out that the drainage of the newly established fields is not enough, leading to negative changes in plant species composition, slower nutrient release in spring and slower soil-ripening processes. The landowners press currently for subsurface drainage pipes.

Lessons learned

As the dredging volumes of mud are large and the costs for dumping in the Ems estuary are high, landfill forms an appealing alternative. As a result, the landfill sites are filled up quickly and the need to find alternative landfill sites will remain high.
After landfill, the drainage of the land is problematic. Better development and measures are needed.

Stakeholder processes

The Landkreis Leer is the overseer of the Wasser- und Bodenverband which was established in 2005. The organization consists of landowners and is the municipality of Westoverledingen. The Verband concentrates on the acceptance of mud of the Ems to improve the soil quality in Ihrhover/Großwolder Hammrich area. To that end several land owners and the Wasser- und Schifffahrtsamt Emden (WSA), have developed an appealing plan. After a considerable assessment of the applicability the plan was carried out in 2006. The Wasser- und Bodenverband also aims at a land consolidation process (Flurbereinigungsverfahren; ruilverkaveling) under the guidance the authority of Geoinformation, Landentwicklung und Liegenschaften (GLL, ehemals Amt für Agrarstruktur) Aurich also to help with the requirements, such as for example, to optimize the identification of compensation areas as required by Nature conservation laws. The intensive cooperation of the above-mentioned organizations made the project feasible.

Discussion points

At the moment there seems to be a virtually unlimited supply of mud dredged from the estuary to be used for landfill. However, there might be some potential problems which might pose limits to the deposition of mud:

1) as shown by Vos (2015) for peats below the Dollard polders mud deposition puts a weight on the peats which may lead to considerable compaction. The question is therefore how thick can a mud layer become before it exerts too much pressure on the underlying peats.

2) a comparable problem might be the weakness of the peat. Is it possible that the clay might sink into the peat, thus leading to an irregular surface?

3) With an average total of some 1.8 million m^3 the annual deposition on land and near the waterway is considerable and comparable to the practices before the 1990-ies. Historical studies learn that the amount of mud annually available to the Ems is some 3-4 million m^3. This seems to be an upper limit for the Ems estuary and river at large. The question is: are there limits to storage of mud dredged from the lower Ems river because the Ems estuary also needs a certain amount of mud?

4) The strong sedimentation of mud in the Ems tidal river makes dredging unavoidable. The dredging sludge is fresh to slightly brackish. At the same time, there is a need for improvement of the agricultural quality of the land and sustainable water management. This is reached via heightening in combination with reparcelling of the area and re-structuring water management in these new high lying lands. Given the above discussion points the question is whether the approach of massive and thick landfills is the right approach or that mud should be "smeared out" over a larger area, as envisaged in the (temporary) large-scale managed realignment plans, so that agriculture can diversify, peat subsidence will not be a risk and on the long run the area can grow with sea-level rise.

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Seaward Solution Rysumer Nacken

- 57. Änderung des Flächennutzungs- planes (ca. 25 ha)
- 62. Änderung des Flächennutzungs- planes (ca. 240 ha)
- Bebauungsplan D150 "Rysumer Nacken" (ca. 134 ha)
- Bebauungsplan D150K "Wybelsumer Polder" (ca. 240 ha)

Gestaltungsplan mit Schnittführung im Bereich der geplanten Umschlagsflächen sowie Darstellung der Lage im Raum

The tidal flats of the Rysumer Nacken came into existence due to the building of an embankment. Thereafter the southern area was used as a dredging spoil dump site, which effectively put an end to the tidal character of the area. It is an example of an early mud-management development where a relatively one-sided approach was taken, and natural areas were still mainly considered as space to be used to solve human problems. Although nowadays such an approach is widely felt as no longer appropriate, there is tremendous pressure to enhance the economic development of the Emden harbor and Ems fairway. In this, the use of especially the high-lying Rysumer Nacken Süd is regularly reconsidered.

The Rysumer Nacken is located on the eastern bank of the Ems between the Lighthouse of Campen in the north and the Knock channel in the south near the city of Emden. The area owes its current form to the relocation of the main waterway of the Ems, an enterprise to make the Port of Emden more accessible for larger ships. In the course of the relocation, the 3.5 km long stone embankment from the Knock to the north was built between 1930 and 1933, behind which strong sedimentation occurred. In the period 1949-1995, the area served as a landfill for ever larger volumes of dredging material from the Ems. As a result, the area became elevated about 5 to 8 meters above mean sea level. This led to a process with the European Committee (1990), considering the EU Bird Directive. However, the German Federal Government stated that Rysumer Nacken had not been designated as a special protection zone within the meaning of Article 4(4) of the Directive; the national park "Niedersächsisches Wattenmeer" ends north of this area. The Rysumer Nacken consists of two different areas, the Rysumer Nacken Nord, a pure wadden area, and the Rysumer Nacken Süd, an already dammed area, where the dumping took place. The arguments were accepted by the EU Committee, but the process gave a warning to the precautions to be taken for landfills near or in the special nature protection areas.

Originally, it was planned to establish farms on the fertile land, but it was decided to release the in total some 480 ha of land for industrial settlements. In 1977, a gas terminal has been built, responsible for the distribution of natural gas from Norway. For a while not much changed and a large part was grazed with robust cattle breeds. Since 2006, industrial settlements are developed. Wind turbines are manufactured and Windpark Rysumer Nacken was built in 2007-2008 (Bard & Enercon). Further industrial settlements are planned, so most of the land may be used. The city of Emden actively promotes the use of the area. Plans for a new harbor in the Rysumer Nacken were proposed by Niedersachsen Ports GmbH & Co. KG, the city of Emden and the IHK-Nord (industry and trading houses) The plans were terminated in 2014, partly due to protests by BUND, NABU and WWF which pointed out the far-reaching consequences of further influencing the estuary. New plans to develop the Rysumer Nacken for industry and compensate in the Wybelsumer Polder are currently planned by the city of Emden via Ingenieurbüro W.Grote GmbH. If plans are realized the larger part will become industry area.

Large parts of the Rysumer Nacken are still not in use and nature developed relatively undisturbed. Sandy soils and large reed areas offer retreats for rare plant and animal species, such as orchids. Also, some woods with alders, birches and pastures are present. There are also several ponds, which serve as a breeding area and should therefore be avoided during the breeding season.

Lessons learned
Over the period of the establishment of the Rysumer Nacken the natural values of the Ems estuary have become increasingly important in considerations concerning the development of functions of the area. This is clearly reflected in the most recent plans were a compensation area is sought for in the Wybelsumer Polder upon development. However, in the same period, the economic interests also expanded. At the moment, the strengthening of these two aims are still at odds with each other. However, due to many green developments such as ever Greener Ports, there might come a time that these can be reconciled. For the moment the Rysumer Nacken is still an example of a development set into motion for a single cause and not the result of an integrative planning process. If mud management is to be successful both on the local and regional scale such a planning is needed.

Furthermore, the landfill does not only take space but also changes the landscape considerably in height. Such changes have a huge impact on the landscape, loading of the subsurface, water management and nature development and are -to a considerable extent- irreversible. Also here, an integrative approach is needed.

Stakeholder process
The city of Emden, economic interested parties and the government of Lower Saxony all had interest in the deepening and maintenance of the fairway to the Ems. As a result. The Rysumer Nacken was formed. Thereafter various initiatives were taken to use to the area for industrial development and harbor activities. This was hindered by the lack of an extensive hinterland for cargo brought in by ship and by the Dutch economic interests. Moreover, the ever-decreasing natural values of the Ems estuary led to protests of nature conservation groups and several of the initiatives did not bear fruit. Presently, such discussions are still ongoing.

Discussion points
The Rysumer Nacken are an example of a single-user driven development and an integrative approach was not followed. What would be prerequisites/elements for an integrative approach?

The height of a mud landfill forms a long-term influencer in many respects. Would a lower but larger area be more recommendable?

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Seaward Solutions Foreland Salt Marshes

Along the Wadden Sea man-made tidal marsh formation is a wide-spread practice. The system has been brought about by artificial drainage systems and brush wood groins. Originally these were managed to increase farming lands. Due to their height and width they also play an important role in breaking wave energy in front of the dikes. Natural values have decreased due to vertical accretion which enhances vegetation succession. During the last quarter of the 20th century maintenance of the drainage systems has largely ceased and many of the Foreland Salt Marshes are gradually developing towards a more natural situation.

A narrow belt of fertile marshland, stretching down from Denmark to the Netherlands dominates the mainland shores of the Wadden Sea. Based on the most recent data, salt marshes in the Wadden Sea extend over almost 40,000 ha (= 20% of European salt marshes). About half of the total are foreland salt marshes (Table 1). During the past century saltmarshes have grown in areal extent[1]. This growth has reduced the tidal water volumes, leading to the shallowing of tidal channels and gullies which originally used to drain these areas.

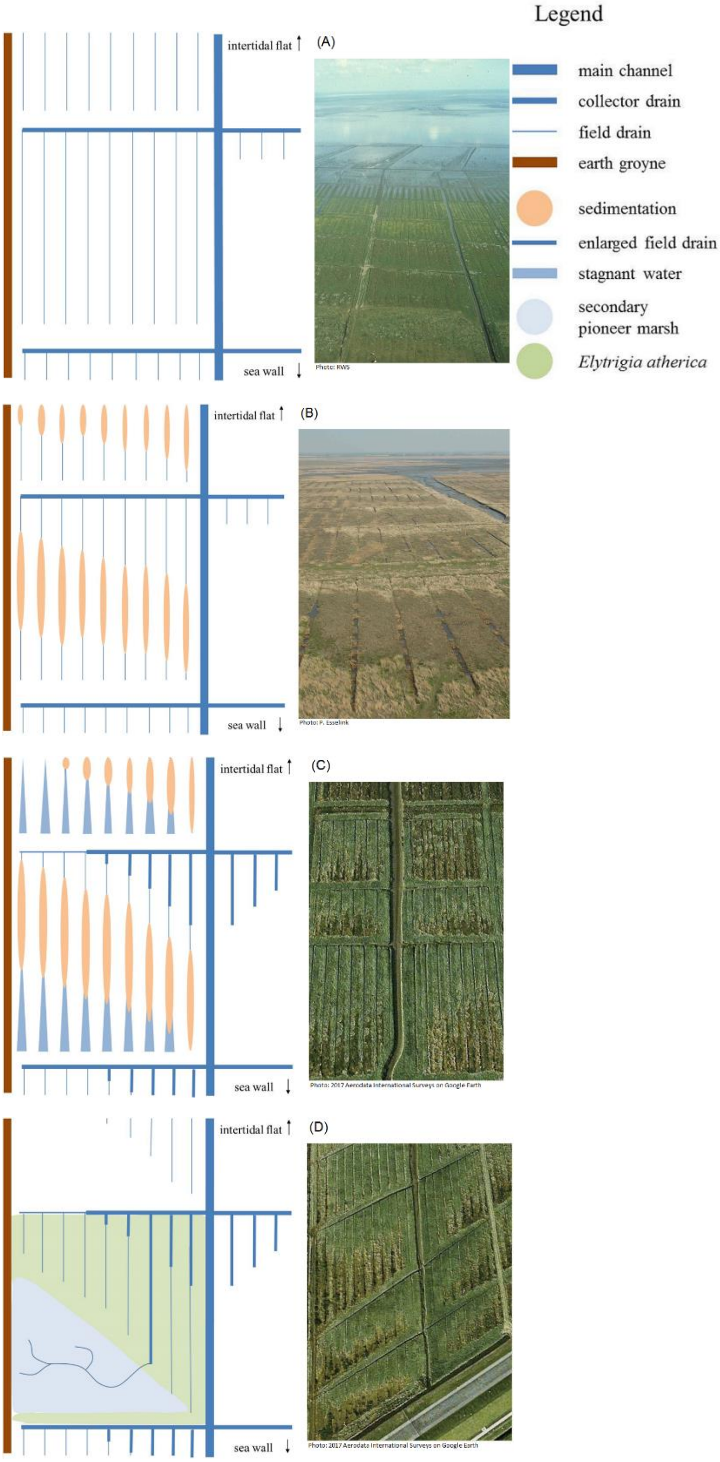
Despite the extension of salt marshes during the past century, pioneer and low-marsh vegetation types remained relatively constant and vegetation of late-succession stages increased. Along the Wadden Sea man-made tidal marsh formation finds its beginnings several centuries BC. From that time decimeters high mud ridges were formed by humans on the lower tidal marshes, apparently to further sedimentation. On the middle marsh summer dikes were built, restricting flooding to a few times per year, mainly during winter. Enhancement of salt marsh development can be shown from at least the late medieval times onwards. Maps and descriptions are available from halfway the 16th Century. Enhancing marsh development was mainly done by means of systems of ditches and earthen dams (so-called "*farmer's method*"). Since the 20th century upkeep of drainage and brushwood groins were combined (so-called "*Schleswig-Holstein method*") to establish foreland salt marshes.

