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## **Severn Tidal Power**

### **RSPB briefing on the implications of the Eastern Scheldt (*Oosterschelde*) for the Severn Estuary**

#### *Introduction*

2010 is a big year for the Severn, with the UK Government making critically important decisions on whether or not it should support tidal power development in the estuary, and if so on what terms.

The RSPB has sought to support and influence the UK Government's Severn Tidal Power Feasibility Study (STPFS) over the last two years and we championed the establishment of the Severn Embryonic Technologies Scheme (SETS).

The Severn is one of our most important and dynamic estuaries. Whatever choices are made about tidal power on the Severn must be informed by a thorough assessment and understanding of the geomorphological and hydrological implications. Fundamental to this, is the need to learn lessons from sites where comparable developments have taken place. The RSPB is convinced that reference in the studies to barrage projects in dis-similar environments – in particular the tidal power station at La Rance in Brittany - has severely underestimated the risks posed to the Severn by a tidal power barrage. To this end, we have been reviewing projects that might inform our response to the Severn, and in particular the lessons learned from the Eastern Scheldt in the Netherlands. There, construction of a storm surge barrier in the 1980s has had – and continues to have – massive negative implications for both wildlife and flood risk management including:

- **Significant and ongoing erosion following construction: By c2050 the area of intertidal will have halved** - by 2100 only 1500 hectares of the original 11,000 hectares will remain
- **The losses of intertidal habitat due to the construction of the barrier far exceed losses due to sea level rise** – 5100ha and 1200ha respectively by 2045
- As intertidal areas in front of flood defences ('dikes') are lowered or lost to erosion, **flood risk increases**, resulting in a **need for additional investment** to protect lives, land and property. Extra costs over the next 50 years on the Eastern Scheldt are estimated to be at best 25 – 45 million euros, and at worst 90 – 260 million euros depending on factors such as rates of sea level rise
- As tidal flats are eroded the area and duration of their exposure for feeding birds is reduced – **calculations suggest an 80% decline in Oystercatchers by 2045**

We consider that **lessons from the Eastern Scheldt are of critical importance** in informing next steps and future decision-making on the Severn and other estuaries where tidal power projects are proposed. Only adopting an 'eyes wide open' approach to the risks will we ensure that the UK makes the best and most informed choices for renewable tidal energy.

### *Setting the context: Climate change and renewables*

Faced with the threats of climate change to the natural world the RSPB believes that a renewables revolution is essential to safeguard biodiversity. The RSPB therefore supports the Committee on Climate Change's conclusion that we should have zero carbon electricity by 2030. This will require us to make choices about technology mix, and judgements about environmental and social costs.

Inappropriately designed and/or sited developments can also cause serious and irreparable harm to biodiversity. Such damage is not inevitable. It is therefore essential that decisions about deployment of renewable energy be informed by, take account of, and seek to minimise environmental and other impacts. We argue that the UK Government should seek to ensure that the energy revolution takes place in harmony with the natural environment.

### *What has the Eastern Scheldt got to do with the Severn Estuary?*

The Eastern Scheldt storm surge barrier in the Netherlands provides an excellent comparator for what might happen if a barrier is constructed across the Severn. The objectives differ – prevention of storm surges in the Eastern Scheldt and generation of tidal power in the Severn. However, both the estuaries and the structures concerned are physically similar (construction of large and only partially permeable barriers across dynamic estuaries with high sediment loads), and therefore the environmental consequences are comparable.

### *What are the implications for the Severn of the Eastern Scheldt experience?*

Given similarities between the physical characteristics of the Eastern Scheldt and the Severn – and between the storm surge barrier and a tidal barrage - it is likely that similar effects to those seen in the Scheldt would occur if a barrage were constructed in the Severn:

- **Long term and ongoing erosion of intertidal areas:** Barrage construction (like construction of the Scheldt storm surge barrier) would lead to reduced water flows, making the deep estuary channels 'hungry' for sediment, and causing significant, long term erosion of intertidal areas
- **Increased flood risk:** As in the Eastern Scheldt, loss or lowering of intertidal areas in front of flood defences would result in a need for additional investment to maintain effective protection from flooding. In this respect, a barrage would probably have a worse effect than a barrier – holding water levels high for long periods of time, and therefore maximising the amount of damage that wave action will do in the upper intertidal areas and to the defences themselves
- **Catastrophic declines in internationally important bird populations:** As in the Eastern Scheldt, as tidal flats are eroded the area and duration of their exposure for feeding birds is reduced. We would expect to see catastrophic declines in the internationally important populations of waders and wildfowl

Clearly, the scale of such effects would differ between the two estuaries – but it is worth bearing in mind that the **Eastern Scheldt is less than two thirds of the size of the Severn.**

It should be noted that – unlike the storm surge barrier which has open sluice gates for most of the time to allow limited tidal flow through the barrier – the turbines and water pressures associated with a tidal barrage would have additional effects not seen in the Eastern Scheldt.