Maintenance

Originally the maintenance was targeted to extension of foreland salt marshes to establish meadows for grazing animals. During the last quarter of the 20th century the aim is directed towards nature conservation. This led to changes in management that varied from minimal intervention to strategic upkeep of parts of the drainage and groin systems. One of the focus points is on slowing down succession and development of climax vegetation. The size of foreland salt marshes depends on the upkeep of the

[1] Over the period 1995/2001 to 2008/2014 mainland tidal marshes did not change much in areal extent in the Netherlands and Denmark, whereas expansion was observed in Schleswig-Holstein with ca 14% or 1,160 ha. For Lower Saxony available data show a decrease in area over the period 1995/2001 to 2002/2007.

brushwood groins at the seaward marsh edge. Natural expansion without human intervention of mainland marshes is mainly confined to the Leybucht and Jadebusen in Lower Saxony and the Schleswig Holstein region, N of the Elbe estuary.



Schematic overview of changes in the artificial drainage system after the traditional maintenance was discontinued. (A) Starting situation. (B) Central parts of the ditches or field drains have silted up. (C) As a consequence, drainage ceases upstream, whereas downstream the field drains deepen and decrease in width. The latter also occurs in the downstream part of the collector drains close to the main channel. (D) The increased soil-waterlogging causes local replacement of vegetation with Elytrigia atherica by secondary pioneer vegetation, and low-marsh vegetation. The photographs show examples from sites *in the Netherlands and Germany (text and figure from: Esselink et al., 2016; modified from van Wesenbeeck et al., 2014).*

To enhance development of man-made salt marshes, digging and a regular upkeep of the artificial drainage system were traditionally important management practices (figure). The function of artificial drainage was to (1) enhance vegetation on high intertidal flats; (2) increase the carrying capacity for livestock grazing; (3) prevent the formation of depressions and (4) prevent water logging of the dikes. Nowadays nature organizations are improving the drainage- and creek-quality to realize nature goals. For instance, to transport more mud in the direction of low areas near the dikes (Holwerd Oost), or for young or small fish which find shelter and food in those water courses (project Swimway).

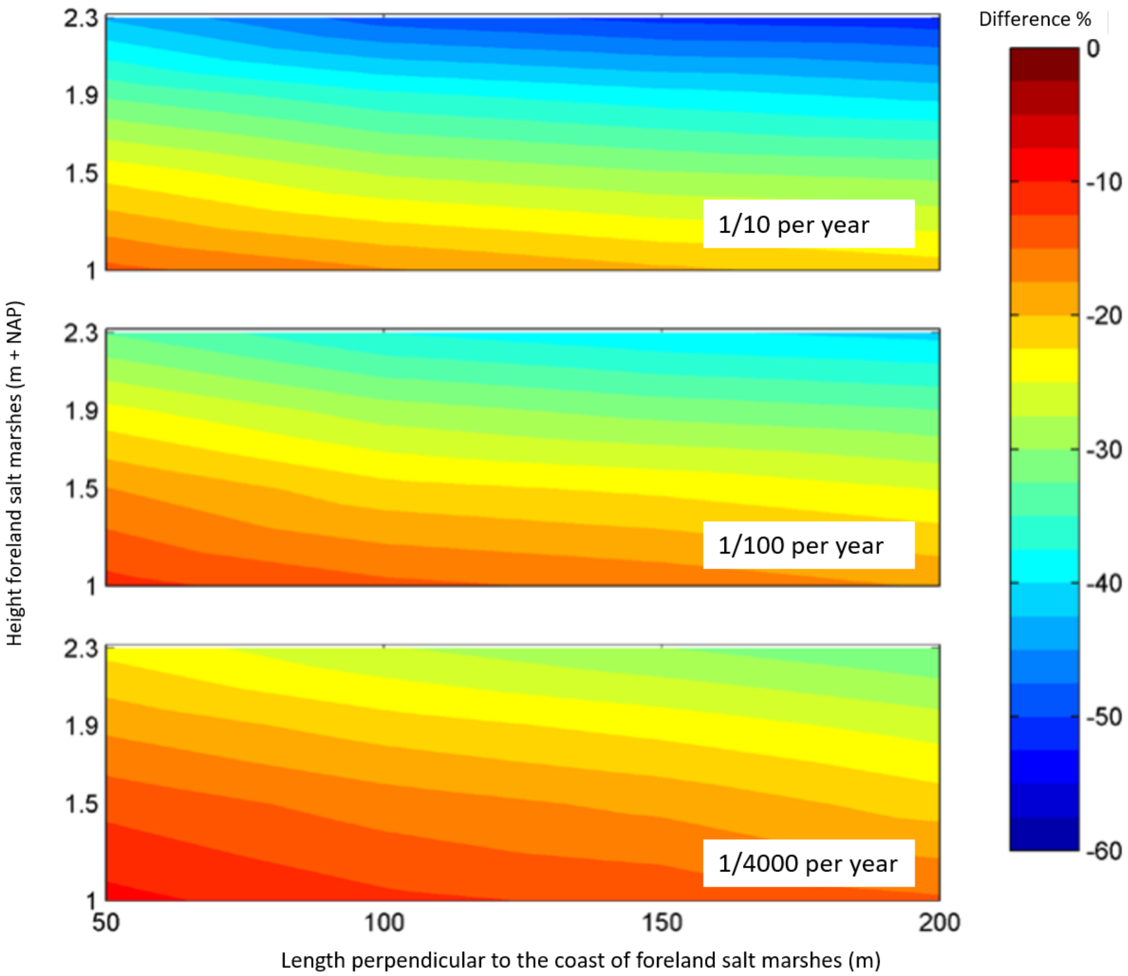
Foreland salt marshes show an average elevation increase of almost 10 mm/yr, i.e. well above the increase rate of MHT (2.0–3.0 mm/yr). The high accretion rates lead to a relatively quick vegetation succession and can eventually lead to a species-poor climax vegetation dominated by sea couch. Although grazing delays the succession, a more dynamic system helps to create a more natural marsh in which accretion and erosion are kept in balance by cyclic succession. To that end, upkeep of brushwood groins has been reduced by 40% in the Dutch Wadden Sea. Also, maintenance of artificial drainage systems has been stopped over extensive areas in Germany and the Dollard area (70- and 80-ies), and along the Frisian and Groningen coast (from the 1980s onward, stopped completely by 2001). Furthermore, in some restoration projects parts of the drainage system were filled up or the top soil was removed. In Lower Saxony clay mining projects are used to establish a more natural development of the creek systems (See Factsheet clay pits). In managed retreat projects in the Netherlands and in Germany more natural creeks are built to start a landscape which will function and develop in more natural way (See Factsheet managed retreat). In the Netherlands, ditching is only continued locally by farmers in order to facilitate livestock grazing. As a result of stopping artificial drainage systems, many foreland salt marshes are slowly shifting towards a state with increased naturalness. However, it should be realized that, given their artificial origins, such semi-natural areas cannot be restored to completely natural salt marshes.

Overview of tidal marsh types in the trilateral Wadden Sea (After: Esselink et al., 2016).

Landvorm	Netherlands	Lower Saxony	Hamburg	Schleswig-Holstein	Denmark	Total
Year of survey	2008/2012	2004	2009/2014	2011/2012	2010/2012	
Island salt marsh						
Barrier connected (foreland incl.)	4.640	3.670	310	1.700	3.280	**13.600**
De-embanked (summer) polder	90	150	40			**280**
Mainland salt marsh						
Barrier connected				780	1.340	**2.120**
Foreland type	4.000	5.460		8.580	2.520	**20.560**
De-embanked summer polder	360	380				**740**
Hallig salt marsh						
	50			2.180		**2.230**
Total	**9.140**	**9.660**	**350**	**13.240**	**7.140**	**39.530**

To slow down succession grazing with livestock or mowing is used at many locations. Grazing creates a short turf. Although the number of plant species is, on the larger scale, somewhat higher in grazed than in ungrazed areas, different plant communities tend to converge to become a community dominated by *Elytrigia atherica,* unless sediment input is small and wet conditions prevail. Mowing results in lower plant species richness. Short term cessation of grazing is beneficial for plant species richness and invertebrates. Long term cessation results in tall vegetation. This is not good for geese and waders but good for songbirds. Resuming grazing can remove the tall vegetation and litter and increase plant species richness, especially on the high marsh. Grazing leads to higher compaction of the soil than no grazing, thus reducing the net accretion rate. Furthermore, it reduces the large soil fauna and leads to anoxic soil conditions.

Furthermore, it should be noted that foreland tidal marshes play an important role in dampening the waves which are directed towards the mainland dikes. Last figure shows that primarily the height and, secondarily, the length of a foreland salt marsh leads to a significant dampening of the waves which impact the dike. Wave conditions are given for 1/10 year, 1/100 year and 1/4000 year storm surge. Recent studies for the Dutch Wadden coast revealed that there are locally possibilities to generate new foreland salt marshes. Furthermore, experiments are being carried out to generate new foreland marshes (see local examples).



Dampening effect of height and width of foreland salt marshes on waves, given as difference percentage (Van Loon-Steensma et al., 2012)

Research

Monitoring is in place in several areas to study accretion, vegetation, biodiversity, maintenance of brushwood groins and drainage systems and Natura 2000-habitats on annual basis which is reported to the managers. It is an instrument to steer the abiotic and biotic maintenance of the Foreland Salt Marshes.

Results

At present many of the Foreland Salt Marsh areas are developing in the direction of a more natural system. Foreland Salt Marshes are increasing in height faster than MHW rise. On the longer run succession will lead to a larger area with climax-vegetation. Also, it decreases the space for the pioneer zone, which is wedged between the seaward extension of the tidal marshes and the tidal flats. Although grazing delays the succession to the climax vegetation, a more dynamic system could help to create a more natural marsh in which accretion and erosion are kept in balance by cyclic succession.

Lessons learned

Although ceasing maintenance has furthered the naturalness of the Foreland Salt Marshes, sedimentation-driven succession will lead to climax vegetation and squeeze of the pioneer zone. A new management course may be needed, but succession is not the only problem (see discussion points). A clear definition of means and targets will help to identify the best management and will enable evaluation of the management practices.