For example, a **barrage would act as a barrier to migration of internationally important fish populations** including salmon and rare lamprey, which currently move through the Severn on migration between the sea and their breeding grounds in the Rivers Wye and Usk.

#### *What are the implications for the UK Government's Severn Tidal Power Feasibility Study?*

The UK Government is nearing completion of its feasibility studies into the current short-list of tidal power options for the Severn, but has failed to make the results of those studies available. However, on the basis of what little we know, it would appear that the results of the geomorphological assessments, in particular in relation to the Cardiff to Weston barrage proposal, **may show a range of impacts as severe, if not more so, than those seen in the Eastern Scheldt**. The RSPB has been consistently critical of the Government's approach to the STPFS which has been barrage-centric and focussed on technical feasibility and energy yield. Both early indications of the results of the Study and the lessons from the Eastern Scheldt are further evidence of the folly of this approach. The failure to consider environmental and social costs has led to a focus on immensely damaging and costly options for tidal power generation, instead of a focus on developing other potentially more benign technologies, which have been sidelined within the process.

#### *Conclusion*

It is arguable that, had the Eastern Scheldt case been more properly investigated at an earlier stage in the process, the vast amounts of time and money spent assessing the impacts of a Cardiff to Weston barrage could instead have been used further to develop the potentially less damaging options which have been considered by, but thus far sidelined within, the Government's Severn Tidal Power Feasibility Study.

#### *Recommendations and next steps*

- 1) The results of the **Government's STPFS geomorphological studies** will be critical to – and are a prerequisite for – the next steps in the decision-making process. They **must be made available at the earliest possible opportunity**.
- 2) The **lessons learnt from the Eastern Scheldt storm barrier must be fully incorporated into development of understanding of the likely impacts of tidal power developments on the Severn and other UK estuaries**. The UK Government has repeatedly been made aware of the relevance of this case to the Severn, and yet key information is only now available in English thanks to collaboration between Dutch experts and the RSPB.
- 3) Future assessments and decision making in relation to the generation of tidal power in the Severn and other major UK estuaries must leave behind the barrage-centric and technical feasibility-led approach adopted to date, and must instead **focus on how to maximise clean energy production, while minimising flood risk implications and harm to the natural environment**.

We do not have all the answers – but believe that the story of the Eastern Scheldt begs fundamental questions which must be addressed by politicians as a matter of urgency before irreversible and potentially catastrophic decisions are made about the future of the Severn and other major UK estuaries.