Stakeholder processes

The stakeholder processes mainly consist of interactions between responsible ministries, tidal marsh owners and users (partly private parties) and nature organizations. All salt marshes in the Wadden Sea area are part of Natura 2000. Next to the national legislation and nature protection regulations in the three Wadden Sea countries, the trilateral 2010 Wadden Sea Plan (WSP) provides the framework for the management of the entire area (CWSS, 2010). In the WSP, the following five targets have been formulated for salt marshes:

1. To maintain the full range of variety of salt marshes typical for the Wadden Sea landscape;
2. To maintain a salt marsh vegetation diversity reflecting the geomorphological conditions of the habitat with variation in vegetation structure;
3. To maintain or to achieve favorable conditions for all typical species;
4. To achieve an increased area of salt marshes with natural dynamics;
5. To achieve an increased natural morphology and dynamics, including natural drainage of mainland salt marshes, under the condition that the present surface area is not reduced.

Targets 1 to 3 pertain to all types of salt marshes. Target 4 is only relevant for salt marshes which formed without any interference of humans and are mainly related to islands. As such they are hardly relevant for Foreland Salt Marshes. Target 5 is relevant for Foreland Salt Marshes as nowadays parts of the Foreland Salt Marshes are dug out to enhance a more natural development (for instance: Noorderleech; Holwerd Oost in the Netherlands; Neuwapeler Außengroden in the Jadebusen; Elisabeth Außengroden in Germany).

Discussion points

- Especially in the pioneer zone upkeep of brushwood groynes might be focused on the development of the pioneer zone. Succession reversal and nature and policy goals could be combined with an increase in dynamics and naturalness in the process. It would imply a new big shift in maintenance practices, which should be more focused on tailor-made solutions addressing the local peculiarities of the Foreland Salt Marsh in question.
- However, already now growth season changes and changes in precipitation patterns are marked. On the long run sea-level rise will yet be another effect of climate change. All these changes can be expected to influence the development of the Foreland Salt Marshes. How should we react on the current and future climate-related changes?
- Should squeeze of the pioneer zone be the focus of future Foreland Salt Marsh management or should be focused more on climate change and sea-level rise? Or a combination? And how?

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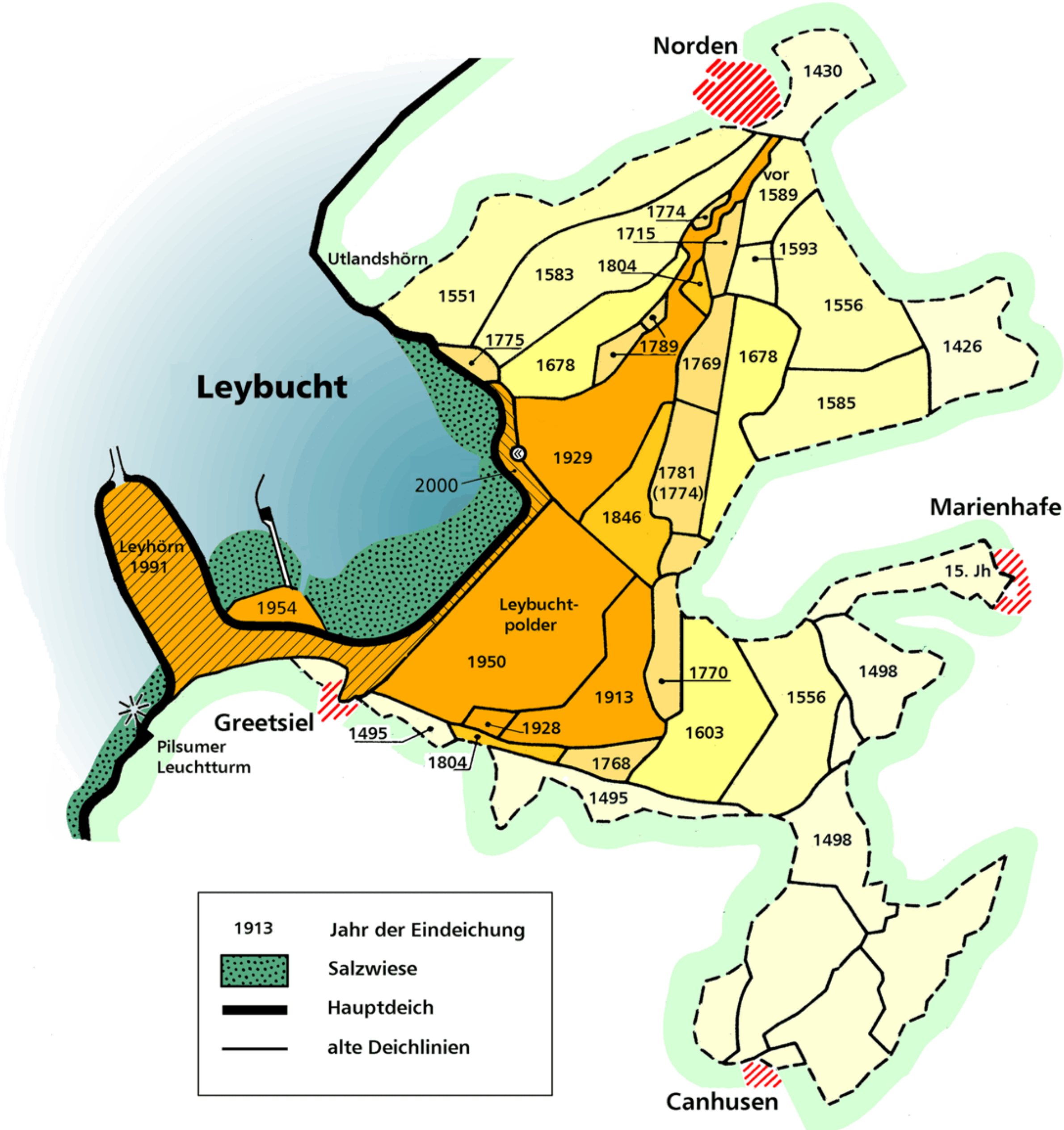
Seaward Solution Factsheet Leybucht



The Leybucht has formed due to flooding of the mainland. Thereafter strong sedimentation of fines resulted in a rapid silting up and poldering of the area. It is thus a great example of strong mud deposition capabilities in the Wadden Sea area.

With an area of about 28 km², the Leybucht is the third largest bay in Niedersachsen after the Jade Bight and the Dollard embayment. The area consists of 30 ha subtidal area, 1800 ha tidal flats, 690 ha tidal marshes and 280 ha summer polders. It is situated between the port of Greetsiel and Norddeich, about 18 kilometers north of Emden. The Leybucht was probably formed during the storm surge of 26 December 838. Later storm surges such as those of 1374 and 1376 enlarged the bay to its maximum extent with an area of 130 km², stretching from Greetsiel in the west to Marienhafe in the east and Canhusen in the south. In the following centuries, mud sedimentation led to heightening so that areas could be poldered.

By 1950 the bay had been reduced strongly by the construction of the Störtebeker dyke, which enclosed the Leybucht Polder and straightened the coast line. Although there were plans in the following years to reclaim the entire bay in order to shorten the line of dykes significantly and to improve coastal protection, these ideas were rejected on nature conservation grounds. In March 1984, an amended plan was submitted in order to reconcile requirements of coastal protection, nature conservation, drainage requirements and the village of Greetsiel. Already at the beginning of the planning there was a lot of resistance from nature conservation associations and Leybucht residents against this construction project, but - probably because of the extensive information - there were relatively few complaints. In total some 740 hectares of the Ramsar site would be affected. To reinforce the dyke system the first preparations began in October 1985 to build the New Störtebeker Dyke. It was completed in October 2000, and was built in front of the old dyke. A large part of the salt marshes could thus be saved, but some 100 ha were lost. In 1991 the Leyhörn was reclaimed. Ìn 1994 the 650 ha Leyhörn became a nature reserve. As compensation for about 130 hectares of salt marshes which were enclosed in the Leyhörn, the summer polder Hauener Hooge has been opened to the old Greetsieler Aussen Tief. About 80 hectares of the previous area can develop back into salt marshes due to the renewed tidal influence.

Since 25th june 1976 the area was protected as a Ramsar Site. As of the start of 1986 the Leybucht got special protection by Lower Saxony as part of the national park „Niedersächsisches Wattenmeer". In July 1989, the Ramsar Bureau received a document from WWF Germany, indicating that the operations at the Leybucht violated both the Ramsar Convention and the EC Bird Directive. Ramsar Bureau made the following recommendations:
(a) The future dyke line along the Störtebeker Deich should not enclose any existing areas of saltmarsh.
(b) Compensation measures for the 740 hectares affected by construction of the “nose” should include at least:
- establishment of a legal nature reserve over the whole area outside the dyke;
- establishment of a nature reserve covering the whole area inside the dyke;
- breaking down of the Sommerdeich in two places, within Leybucht and beyond Norddeich.

Leybucht area

By 1990 WWF Germany had complained to the European Commission. The Commission considered the complaint justified and forwarded it to the European Court. The Court ruled that Member States are only allowed to decrease an area of special designated protection zones if there are extraordinary reasons in the general public interest which exceeds the environmental interests. Economic and recreative interests are not qualifying.

Research

Knaack & Niemeyer (2004) looked into the changes for the period between 1960 and 1999. The major morphodynamical change was from a two-gully system into a single tidal gully. The intake area below mean high water in the Bay decreased by 40 % from 1960 to 1999, due to the silting up in the inner parts of the bay. Ongoing silting up is expected as a dynamical equilibrium has not yet been reached.

Lessons learned

The economic development of such bay-areas is difficult without influencing the great natural values. The jurisprudence of the EU indicates that basically it is forbidden to decrease the areal extent of a designated nature area. Furthermore, the ongoing infill of the Leybucht suggests that the changes may have furthered mud sedimentation. Due to the process natural values are reduced which is not recommendable. Such long-term effects should be considered when large-scale measures are undertaken.

Stakeholder process

A vivid discussion between the EU, NLWKN and nature conservation associations such as WWF and the local community clearly has led to some jurisprudence giving stronger direction to future initiatives.

Discussion points

In general, the approach to see the special designated protection zones of the Wadden area as a commons which can be used to further economic and touristic development by reducing its surface area appears to be a no-go. Reversely it may be asked if managed realignment for economic and touristic development would be allowable, since -if the scale is sufficiently large- also in that way, long-term morphological developments might be triggered.

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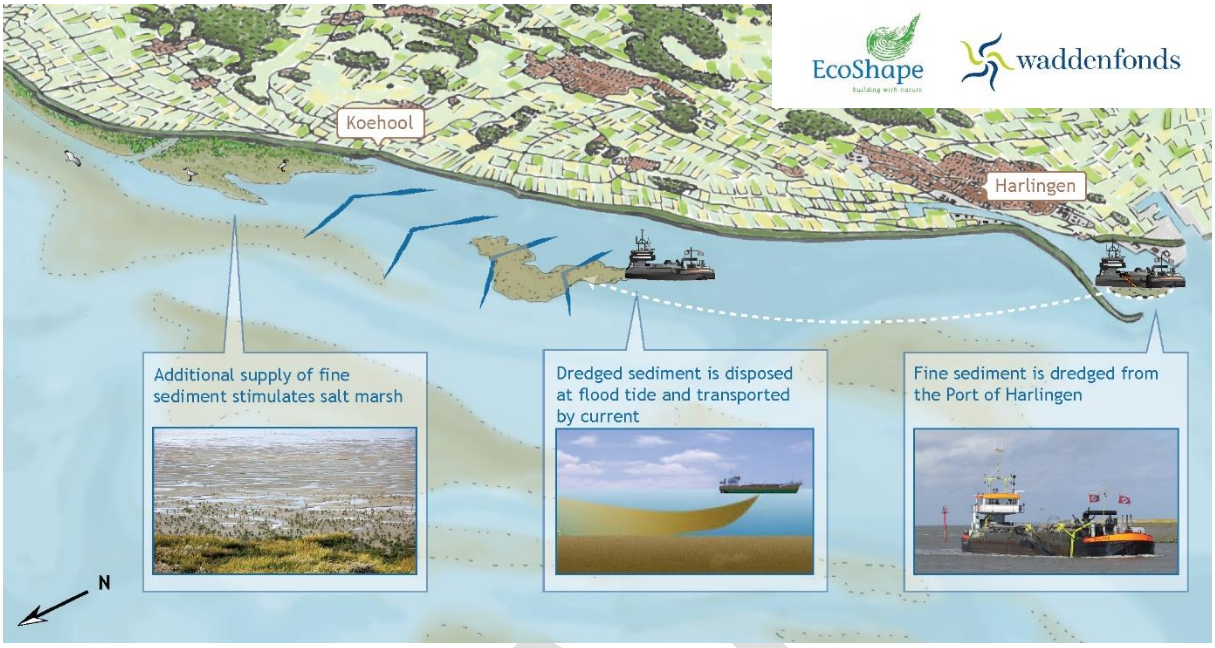
Seaward Solution Factsheet Mud Motor



The Mud Motor is disposal of sediment dredged at the Port of Harlingen at a specific location from where the mud is transported by natural processes, such as tidal flow, to nearby salt marshes and adjacent tidal flats. By increasing the sediment supply to the tidal flats, those will increase in height and create more favorable salt marsh expansion conditions. The aim is to stimulate the growth of salt marshes leading to increased dike safety and to reduce the recirculation of dredged sediment. Thus, three goals are aimed for: nature development, increased height of the foreland of the dike and a more economical way of dredging practice.

Accumulation of sediment is common in ports such as Harlingen and dredging is required. Dredged sediment is disposed offshore, as close to the port as possible to limit the costs. At the same time, a considerable part of the disposed sediment may return to the port under influence of tidal and density driven flows, which increases the maintenance dredging volumes. The goal of the Mud Motor is to re-use the dredged sediment in a beneficial way by stimulation of salt marsh development and reducing the return flow of sediments to the harbor. In this way mud might strengthen the intertidal muddy environment and the supratidal salt marshes. Due to this it may also help to provide extra wave dampening in front of the dikes.

Underlying hypotheses of the Mud Motor concept (using natural transport processes to re-use dredged sediment for salt marsh expansion) are that the sedimentation in and in front of the salt marsh is supply-limited (i.e. increasing the supply will result in increased sedimentation) and the salt-marsh expansion is limited by the coastal profile (inundation times are too large). The advantage of accelerating marsh-development processes in this way, is that the desired gradients that are associated with natural salt-marsh development are preserved and/or enhanced.

The Mud Motor was expected to generate three beneficial effects:
1. less recirculation towards the harbor, and therefore less maintenance dredging;
2. promotion of the growth and stability of salt marshes, improving the Wadden Sea ecosystem;
3. stabilization of the foreshore of the dikes, and therefore less maintenance work on the dike.

The Mud Motor pilot at Koehoal used dredged material from the port of Harlingen in the south (with annual dredging rates up to 1.3 million m^3). From the port to the salt marshes a flood-dominant tidal channel, ‘Kimstergat’, exists, which has been narrowing and slightly deepening over the last decennia. At Koehoal, the sea dike deflects from the Kimstergat channel and tidal flats are found and a narrow fringe of salt marshes has developed, which are increasing in width when going in eastward direction. At this transition point, the pilot aimed to enhance salt marsh growth. Eastward of Koehoal, large tidal flats are found, also forming a local tidal divide between the Kimstergat channel and the next tidal channel.

Research

The research for the Mud Motor pilot (within an Ecoshape project and a STW project) focused on field work. In the field, the effectiveness of the proposed disposal location was assessed with a tracer experiment, giving confidence in the disposal location. Over a three-year period, the sedimentation rates at the salt marshes and the tidal flats in front of the salt marshes were monitored, as well as vegetation cover, density and species distribution. The bed elevation was also measured for a shorter time period with a higher frequency, in combination with measurement of waves, currents and wind this showed very large natural dynamics in the bed level elevation at the project site and a large effect of wind-driven flows, even under moderate wind speeds. All beforementioned measurements took place at the tidal flats and the salt marshes. During 13-hour measurement also hydrodynamics and sediment suspensions in the Kimstergat tidal channel have been measured. To a lesser extent, numerical models have been used. First at project initialization, to determine the optimum disposal location and at the end of the project to test the hypothesis (understanding) of the sediment transport processes at the project site. The aim was to develop fundamental knowledge needed to understand and quantify the physical and ecological aspects of the Mud Motor concept for further upscaling and exporting.

Approach

Increasing the sediment supply to enhance of salt marsh growth is an alternative to the traditional approach of slowing down tidal flows and breaking waves with semi-permeable brushwood groins to stimulate sedimentation.

Over a period of two winters (2016 and 2017), 470,000 m³ of fine-grained sediment (D50 of~10μm) dredged from the Port of Harlingen was deposited at the end of the tidal channel Kimstergat, with an average of 22 sediment disposals per week of operation. It was expected that this mud would be transported by the tidal currents to the study site. Expectations were that level of the marsh would rise 1-2 cm due to the pilot.

Results

A general effect of the Mud Motor on sedimentation could not be shown. The bed-level dynamics at the project site is comparable with the reference location not affected by the Mud Motor (at Zwarte Haan). The field measurements revealed that the sediment disposed at the Mud Motor pilot location is partly transported to the tidal flats at Koehoal by flood-dominant tidal flows. At the extensive tidal flats at the end of the Kimstergat channel, there is ample opportunity for deposition and sediment is (temporarily) stored. When moderate to strong winds from the north-west blow over these shallow and muddy tidal flats, sediments are resuspended and transported and dispersed further, also to the project area. Mud is already abundant in the area and thus not a limiting factor for vertical accretion of the mud flats and salt marshes. Adding mud with a mud motor did not change that significantly. The large natural dynamics of the project site in combination with the relatively small signal from the pilot did not show convincing sedimentation rates that can be attributed to the Mud Motor. In the dredging volumes a decrease occurred during the short pilot period of 2 years, which is not conclusive considering the strong variations over longer time spans.

Measurements showed that the transport rate through the tidal gully was increased by a factor 1.6 - 2 due to the Mud Motor. The sediment dynamics of the area are strongly influenced by the sedimentation of muds since the closure of the Zuiderzee and as a result the tidal marshes grows since 1996, when the coastal profile was accreted enough to have suitable inundation times for vegetation to establish until 2005, a period with few storms and relatively much rain.

During the experiment, the heights of the tidal marshes fluctuated strongly over time with sedimentation and erosion of up to 1 dm, likely depending on the erosion and consolidation of the sediments. During the first Mud Motor period (September 2016 – August 2017) the tidal marsh and the mudflats showed vertical accretion, but the area of the tidal marsh decreased. In the period September 2017 - August 2018) the tidal marsh and the mud flats were eroded, but the vegetation covered a larger area. The vertical growth of the tidal marsh was hence not directly related to the horizontal extent of it.

Given the surplus of muds the main limitation for tidal marsh growth appears to be too much hydrodynamic energy. The most important factors for sedimentation are: wind conditions (wind can generate large set-up at the project site, resulting in erosion), consolidation of the mud and fixation of the mud by vegetation development. When sediment is deposited at the desired location, a time window with calm hydrodynamic conditions should follow so that sediment can gain enough strength to remain during more dynamic conditions.

Lessons learned
Although the Mud Motor may be a useful concept, it will not contribute to mud deposition on tidal marshes or between brush wood groins in areas where mud is not a limiting factor. Thus, care should be taken to identify areas where extra mud disposal may contribute to a transport of mud in the direction of the deposition site. Furthermore, disposal of mud at larger distances of the harbor may increase transport costs, but decrease return flow of mud to the dredging site. If such disposal is economical viable should be established for each separate case via modelling and measurements.

Stakeholder process
The Port of Harlingen produced large volumes of dredged mud (ca. 1 million m^3 per year), leading the secretary of the Wadden Sea Ports Harlingen to ask EcoShape for solutions. It Fryske Gea had developed a vision in which increasing the tidal marsh area was a goal. In a brainstorm the Mud Motor came up as a possible solution. It was subsequently rewarded by the Waddenfonds. Stakeholders: Port of Harlingen, Van Oord, Royal Haskoning DHV, Arcadis, It Fryske Gea, Wageningen University and Research, Deltares, Gemeente Harlingen.

Discussion points
- A Mud Motor will have the most impact in areas where mud is limited (see Lessons learned) but can only be executed if enough mud is available. Are there areas where both are present within economical viable distances?
- Do we want to build Mud Motors in areas where the bottom is mainly sandy?
- Are Mud Motors a solution to further sediment deposition in de-poldered areas (managed retreat and double dike areas)?

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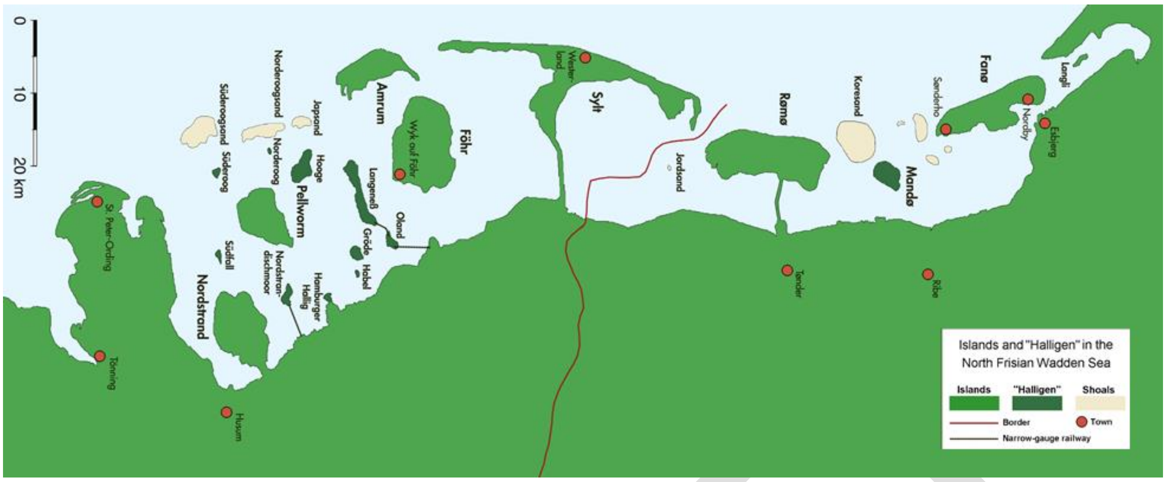
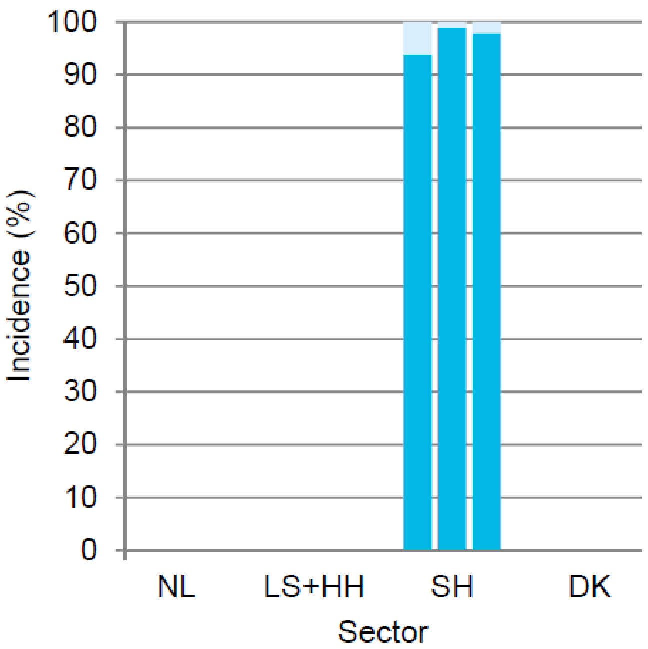
Landward Solutions Halligen



The Halligen (halliger in Danish) are salt marsh islands with no or low protective dikes. These islands struggle to keep up with MHW rise. Does nourishing with mud provide a solution or is it enough to open dikes and allow more frequent flooding?