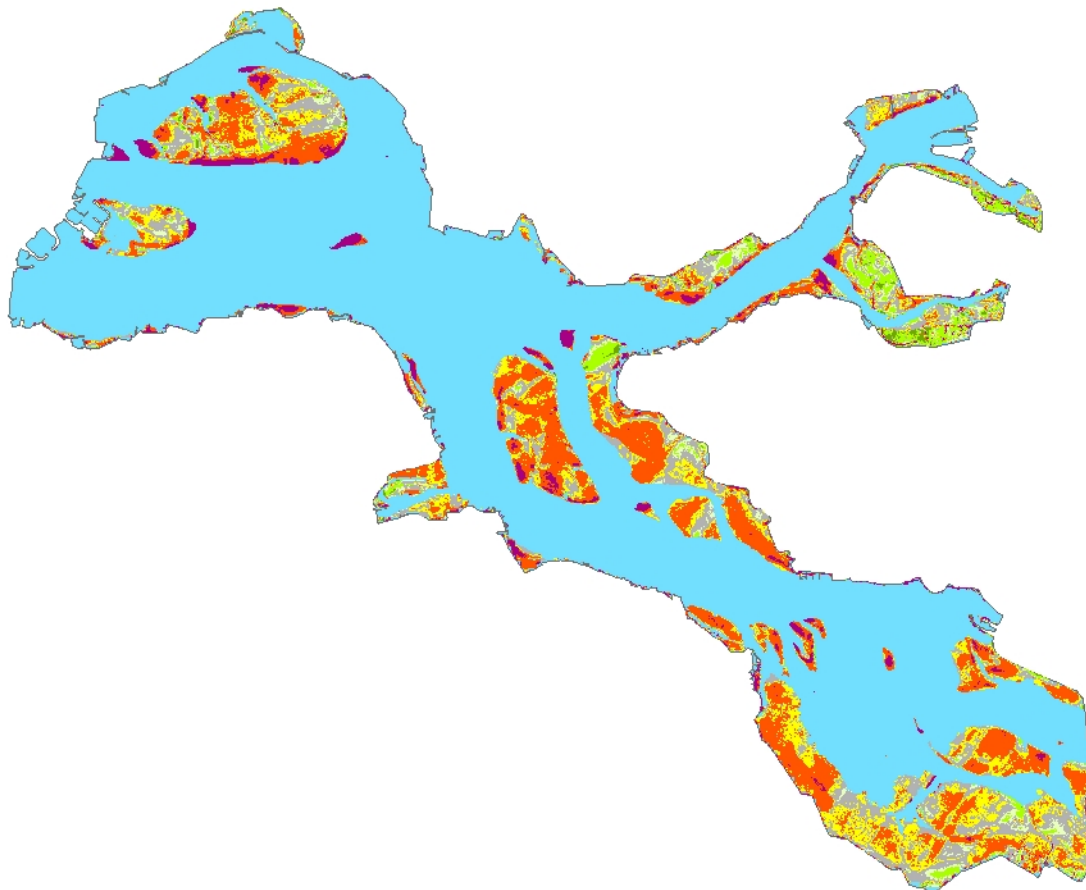


Rijkswaterstaat  
Ministry of Transport, Public Works  
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# Sand demand Oosterschelde

An analysis of the erosion of the tidal flats of the Oosterschelde after construction of the storm surge barrier and its effect on flood safety, nature, shipping and fisheries.

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Introduction	3
Summary	4
1. Sand demand and the loss of intertidal area	8
1.1 What is sand demand?	8
1.2 What are the effects on the tidal flats?	9
1.3 What are the effects on salt marshes?	11
1.4 What determines the rate of erosion?	11
1.5 What has the future in store?	14
1.6 Sand demand in the Voordelta	17
2. Effects on safety, nature and users	18
2.1 Nature	18
2.2 Flood safety	23
2.3 Shipping	25
2.4 Shellfish fisheries	26
2.5 Recreation	27

## Introduction

The Oosterschelde is situated in the delta of the Rivers Rhine, Meuse and Scheldt in the south west of the Netherlands. The Oosterschelde is surrounded by the former islands of the province of Zeeland which are protected against storm surges by dikes and dams. The delta has a long history of reclamations and land loss after flooding. Beginning in the Middle Ages the first attempts were made to protect the land with dikes. The polders (former low-lying sea bed) and dikes created a risky situation. Because of land subsidence and sea level rise the reclaimed lands slowly sank below the mean sea level. Breaking of a dike during a storm surge immediately resulted in serious flooding. At the end of January 1953 the delta was startled with an extreme storm surge. The dikes breached at hundreds of separate locations. The flood caused 1836 victims and 200.000 hectares of submerged land.

Shortly after the catastrophe of 1953, work began on the delta project. The delta project consisted of raising and strengthening the dikes and dunes and shortening the coastline by over 700 km. The



completion of the Flood Barrier in the Nieuwe Waterweg in 1997 marked the completion. In the original plan the Oosterschelde would be cut off from the sea by a solid dam and converted to a fresh water lake. But social beliefs and attitudes changed in the 1960's and these changes also impacted the delta project. In the 1970's an impassioned battle between the established order and the environmental movement together with local fishermen on the other hand over closure of the Oosterschelde resulted in compromise. A new type of storm surge barrier was constructed which only closes during storm surges and leaving the area

not completely closed nor completely open. The barrier was completed in 1987 and is considered up until today as the crown jewel of the delta project.

As times passed it became clear that elimination of the natural powers and dynamic processes had environmental and safety drawbacks. The Oosterschelde suffers from "sand demand". Due to the construction of the storm surge barrier the tidal flow velocities have fallen to a level on which they are no longer able to transport a significant amount of sediment through the gullies and onto the tidal areas. As a result the valued tidal areas slowly erode to a level below the mean sea level. This slow drowning of intertidal areas causes erosion of the foraging area of the over 100.000 waders and shrinkage of the wave damping foreland of Oosterschelde dikes.