There are ten German Halligen on Schleswig-Holstein's Wadden Sea and one in the Danish Wadden Sea, with areas ranging from 7 to 956 ha. The Halligen result of frequent floods and poor coastal protection during the Middle Ages. Originally, these islands were former parts of the mainland or bigger islands, separated therefrom during storm surges. The salt marshes of the Halligen thus accreted on low-lying old land. Sometimes, owing to sediment deposition, islands have grown together to form larger ones (Langeneß) or amalgamated with the mainland (Hamburger Hallig).

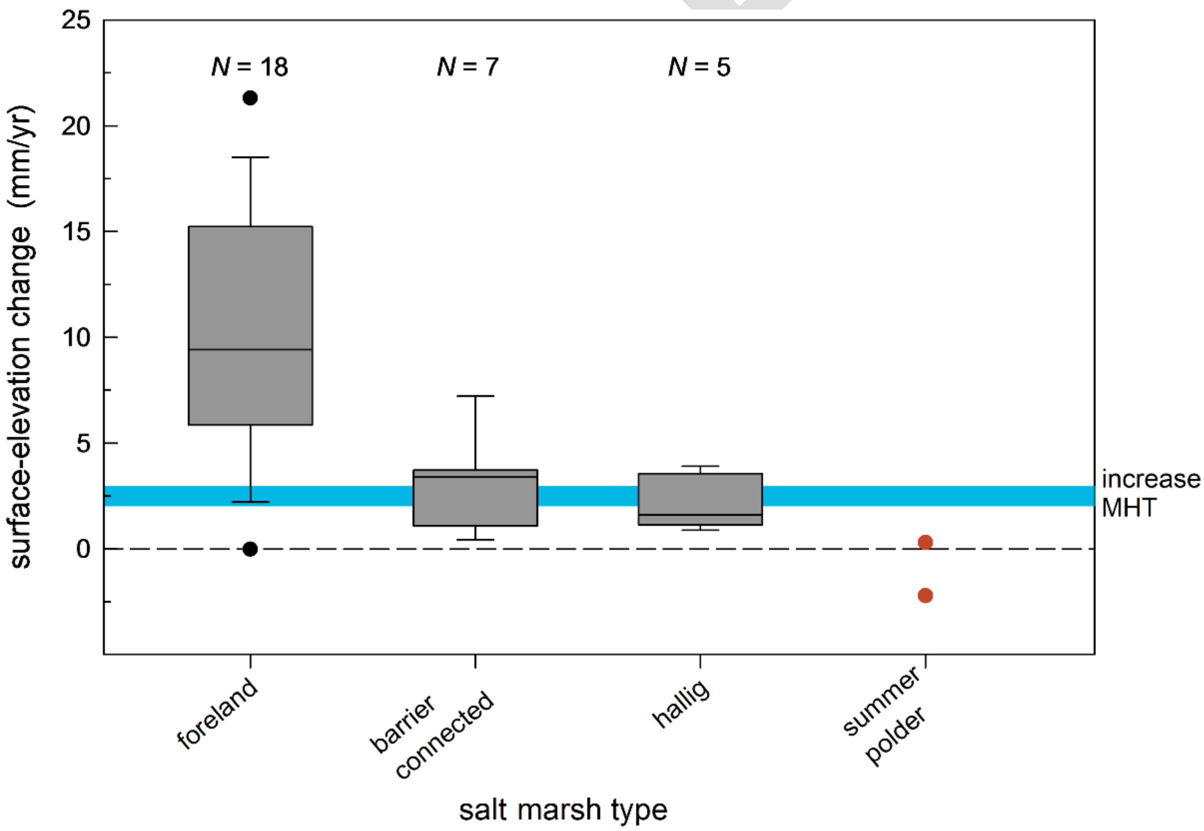


Development of the extent of artificial drainage in the Halligen salt marshes over the periods 1995/2001, 2002/07 and 2008/2014 (left to right). Darker blue shows: last human intervention more than ten years ago. Light blue shows last human intervention less than 10 years ago (Esselink et al., 2016).

On the islands one or several meters high, man-made mounds are present, the so-called Warften (Værft in Danish), to provide protection against storm tides. Hallig salt marshes are generally protected by revetments and are recently not increasing or decreasing in surface area. Some Halligen have overflow dikes, comparable to summer dikes on tidal marshes. For centuries, flooding events happen on average of 4-5/year on Halligen with low dikes, and between 40-50/year on those without coastal defense. During such storm surges sediment is deposited that has enabled the islands to grow apace with sea level rise, allowing them to keep above MHW. Furthermore, the Halligen and other islands form a barrage against waves which allows the mainland dikes to be lower.

On several islands, such as Hooge, low dikes were constructed to reduce the number of flooding events during the summer months, when cows and sheep still graze on the salty land. Next to that sluice gates and culverts are used to help keep the islands drained. The reductions in flooding frequency lead to a smaller sediment deposition on the Halligen, leading to slower vertical growth. This is a problem considering accelerated sea-level rise. On non-diked Warften, net-sedimentation rates depend mainly on the distance to the tidal flats and on the distance to larger creeks. In central parts sedimentation rates may become lower than MHW rise.

For salt marshes, the increase of mean high tide (MHW) is an important parameter. Over the last century, increase of MHW varied within the Wadden Sea due to differences in vertical land movement and changes in wind climate. Since 1900, average increases of MHW in the Wadden Sea have been in the order of 2–3 mm/yr with highest values in the German sector east of the Elbe.



Vertical sedimentation rates in salt marshes and summer polders, based on various measurement techniques. Elevation changes based on overlapping and varying periods in time, mostly starting around 1990 or later. Grey boxplot with median and 25 and 75 percentiles. Vertical lines give the minimum and maximum values or 1.5 times the interquartile range of the data. Black dots show outliers. The horizontal blue bar gives the range of the long-term increase of MHT level since about 1900 (Esselink et al., 2016).

Discussion Points

Tidal marshes situated near tidal flats and creeks silt up relatively quickly if enough shelter is present. As a result, the tidal marshes can expand rather quickly. However, as a result the central parts of tidal marshes are positioned at an increasingly larger distance from the tidal flats and sometimes from creeks as well. Due to this sedimentation rates decrease, and succession is slowed down or even reversed. The same result can be reached by decreasing the management of the area so that outer tidal marshes do not silt up as rapidly. The discussion point therefore is: should we expand tidal marshes so that central parts can regress, or should we not strive for expansion of tidal marshes? Would a decrease in tidal marsh area in combination with removing of dikes help the central area of the Halligen to silt up more rapidly? What are the implications for natural values and agricultural values?

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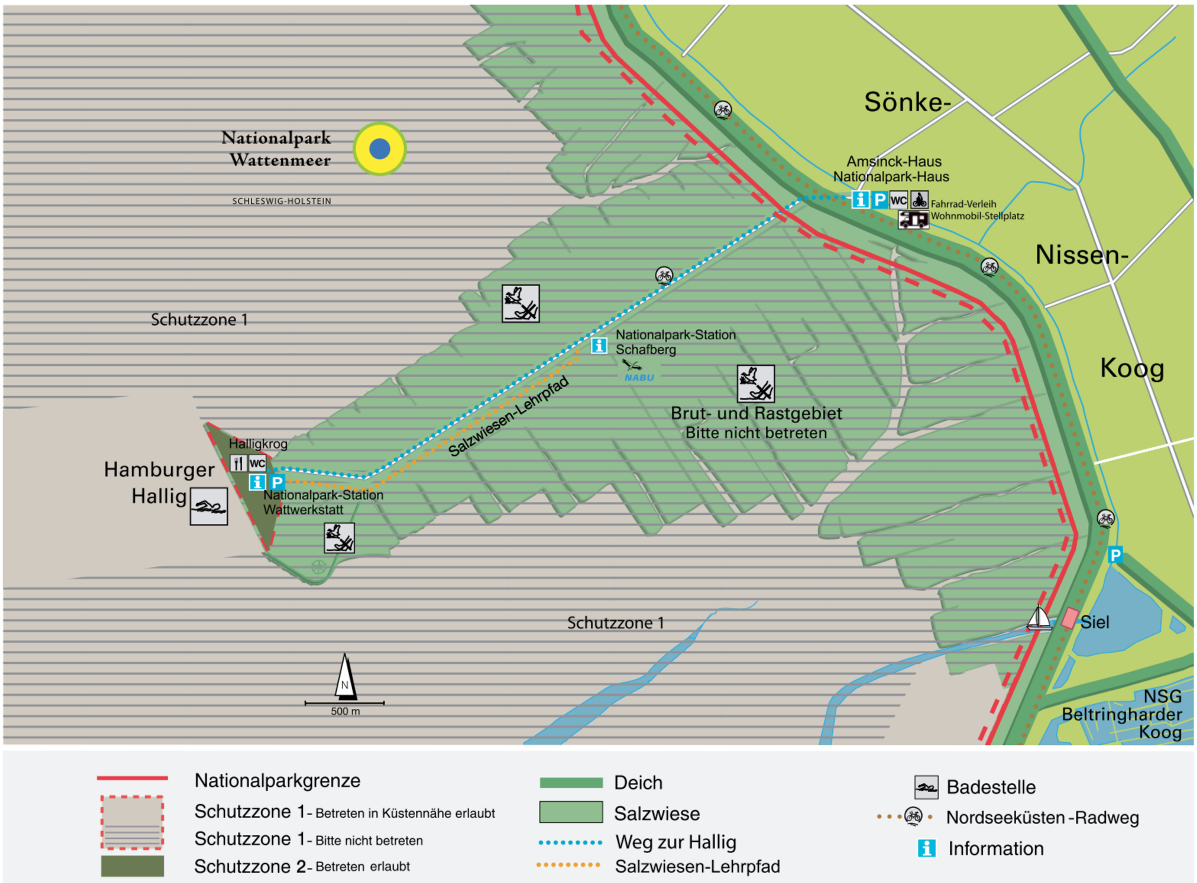
Landward Solutions Hamburger Hallig



Hamburger Hallig is situated in the North Frisian Wadden Sea area in Schleswig-Holstein, Germany. It is not protected by sea dikes. It is therefore counted among the Halligen islands. Its history illustrates the possibilities and restrictions of mud sedimentation.

History

The island was named after two merchants from Hamburg, the brothers Rudolf and Arnold Amsinck. They were granted a privilege to purchase and maintain land NE of Strand island and formed the Amsinck polder by constructing dikes in the period 1624-1628. The Burchardi Flood of 1634 destroyed the dikes, leaving only one artificial dwelling hill with "Hamburger Haus" on it intact. Afterwards the dikes were restored at high financial costs. Dikes were damaged repeatedly and in 1711, the island had again become an undiked Hallig. It remained property of the Amsick family until 1760.The house on the island was destroyed in the February flood of 1825.

In 1859/60 a causeway was built connecting the island with mainland of North Frisia but it broke soon after construction. In 1866/7, a fascine dam was constructed between the Bordelum sluice and Hamburger Hallig. It was paved in 1874. The causeway became traversable in 1901 and was paved in 1970 with concrete slabs, allowing cars to be driven to the island. The road is covered some 60 times per year during extremely high-water level events.

Modern coastal management protects the west coast of Hamburger Hallig from further erosion. Today, there are three artificial hills (German: Warft) on Hamburger Hallig including one hill on the floodplains and one without buildings. These are the main Warft with three houses on it, Main Warft, Kuhberg and Schafsberg. Schafsberg is a hill two kilometres halfway between Hamburger Hallig and the mainland.

Sedimentation
The interruption of tidal current by the causeway led to a considerable increase in mud sedimentation on either side of the dam. Due to sedimentation resulting from building brushwood groins and drainage systems extensive foreland tidal marshes were formed. The experience gained from the construction of the Hamburger Hallig dam considerably influenced development of land reclamation in North Frisia. In 1928 at the mainland side the Sönke-Nissen-Koog was diked and foreland tidal marsh formation was once again stimulated by extensive tidal marsh formation measures. In 1908, the area of Hamburger Hallig measured 96 hectares; by 1930 it amounted to 216 hectares. Today, the Hamburger Hallig, together with the floodplains and 700 ha salt marshes off the Sönke-Nissen-Koog polder, encompasses an area of roughly 1,000 hectares.

Net-sedimentation rates depend mainly on the distance to the tidal flats and on the distance to larger creeks. The results of the grid mapping and of the vegetation mappings in long-term ungrazed salt marshes indicate that *Elymus athericus* spreads in the upper salt marsh mainly on sites with high sedimentation rates. In the central part of the Hamburger Hallig salt marsh where annual net sedimentation rates are below 0.1 cm the relative elevation above mean high water (MHW) has decreased from 1980 to 1995 due to the sea-level rise. In this area the spreading of Elymus seems to be limited by re-wetting. In the low salt marsh, large stands of *Atriplex portulacoides* have spread mainly on areas close to the tidal flats in the intensively grazed and the ungrazed salt marsh of Sänke-Nissen-Koog. The cover of *Aster tripolium* stands which had been dominant all over the ungrazed plot of this salt marsh in 1992 has decreased considerably until 2002. In contrast, *Aster* spread in plots with both moderate and high grazing intensity.

Low sedimentation rates are also problematic on the areas of the Halligen behind dikes. If sedimentation rates are too low, the area will lower with respect to MHW and storm surges will be covering the area much more frequent.

Overview of MHW rise and sedimentation rates at various parts of the Hamburger Hallig and nearby Sönke-Nissen-Koog (after Kiehl et al., 2003)

Parameter	Mean height change mm/yr	Period	Source
MHW rise	8	1975.5-1990.5	Kiel et al, 2003
Foreland Hamburger Hallig, no grazing since 1980, central part of tidal marsh	<1	1995-1999	Schröder & Lünning, 2000
Foreland Hamburger Hallig, NW side near the tidal flats	14-22	1995-1999	Schröder & Lünning, 2001
Foreland Sönke-Nissen-Koog, no grazing, far from tidal creek	3-6	1995-1996	Stelter, 1996
Foreland Sönke-Nissen-Koog, no grazing, near tidal creek	6-19	1995-1996	Stelter, 1996
Foreland Sönke-Nissen-Koog, no grazing, near the dike	1	1991-2000	ALR Husum
Foreland Sönke-Nissen-Koog, no grazing, far from dike near tidal flats	15	1991-2001	ALR Husum

Natural values
On 16 April 1930 the Hamburger Hallig was declared a nature reserve to protect the local populations of pied avocets. It is maintained by Naturschutzbund Deutschland (NABU). The vegetation is mainly characteristic of the lower and middle tidal marsh. The tidal marshes form an important resting area for arctic geese and ducks during their migration with many thousands of birds during much of the year. The tidal marshes of the Hamburger Hallig were grazed relatively intensively by sheep (3.9 sheep units/ha).

Discussion Points

Tidal marshes situated near tidal flats and creeks silt up relatively quickly if enough shelter is present. As a result, the tidal marshes can expand rather quickly. However, as a result the central parts of tidal marshes are positioned at an increasingly larger distance from the tidal flats and sometimes from creeks as well. Due to this sedimentation rates decrease, and succession is slowed down or even reversed. The same result can be reached by decreasing the management of the area so that outer tidal marshes do not silt up as rapidly. The discussion point therefore is: should we expand tidal marshes so that central parts can regress, or should we not strive for expansion of tidal marshes? Would a decrease in tidal marsh area in combination with removing of dikes help the central area of the Halligen to silt up more rapidly?

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Wikipedia

Seaward Solutions Geise Leitdamm

The Geise-Leitdamm is a 10 km long training wall (jetty) in Lower Saxony, situated southwest of Nesserland. It separates the Emder Fahrwasser from the Dollard area. As such it also hinders the transports of water and mud between both. Such walls might be effective to manage mud but have a large impact on the hydrodynamic and morphological system.

At the same time as the development of the port in Emden, the Emder Fairway (Emder Fahrwasser) has been adapted to the increased shipping. The first Geiseleitwerk for the improvement of the waterway dates from 1872-1875 and consisted of a training wall with a system of groins. This work was constructed on the Wybelsumer plate to fixate this plate. The shoal formed the western offshoot of the Geise: an a intertidal flat continuing to Pogum. The works at the Geise Leitdamm were extended in order to prevent the infill of the shipping lane. With the heightening and addition of the system of groins on the Geise in the years 1896-1900, the Geiseplaat became increasingly higher. Due to these works the Emder Fairway was largely separated from the Dollard.

Research

Measurements in 1949 and 1952 showed that there was a flood surplus of approx. $6*10^6$ m^3 (=126-120$*10^6$ m^3) flowing in via the Mouth of the Dollard, whereas an ebb surplus of $6*10^6$ m^3 (7-13$*10^6$ m^3) flowed out via the Emder Fahrwasser. This is likely to have resulted in a net mud supply from the Dollard area towards the Fahrwasser.

The training wall separates the Dollard from the Emder Fairway and tides determine the exchange between the Dollard and the Ems and thus the transport of mud. At present, the Ems tidal river is characterized by very high sludge concentrations. Any tidal exchange between Emder Fahrwasser and the Dollard might likely result in a net transport of mud from the tidal river to the Dollard. As an example: around 1992 mud transport was thought to occur from the Emder Fahrwasser towards the Dollard, because the Geise- Leitdamm was damaged at several locations and thus permeable (De Jonge, 1992). Reparations have been made and gaps are absent nowadays. However, recent research indicates that mud from the Dollard is currently entering the Ems tidal river via the Geise-Leitdamm.

Discussion points

The Ems estuary is a degraded ecological system, mainly because of a strongly artificial morphology, high levels of turbidity, limited quality and quantity of estuarine habitats and local extended periods of anoxic conditions. Thus, an Integral Management Plan is being undertaken as a coordinated initiative by Germany and The Netherlands. Among others, current options focus on trapping part of the mud to lower turbidity, improve light penetration, primary production and fish migration.

Training walls might separate areas with high mud concentrations from areas with low mud concentrations. As such they might alleviate the environmental stress at some parts and heighten it at other parts. Is this a good solution to be used in estuaries? Or should compartmentalization be avoided?

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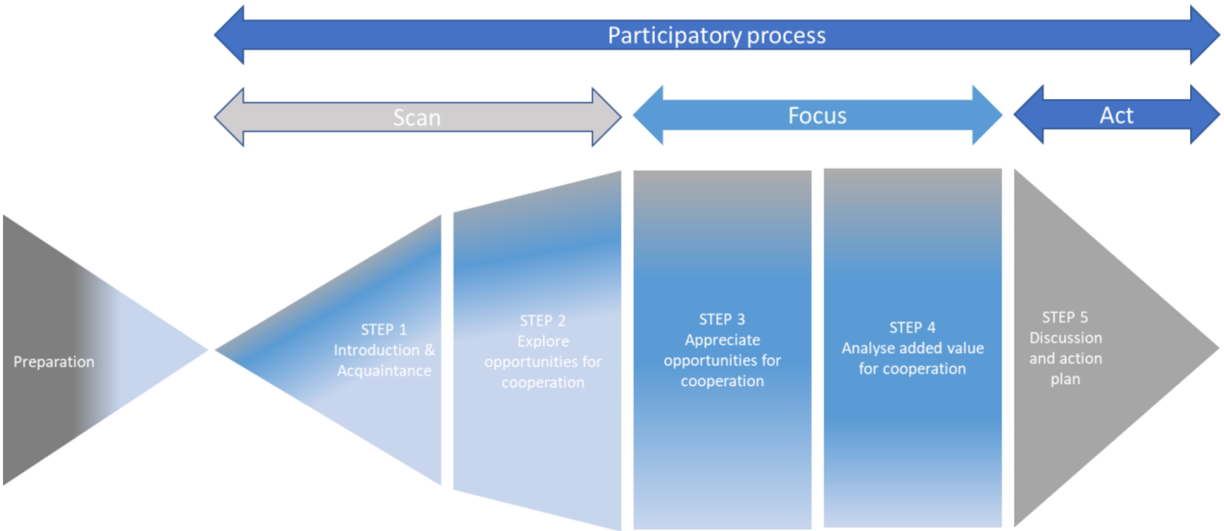
1 Mud dynamics in the Het Eems estuarium, research phase 1: literature review mud and primary production
2 Mud dynamics in the Eems - Dollard, research phase 1: working plan phase 2 and 3
3 Mud dynamics in the Ems - Dollard, research phase 2: analysis existing data
4 Mud dynamics in the Ems- Dollard, phase 2: setup hydrodynamic models
5 Mud dynamics in the Eems - Dollard, phase 2: setup sediment transport models
6 Mud dynamics in the Ems estuary: set-up of primary production model
7 Mud dynamics in the Ems Estuary, phase 2: model analysis
8 Mud dynamics in the Ems - Dollard, phase 2: analysis soil samples
9 Ems -Dollard primary production research (datarapport to be found on http:// library.wur.nl/WebQuery/wurpubs/489709 en samenvattend rapport op http://library.wur.nl/WebQuery/wurpubs/489710)
10 Memo on scenario definition
11 Mud dynamics in the Ems- Dollard, phase 3: scenarios for improvement

Wasser- und Schiffahrtsamt Emden & Rijkswaterstaat - directie Groningen, 1986: Duits-Nederlandse Eemscommissie; Rapport Hydrologisch Onderzoek Benedeneems en Dollard 1952 - 1985 DEEL III, 87 pp.