To research the impact of the erosion the Dutch ministry of Transport and water management started a feasibility study of possible measures against the "sand demand". This document is a part of the first product of this study, the report "Verminderd Getij" which discusses process, impact and possible measures against the sand demand.

# Summary

## ***Cause and purpose of the survey into sand demand***

After the flooding disaster of 1953 it was clear that Zeeland had to be protected better against flooding. The first plan consisted of blocking off most of the inlets and estuaries in the delta. In the seventies, the first dams being in place, a change in thinking occurred. The Dutch government, influenced by conservation and fisheries organisations decided against the blocking of the Oosterschelde in favour of a storm-surge barrier. This way valuable tidal nature and shellfish fisheries would be conserved. Professionals predicted, at the time, that nature would experience undesired effects. Channels and tidal flats would reduce in profile. Since then the effects have become visible. The process is developing faster than predicted.

The loss of tidal flats and salt marshes is both disadvantageous to nature and to the maintenance of dikes, to shipping, to recreation and to shellfish fisheries. The Ministry of Transport, Public Works and Water Management has studied the effects in cooperation with the Ministry of Agriculture, Nature and Food Quality and has surveyed whether there are possible measures to stop or reduce the loss of tidal flats and salt marshes. The interim results have been discussed with the National Park, Oosterschelde board and pressure groups.

## ***Cause of the sand demand***

Since the Construction of the Oosterschelde works, less water has been flowing in and out of the Oosterschelde. In effect, the tidal channels are too big for the smaller amount of water. This causes the water to flow more slowly than before and it has insufficient power to move the sediment from the channels onto the intertidal area. Sand is being moved from the intertidal area into the channels in heavy storms where it remains. The eroding forces are still working, but the sedimentary forces are not. The balance is disrupted; the erosion of the intertidal area prevails. This process is known as the 'sand demand'.

In order to regain the sediment balance, four hundred to six hundred million m<sup>3</sup> of sand are needed. This is 30 to 50 times the annual volume of sand needed for nourishment of the entire Dutch coast. Winning this amount of sand from the sea is not feasible from a logistic point of view and for reasons of costs.

## ***The future of the intertidal area***

140 million m<sup>3</sup> of sediment is stored in the intertidal area; this is inadequate to make up for the sand demand. If no measures are taken for the conservation of the intertidal area, the following developments can be expected.

By around 2050 the *tidal flats* of the Oosterschelde will be halved. The surface area diminishes from eleven thousand hectares in 1986 to about five thousand ha in 2045. In the period to 2100 the intertidal area will reach an end situation of about fifteen hundred ha.

*Salt marshes* will only be found in sheltered locations (Rattenkaai and Krabbenkreek) in 2050. The salt marshes in unsheltered locations will have disappeared completely around that time.

The intertidal areas are disappearing as a result of two processes: the margins are retreating and the tidal flats are becoming lower. This second process is causing the intertidal area to 'drown' slowly.

## ***Consequences for nature, safety and use***

*Nature.* Many benthic animals, such as cockles and mussels live in the intertidal areas. They are food for waders. The loss of intertidal area causes less food to be available. As tidal flats will emerge for increasingly shorter periods, birds will have less time to forage. Calculations suggest that this will cause the number of oystercatchers to be reduced by eighty per cent by around 2045. Other waders dependent on mud-flats are awaiting the same fate.

*Safety.* Dikes around the Oosterschelde will have to be strong and high enough to withstand high waves and water levels. If the intertidal area in front of a dike becomes lower (or disappears completely) as a result of the sand demand, then higher waves will reach the dike. This will create a greater load. The effects of sand demand have been considered in the design of the current dike reinforcements, but its effects have been underestimated, resulting in a need for extra investment for dike reinforcement over the next 50 years. Depending on the impact of other factors such as climate change, the expected extra costs will vary from € 25 to 45 million in the most favourable case to € 90 to 260 million in the worst case.

*Shipping.* Periodical dredging operations remain necessary in the large shipping channels. Some smaller channels near the intertidal area will become considerably shallower.