Method Cooperating for Added Value



Cooperating for Added Value or 'Co-Add' is an instrument which shows how to actively shape cooperation in situations where (more) cooperation is desired. *Co-Add* has been applied within the framework of the High-Water Protection Program (HWBP) in the area Noard-Fryslân Bûtendyks (Netherlands) on behalf of the Program Waddenzeedijken. The preparation and five process steps give a practical direction how to use the instrument. After an introduction, the parties will present the opportunities for collaboration, after which each party makes a valuation of the different opportunities. On the basis of individual valuations, the added value of cooperation for the group is determined and how the added value of collaboration can be achieved.

Successfully establishing cooperation is not straight-forward. Often it is new, sometimes threatening with risks for planning and budgets. However, cooperation can lead to extra benefits. An example is '*Building with Nature*'-solutions which serve several functions at once: natural values and human interests. The search for a win-win will especially be easy if working together will deliver extra benefits for all parties (no regret).

Co-Add shows how stakeholders can actively form and establish cooperation in situations where cooperation is wanted. The goal of *Co-Add* is to facilitate cooperation between stakeholders. In a participatory process, stakeholders can explore which goals they can achieve, if cooperation provides an added value and how they can reach these goals. Important is that stakeholders will participate only if this will deliver more profit than working separately. Parties cannot be forced to cooperate: they have to choose voluntarily to do this.

The preparation and the five process steps show schematically how the instrument can be used (figure):

Preparation
The purpose of the preparation is to determine if and how *Co-Add* can be applied in the situation. The result is a go/no-go decision on the application of *Co-Add* and a process design in the event of a 'go'. The question to be answered is whether cooperation creates potential added value and whether parties are willing to cooperate with them.

Step 1 Introduction: to a joint knowledge base

The first step is an introduction and meeting in which parties get to know each other and to understand the context better. This creates willingness and confidence to get started together and create a common knowledge base, preferably during a field visit.

Step 2 Opportunities for cooperation

The second step is a brainstorm to get an overview of opportunities for cooperation between parties. The brainstorm should be wide and without judging opportunities. Judging and prioritizing happens in the next steps. Depending on the context and purpose of the process, opportunities are sought from certain topics, a specific subject or problem, or from coalitions.

Step 3 Appreciation of Opportunities

Each party appreciates the chances which appeared in step 2. Parties are asked if the opportunities make it easier or more difficult to achieve their organizational goals. The rating is then displayed in a rating table. It shows whether parties will win or lose with a certain opportunity. Rating can be done through an online survey, a method of stickering, or completing a multi-criteria table.

Step 4 Analysis added value of cooperation

In step 4, an analysis determines the added value of collaboration. First, it is determined whether there are opportunities which prove directly feasible or unfeasible, because everyone wins or loses. After that, the potential added value of cooperation is considered. Finally, we look at how the (potential) added value of cooperation can be achieved. For example, by compensating losers or combining opportunities.

Step 5 Prioritization and follow-up action

Step 5 defines follow-up actions for collaboration based on the added value analysis. It is important to first discuss and check the analysis. Then parties discuss, using the analysis, on which matters they want to participate.

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More info on the application of Co-Add (in Dutch): *https://pov-waddenzeedijken.nl/wp-content/uploads/2020/02/DmV-Bijlage-3b-Handreiking-Meerwaarde-van-Samenwerken.pdf*

Seaward Solution Dredging

https://beeldbank.rws.nl, Rijkswaterstaat / Rob Jungcurt

The increasing depth and width of the ships requires increasing depths and widths of the fairways to the major harbors. Next to that, harbors have to be expanded regularly and have become deeper over time. Furthermore, the dimensions of several fairways for ferries have to be maintained in depth. Both fairways and harbors require maintenance dredging as they become filled up with sediments. Here we discuss the practice of dredging in the Wadden Sea area and the estuaries.

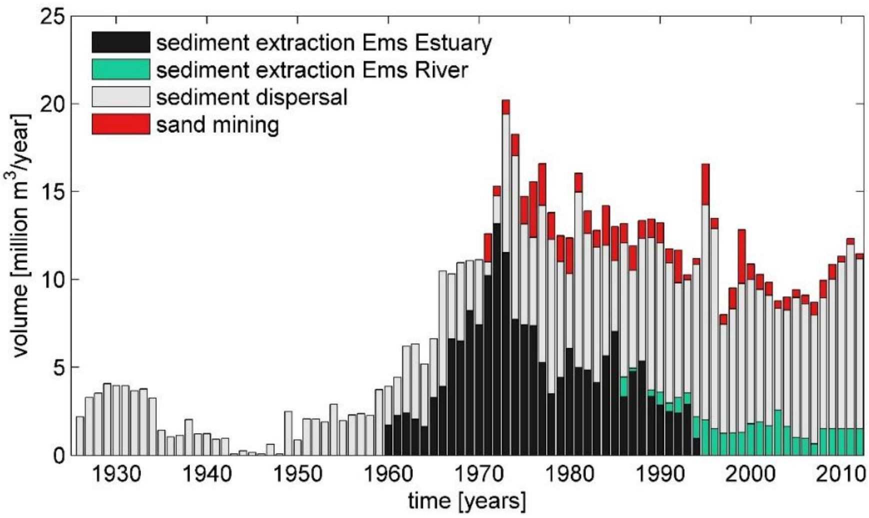
Dutch Wadden Sea

In the period of 1989-2017 an average amount of $1.6*10^6$ m^3/yr was dredged in the Dutch Wadden Sea (excluding the Ems estuary), of which approximately 56 % mud and 44% sand. Currently, about $3*10^6$ m^3/yr sediment is being dredged, of which $1.7*10^6$ m^3/yr consists of mud. Based on the recent trends, an estimate was made of the future dredging activities up to 2023, which would then increase up to $10.5*10^6$ m^3/yr. The dredged sediment is subsequently disposed within the Wadden Sea. Therefore, this is considered as redistribution of the sediment within the system, instead of a sediment sink.

Ems Estuary

Between 1960 and 1994, $5.1*10^6$ m^3/yr was dredged from the port of Emden ($1.5*10^6$ m^3/yr) and fairway ($3.6*10^6$ m^3/yr) and brought on land (sediment extraction in **Fout! Verwijzingsbron niet gevonden.**). Another $5*10^6$ m^3 of sediment was dredged from the estuarine approach channels and ports, and subsequently dispersed within the estuary. Approximately $1.5*10^6$ m^3 of the extracted sediment was sand: the remaining $3.6*10^6$ m^3/yr is mud. Since 1994, sediment is no longer dredged from the port of Emden, but regularly re-aerated, thereby preventing consolidation. The resulting poorly consolidated bed remains navigable, and consequently the port no longer requires maintenance dredging. At the same time, sediment dredged from the approach channel to Emden is no longer extracted but dispersed in the estuary. No dredged sediment is disposed in marine waters outside of the estuary.

The density of the poorly consolidated sediment currently dredged from the approach channels to Emden is 500 kg/m^3, providing a measure to convert historic extracted sediment volumes to mass. Using this density, on average $1.8*10^6$ ton of fine-grained sediment was annually extracted from the port of Emden and its access channel between 1960 and 1994. The annually averaged sand volume extracted as maintenance dredging (of 1.5*10⁶ m³/yr) corresponds to a mass of 2.4*10⁶ton/yr (using a density of 1600 kg/m³, typical for sand). The average amount of sand mining in the period 1970-2011 is 1.1*10⁶ m³/yr (corresponding to 1.8*10⁶ ton/yr). Sediment was also extracted before 1960, but these quantities are not exactly known. One estimate is that on average 1*10⁶ ton/yr was extracted from the estuary between 1924 and 1960 to raise the bed level of polders. However, calculations indicate that the total amount of mud since 1907 may be as much as 150*10⁶ ton/yr/ It is not clear to what extent these numbers overlap with dispersal data from de Jonge (1983), and therefore not added to **Fout! Verwijzingsbron niet gevonden.** for the Ems. Since its last major deepening in 1994, the lower Ems River requires regular dredging. Around 1.5*10⁶ m³ (0.8*10⁶ ton) of fine sediment are extracted annually from the lower Ems River and brought on land.

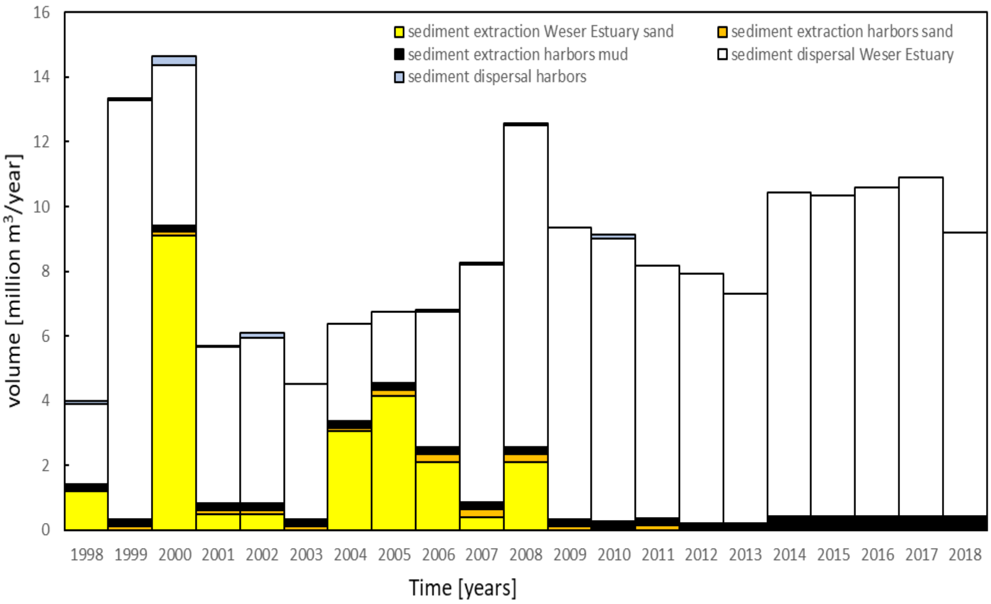


*Dredging volumes for the Ems estuary since 1925: sediment extraction (mainly mud) in the Ems estuary and the lower Ems River, sediment dispersal, and sand mining (from van Maren et al. (2016). Total dredging volumes before 1960 are from de Jonge (1983); dredging volumes after 1960 are from Mulder (2013) for the Ems estuary and from Krebs (2006) in the lower Ems River (until 2006; after 2006 a constant value of 1.5*10⁶ m³ is assumed).*

In terms of sediment sinks, sediment extraction from the outer estuary (port of Emden and approach channel) increased up to the mid 1970's, but became close to 0 in the the early 1990's. On average 1.8*10⁶ ton was annually extracted in the period 1960-1994. After that, around extraction shifted to the lower Ems River, form which around 1*10⁶ ton is annually extracted. On top of mud extraction, 2.4*10⁶ ton was extracted in the period 1960-1994 for navigability, and 1.8*10⁶ ton of sand was mined in the period 1970-2011.

Weser Estuary

In the estuary dredged maintenance volumes have decreased after the 9 m deepening from 7.5*10⁶ m³ in 1979 (mainly in the Lower Weser) successively to 1.7 *10⁶ m³ in 1986 (Wetzel, 1987). However, data over the period 1998-2010 give an average maintenance dredging (including Water Injection) of 5.4*10⁶ m³/yr for the fairway (**Fout! Verwijzingsbron niet gevonden.**). Data over the period 2007-2018 give an average maintenance dredging (including Water Injection) of 8.9*10⁶ m³/yr; a clear increase. From the fairway mainly sand is dredged which is relocated within the estuary and the adjacent North Sea (where it is partially influenced by coast parallel sediment transport).