*Shellfish fisheries.* The effect of the sand demand on mussel fisheries remains uncertain. There will be more shallow water, which is suitable for mussel culture. But conditions will become more turbulent as sheltered locations will disappear. The mussels will get more competition from the Japanese oyster, as the habitat for this species will increase strongly. Cockle fisheries will only be possible if there are more cockles than are needed as food for waders. The decrease of the intertidal area will also cause the cockle stock to decrease. Cockle fisheries, therefore, will be constrained.

*Recreation.* The Oosterschelde remains attractive to holiday-makers, even when the intertidal area disappears. However, before long a 'round around the shoal' trip with sightseeing including birds and seals, will not be possible anymore. This makes the area less valuable.



**Tidal flats in the Oosterschelde**

### ***Measures***

This survey studied three types of measures:

- Controlling the cause of the sand demand (by having more water flowing through the channels or applying more sand in the channels);
- Controlling the effect of the sand demand (preventing the loss of intertidal area);
- Developing similar nature elsewhere.

The technical practicability, the effectiveness and the costs have been assessed for each type of measure. None of these measures has been tested in the Oosterschelde. Therefore, a final assessment on the feasibility is not possible yet.

Measures	Assessment
Removing the storm-surge barrier and the compartment dams	Not studied further. Although effective against the sand demand, but very costly (an investment of billions) and demands radical replacement measures for, among other things, safety.
Having more water flowing through the storm-surge-barrier	Not studied further. High investments that lead only to a partial decrease of sand demand in the channels.
Connecting to Volkerak-Zoommeer or Westerschelde (so called Overschelde)	Not studied further on behalf of sand demand. High investments needed that can only lead to partial decrease of sand demand in channels.
Adjusting scour holes to increase the import of sand	Possible measure in the long term. Deserves further research.
Sand nourishments in the Voordelta	Possible measure in the long term in combination with the adjustment of scour holes. Deserves further research.
Filling up channels until a balance is reached	Not feasible for the whole of the Oosterschelde. Option for local filling up in Krabbenkreek, Slaak or Mosselkreek. Local application needs further research.
Sand nourishment on intertidal area	Promising. Periodical application leads to long term conservation. Deserves further research and a practical test.
Construction of shellfish reefs to slow down erosion	Interesting measure. Oyster reefs are an effective breakwater. The effect of mussel reefs is less certain, but they can possibly be combined with mussel culture and/or food for oystercatchers. Deserves further research and a practical test.
Shore protection	A stepped shore protection seems interesting. It offers the opportunity to conserve elevation zones for ecology and safety. Deserves further research and practical test.
Groynes as breakwaters	Interesting as breakwaters and because of a possible combination with mussel culture. Possible combination with stepped bank protection. Deserves further research and practical test.
Creation of similar nature elsewhere	Conservation of tidal nature in the Oosterschelde is preferable as the quality of tidal nature created elsewhere will be less

A structural and natural solution is preferable. This will possibly become an opportunity by adjusting the scour holes in order to facilitate the import of sand via the storm-surge barrier. This will cause the channels to fill up gradually with sand. Natural filling up of tidal flats will not start for many decades; in the meantime, therefore the intertidal area will have to be conserved with nourishment or measures that slow down erosion. The question remains, however, whether adjustment of the scour holes will lead to the import of sand that is desired. Further research will have to clear this up.

### **Social cost-benefit analysis**

A social cost-benefit analysis (scba) offers an insight in the cost-effectiveness of the measures. Only the costs and benefits that can be expressed in monetary terms will be represented. As part of the survey, an scba for three alternative proposals was carried out. The alternatives include a minimum, intermediate and maximum restriction of the loss of intertidal area. The implementation costs of the measures must be set against perceived benefits. The most important benefit of the three alternatives is that the costs for reinforcement of dikes can be completely or partly avoided if the intertidal areas in front of the dikes are conserved. The conservation of intertidal areas yields other beneficial effects for society as well.

All three alternatives can yield net benefits for society. Extra investments in the conservation of intertidal areas can deliver extra benefits for the ecosystem and the heritage value of protecting conservation and scenic areas. The benefits to nature become even greater if the intrinsic value of nature is incorporated. These are not considered in the social cost-benefit analysis.

Conservation of the intertidal area is more cost-effective for guaranteeing safety than reinforcing the dikes. This is caused mostly by the lower implementation costs of the sand nourishments of the intertidal areas. Moreover, intertidal sand nourishments supply great benefits for nature and other

functions. However, the results of the scba are subject to great uncertainties, especially relating to effectiveness, construction and maintenance costs of the nourishments.

### **Conclusion**

It appears from this survey that possible measures exist to restrict the loss of intertidal area. A structural long-term solution will become possible if adjustment of the scour holes at the storm-surge barrier will bring about sand import in the Oosterschelde. It will take many decades before a structural solution will lead to filling up of the intertidal areas of the Oosterschelde. In the intermediate period, the loss of intertidal area may be restricted with nourishments on the tidal flats in combination with measures that limit erosion.

There are many uncertainties that surround the measures. There is too little understanding of effectiveness, feasibility and costs to decide on the approach to tackle the sand demand at present. Therefore, further research and field tests are planned. At present, the costs for measures for conservation of the major part of the intertidal are estimated at two million euros per year.

### **Natura 2000**

The Oosterschelde has been designated a special protection zone for fifteen mudflat-dependent birds and for the habitat 'large shallow inlets'. The quality objective for the habitat aims at the conservation of the current landscape of salt marshes, tidal flats and channels. Full improvement of quality is not considered to be realistic in view of the sand demand. The sand demand is leading to an expected decrease of tidal flats with about 50 ha per year.

In the provisional conservation objectives for mudflat-dependant birds, the loss of 50 ha of foraging habitat per year is taken into account. With this survey of possible measures, a first step has been made in this research. Further research to reduce or halt the loss of tidal flats both in the short and long term is a priority.

### **Continuation**

The possible measures from this survey are surrounded by uncertainties and have not been tested in the Oosterschelde. Therefore, the survey will continue with a second stage looking at which possible measures will be tested in practice. The following activities are all ready to go: Rijkswaterstaat (Directorate-General for Public Works and Water Management) has carried out a nourishment of 150,000 m<sup>3</sup> sand at the Galgeplaat (a tidal flat) in order to find out whether this is a significant restoration measure. Rijkswaterstaat is researching whether the blockage for sand import via the storm-surge barrier may be reduced or removed and what kind of consequences it will have for the Oosterschelde and the Voordelta.

The consortium Building with Nature, WINN Biobouwers and Rijkswaterstaat together has started the preparation of one or more tests for stabilising measures.

Tests and further research are designed to reduce the uncertainties around the measures. Only then can a start be made with the development of area-specific packages of measures. An integral comparative assessment, by tidal area, will be made for conservation (ecology, safety, co-users) and it will show which measures will be implemented in the short and longer term. It is expected that these area-specific measure packages will be developed in 2012/2013. The decision will then be made whether measures will be developed in detail in a plan study and incorporated in the catchment area-management-plan of 2015-2021.

# 1 Sand demand and the loss of intertidal area

The channels are lacking sand, but what does this actually mean? Why does it affect the intertidal area? And how will the channels and intertidal areas develop in the long run? This chapter will answer these questions.

## 1.1 What is sand demand?

Before the Delta Works a dynamic balance existed in the Oosterschelde between sedimentation and erosion in the intertidal area. The tide brought stirred up sand from the tidal channels onto the tidal flats and left it there. In stormy weather the waves stirred the sand loose, and it flowed back into the channels.

The balance between sedimentation and erosion has been disturbed by the construction of the Oosterschelde storm-surge barrier, the Oesterdam and the Philipsdam. Since then thirty percent less water flows in and out of the Oosterschelde on each tide. Sixty percent of the decrease in discharge is due to the storm-surge barrier that has decreased the opening of the mouth of the Oosterschelde, and forty percent of the decrease is due to the cutting off of the Markiezaat and Volkerak (Lievense, 2004). The smaller amount of water that now flows in and out of the Oosterschelde flows more slowly through the channels. The current velocity has decreased by thirty percent or more. As the power of water to transport sand is highly dependent on current velocity, the capacity for sand transport has been decreased even more: by an average of 75 per cent.



The build-up (accretion) of the intertidal area under calm weather conditions has stopped almost completely, but the erosion under stormy weather conditions continues. The sand that is stirred up ends up in the channels and stays there. The current would only reach adequate power to transport sand if the channels were filled up with four hundred to six hundred million  $m^3$  of sand (Kohsiek et al., 1987), enough to raise the whole island of Noord-Beveland a whole five metres! Only then would accretion and erosion be balanced again.