Overview of data on dredging. Data 1998-2010 based on BIOCONSULT & NLWKN (2012); data 2007-2018 WSV data für dritten. Differences in overlap most likely due to exclusion of sand mining in latter series.

Sand mining

Sand is mined from the estuary and the harbors. Over the period 1998-2007 an average of at least $2.1*10^6$ m^3/yr was removed from the fairway. Mining was mainly done for building purposes near to the Weser. No data could be found for the period after 2007. Over the period 1999-2010 on average some $0.14*10^6$ m^3/yr of sand is dredged from the harbors.

Permanent storage of mud outside the estuary

The muddy sediments dredged from the harbors is brought on land because of contamination with harmful substances. Before 1994 contaminated fine-grained material from the harbors was deposited on disposal sites on land and on a placement site in the Wurster Arm (Outer Weser). Since 1994 Bremen stored on land at the integrated dredged material disposal site in Bremen-Seehausen. Since 2001 also Bremerhaven used the site. Depending on the source storage figures differ somewhat from 0.17 to $0.200*10^6$ m^3/yr (BIOCONSULT & NLWKN, 2012; BIOCONSULT, 2018). More was removed in the period 2006–2008 and 2011 when sediments were transported to the Lower Rhine. Furthermore, since 2011 more material can be removed because it can be stored in the Slufter deposal site at Rotterdam. In 2015 the total need for permanent deposition has been estimated to be some $0.41*10^6$ m^3/yr due to the enlargement of the Kaiserschleuse and the more intense use of the Fischereihafenschleuse (BIO-CONSULT, 2018). This figure was used for permanent storage on land since 2014.

Elbe Estuary

The tidal Elbe has 4 major players in dredging the area: the Water and Shipping Authorities of Brunsbuttel, Cuxhaven and of Hamburg and the Hamburg Port Authority. In total dredging volumes have been growing up to more than $15\text{-}34*10^6$ m^3 since the deepening of 1999.

Until 1999, before the last Elbe shipping lane depth increase, some $2\text{-}3*10^6$ m^3 sediments were dredged annually in the Elbe and the Hamburg harbor. Given a specific density of 550 kg/m^3 this amounts to an annual dredging of $1.1\text{-}1.7*10^6$ ton/yrear. The amount of dredging material produced in the Elbe and the Port of Hamburg has increased from 4.2 million m^3 in 2000, up to $8.2*10^6$ m^3 by 2004 (Nix, 2005). Since the beginning of the years 2000 on average some $9*10^6$ m^3 is dredged (Hamburg Port Authority, 2017).

In combination with all other dredging and mining some $15\text{-}34*10^6$ m^3 is annually dredged in the entire Elbe Estuary in the period 2000-2016. On average some 11,5% of the total sediment is removed from the system. Removal of the mud is as follows:

1) Mud deposited on land

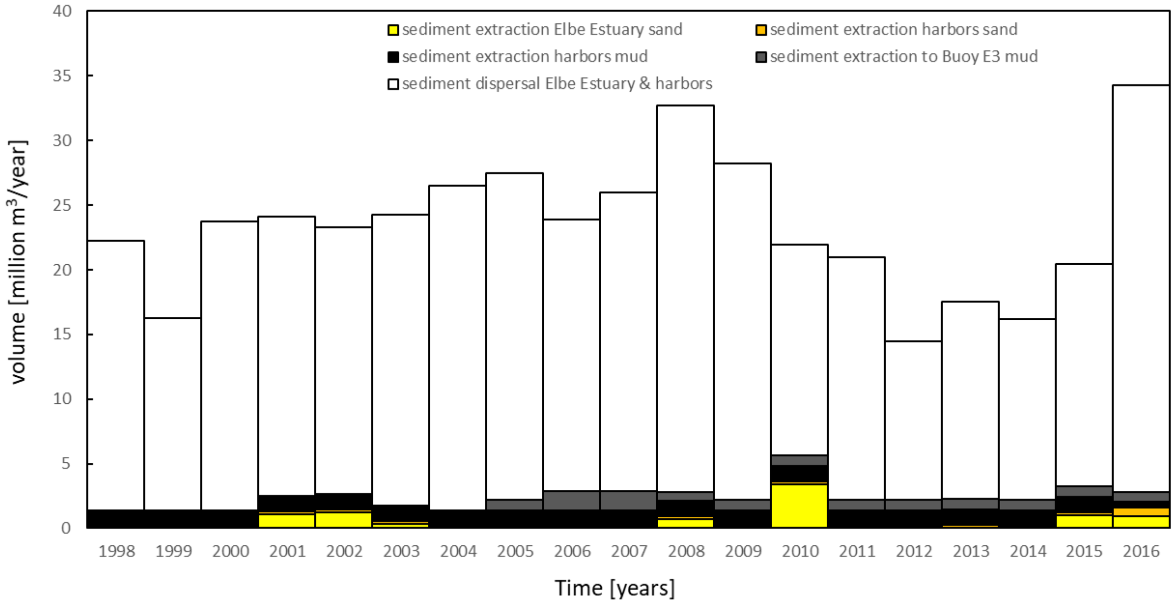
$1.4*10^6$ m^3 or $0.8*10^6$ ton/yrear is treated on land. Traditionally, the dredging material from the Port of Hamburg is stored on land, to heighten areas. At the end of the 1970s, the environmental impacts of this practice became clear. To reduce these effects a dredging material treatment was developed and implemented in the 1980s, the so-called METHA-Anlage. The METHA-Anlage treats some $1*10^6$ m^3 of the most contaminated dredging sludge. It is separated in sand, fine sand and a silt/clay fraction. The contaminated fines are deposited in special depots on land. The not contaminated fine fraction is used as a clay layer on top of dikes. Total permanent deposition is $1.2*10^6$ m^3 (Nix, 2005). This is mainly mud.

2) Mud deposited at Buoy E3

It was decided to place part of the lightly- to not-contaminated sediments even more seaward. The dumping location is at 30 m depth NW of Scharhörn and SE of Helgoland near Buoy E3. It is expected that the deposition is permanent on that location. In 2005 some $0.8*10^6$ m^3 were dumped, in 2006 & 2007 $1.5*10^6$ m^3 and in 2008 $0.7*10^6$ m^3 (Nix, 2005; HPA, 2017). After 2008 it was allowed to dump another $6.5*10^6$ m^3. Up to June 2016 $5.6*10^6$ m^3 was dumped of this new location. For the period 2016-2021 an additional $10*10^6$ m^3 are allowed to dump (HPA, 2017).

Dispersal of remaining dredged sediment: deposition in the seaward part of the estuary

Near Wedel (Island Neßsand), the relatively uncontaminated part of the dredged sediment is deposited at the seaward border of Hamburg in the Elbe. This occurs mainly during the eb-phase (Nix, 2005; Hamburg Port Authority, 2017). This became possible due to the improvement in sediment quality (HPA, 2017). In 1994 and 1996 some 0.7 and $0.5*10^6$ m^3 of dredging material was put back into the stream as an experiment. This was increased to $7*10^6$ m^3 in 2004. The idea was that the sediment could be transported seawards. Comparison of the depth soundings shows that between 1998 and 2003 the flats along the Unterelbe have become shallower by 0.5 m (Nix, 2005).



Dredging volumes for the Elbe Estuary since 1998: (mainly) sand extraction in the Estuary, sand extraction from the harbors; mud extraction from the Estuary plus harbors and sediment dispersal by various means in the Estuary and the harbors. Data WSA & Hamburg Port Authority

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Landward solutions Varde Å

The Varde Å is a river in open connection to the Wadden Sea in Jutland, Denmark, which has been restored and renatured. The Varde is the only major tidal river in Denmark whose outlet is not regulated with dykes and sluice gates. As a result, the river remains under the influence of natural forces. Tides in the Ho Bugt bay affect both water level and flow rate far upriver. The opening of a river to the sea is a possibility to trap fine-grained mud in the mouth of the river.

With a length of approximately 40 kilometers it is the third longest watercourse in Denmark. Its catchment area is 1,088 square kilometers. The river flows through the municipalities of Varde and Esbjerg, forming the boundary between them along parts of its course. The river empties into Ho Bugt bay, north of Esbjerg. The Varde Å estuary is supplied with material from two sources: the drainage area itself and the turbidity maximum in the N-part of Ho Bugt. The first supplies bed load and suspended material, whereas the latter supplies fine-grained, flocculated material only.

Varde A between the Ho Bugt Wadden Sea and Varde (upper corner left), situation 2006

Situation 1990

Approximately 300 meters downstream of the confluence of the Grindsted and the Ansager, 90% of the river's flow was diverted in 1945 by a weir into the Ansager Canal. The canal led to a reservoir, Lake Karlsgårde, to be used for hydroelectric power generation by the Karlsgårde Hydroelectric Plant. In the 1950s, the section of the river between Hessel and Nørholm was dredged and straightened. Originally 10 kilometers long, with 35 bends, this stretch was reduced in length to a straight channel 5–6 kilometers long with four concrete sections. Since 2006, the plant operator, Sydvest Energi, has given up its rights to dam and divert watercourses in the Varde drainage. The plant was completely closed down by the end of 2015. In its lower reaches the Holme river wind past the estate of Nørholm, and at Sig, past Sig Fiskeri, one of the largest fish farms in Denmark. The fish farm draws water from the river, because the owner believes the groundwater contains too much iron oxide. The Holme then flows into the Varde, bringing with it the water from Lake Karlsgårde.

Restoration

A large part of the straightening of the river has been reversed beginning in 2009 in a land restoration project supported by the Actions for Houting project of the European Union LIFE Programme. The Varde Å now flows past Hodde, bypassing the reservoir, which is now fed only by the Holme river.

The lower river valley, west of Varde, was previously under intensive cultivation. Beginning in 1994/95, farmers have modified their practices, no longer using fertiliser and keeping vegetation cut, which it is hoped in association with the higher water table will restore habitat for birds, in particular the endangered corncrake. In 1997–2002 more than 250 voluntarily signed 20-year agreements under Operation Engsnarre (Operation Corncrake), also supported by the EU LIFE Programme.

The Varde River is home to many species of fish, including brown trout, grayling, pike, houting, salmon and sea trout, which attract many sport anglers. Fishing in the river is managed by the Grindsted Sportsfiskerforening (sport fishing association), Varde Sportsfiskerforening and Sydvestjydsk (Southwest Jutland) Sportsfiskerforening. The river is also the only habitat in Denmark of the freshwater pearl mussel. The Varde River together with the lower reaches of the Ansager and the Grindsted has been designated an EU Special Area of Conservation. The designation also covers most of the existing lowlands in the river valley. In the designation, the houting and the freshwater pearl mussel were identified as priority species; especial weight is to be given to fulfilment of provisions relating to their habitat.

The Varde A area is nowadays presenting them as an area offering exciting nature, rich in flora and fauna where one can enjoy long walks, canoeing or fishing. Canoeing is possible over a large stretch of the area from Varde to the Nordholm Gods and Sig Fiskeri. As for fishing, the stream houses river trout, pike and grayling and in recent years, the stock of salmon and sea trout has increased considerably. The EU has appointed Varde Å as an important habitat for inter alia pearl-producing river mussels and houting. It is not only the many different species in the water that make Varde Å an interesting area. The bird life around the stream is also very exciting and the many footpaths, bridges and observation towers of the area contribute to a fun experience for bird lovers in the beautiful area around Varde Å.

Discussion Points

The open nature of the Varde A allows for estuarine circulation patterns to bring in fines from the open Wadden Sea. This is an approach which has led to a major impulse for the whole area with large participation of farmers.

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