Will nature be able to check the sand demand? The Volkerakdam and the Philipsdam are preventing the sediment supply from the rivers Rhine and Meuse. And from the sea no sand is flowing into the Oosterschelde. Jongeling (2007) deems it probable that the scour holes on either side of the storm-surge barrier are preventing the sand transport in and out of the Oosterschelde. The intertidal areas are the only source of sediment in the Oosterschelde itself. Above the low water mark about one hundred and forty million  $m^3$  of sand is stored. Even if all of the intertidal area ended up in the channels, the channels would still be too wide for the tidal flow.

**Tidal flat under the threat of sand demand**

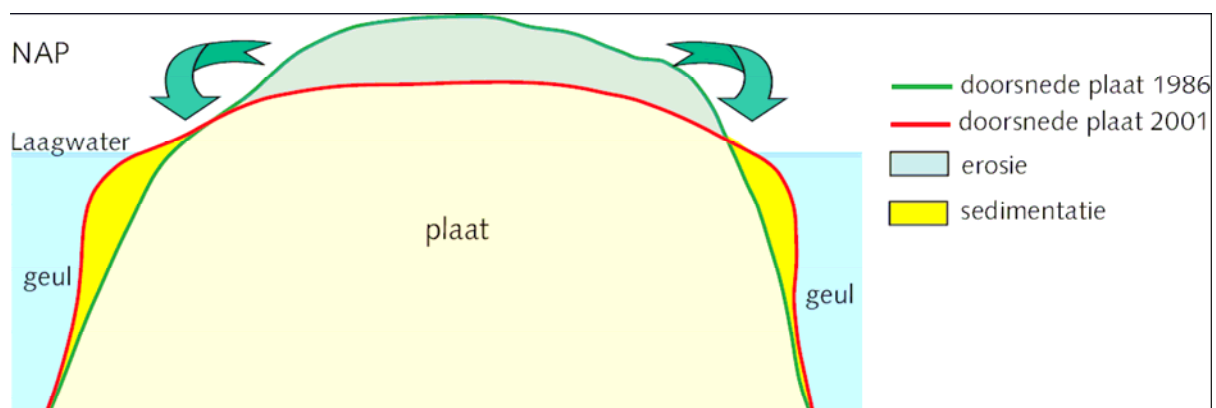
An important observation is that the channels do not pull actively at the sediment of the intertidal area. The current has become so weak that the sediment, once stirred up by wave action and tide in the channels, cannot be returned to the intertidal area.

## 1.2 What are the effects on the tidal flats?

As a result of the storm-surge barrier, the vertical tidal range has decreased ten to twenty per cent (Boeije et al., 1991). At low tide the water level is higher on average and that caused seven hundred ha of tidal flat (six per cent) to be permanently submerged. This caused the intertidal area to decrease from over 12,000 ha to 11,300 ha immediately after the construction of the storm-surge barrier.

The remaining intertidal areas are suffering from the sand demand. In the period 1986-2001 it caused the following changes (see Figure 1 and Table 1):

- The tidal flats have decreased in *area*: the area has decreased by eight per cent, from 11,300 to 10,430 ha.
- The tidal flats have decreased in *elevation*: the average elevation of all intertidal areas has decreased by fourteen centimetres, to 32 centimetres below mean sea level (MSL) in 2001. This amounts to an average decrease of one centimetre per year. On average, the tidal flats are exposed for over an hour less than before, from nine hours to less than eight hours daily.
- The relief of the intertidal areas has decreased. The higher parts are losing sediment that partly remains in gullies and local dips on the tidal flats. This causes the tidal flats to become flatter.



**Figure 1 Halfway score tidal flat erosion 2001. The tidal flats become smaller, lower and flatter due to sand demand. Eventually the flat will become submerged. (The green line points out the surface in 1986, the red line the surface in 2001)**

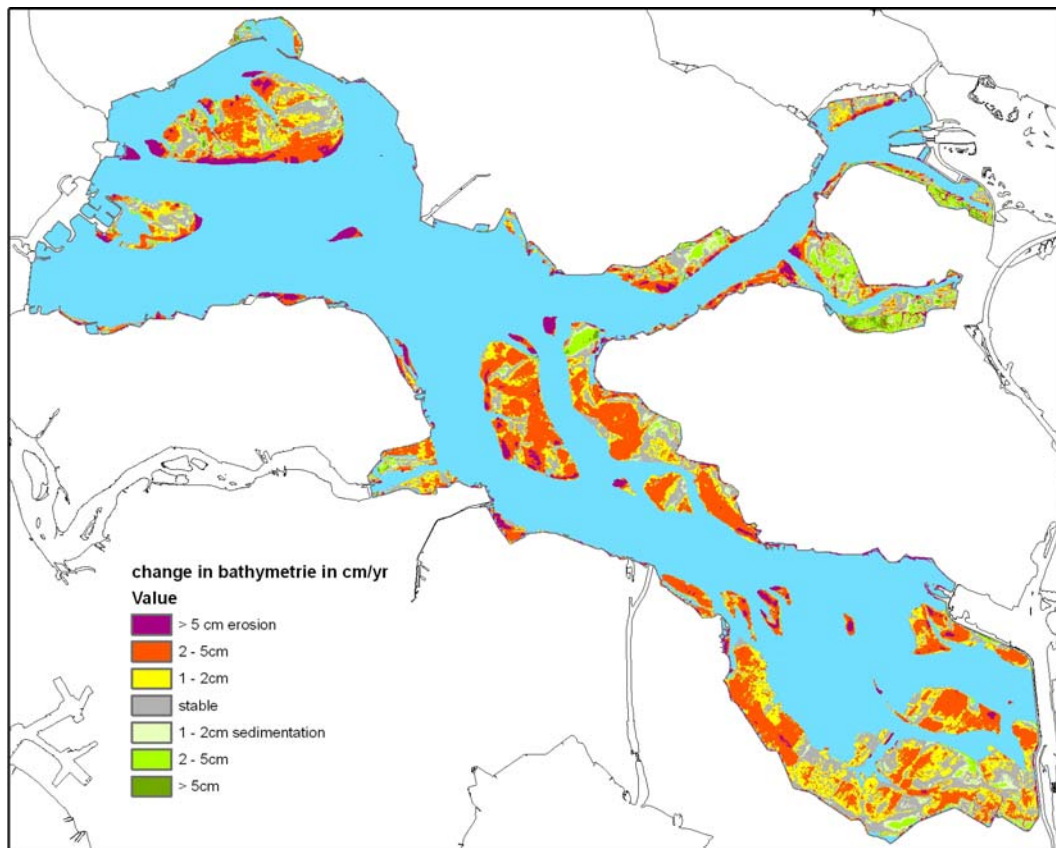
The sediment that has been stirred up on the higher parts of the tidal flats will primarily end up along the margins of the intertidal area and in the deeper water. There the waves cannot move it, and it will remain there until moved by the tide. That way the sand will end up in the channels and it will settle there on natural bars and in the convex banks.

The area of tidal flats decreased until 2001 by fifty ha per year. Erosion is not as fast at all locations. Tidal flats in unsheltered parts of the Oosterschelde are having the greatest losses. Erosion is strongest along the margins that are exposed to the west or southwest, where wind waves are largest and on smaller intertidal areas with a short distance for moving sediment to the channel.

**Table 1 Area and volume of the intertidal area in the Oosterschelde between 1983 and 2001**

	area of intertidal area			average elevation(cm MSL)			volume above MSL (million m <sup>3</sup> )		
	1985	2001	difference	1985	2001	difference	1985	2001	difference
	Before closure	15 yr after							
Oosterschelde	11,300	10,430	-870	-18	-32	-14	138	113	-25,2
Roggenplaat	1602	1486	-116	4	-11	-15	32.7	28.1	-4.6
Neeltje Jans	356	344	-12	-19	-28	-9	6.4	5.9	-0.5
Slikken van den Dortsman	1236	1179	-57	-12	-27	-15	23.2	20.4	-2.8
Galgeplaat	1000	964	-36	-32	-65	-33	16.8	13.0	-3.8
Zandkreek	280	280	0	-31	-44	-13	4.7	4.3	-0.3
Middelplaat	190	176	-14	-59	-77	-18	2.7	2.2	-0.5
Slikken van Yerseke	98	88	-10	-53	-76	-23	1.4	1.1	-0.3
Hooghe Kraaijer	453	417	-36	-80	-106	-26	5.4	3.9	-1.5
Verdronken land van Zuid-Beveland	1980	1847	-133	-72	-91	-19	25.3	20.1	-5.2
Krabbenkreek	832	834	2	21	20	-1	17.1	16.5	-0.6
Slikken van Viane	427	406	-21	-5	-17	-12	8.1	7.4	-0.6

Erosion for instance is strong on the Galgeplaat, the Slikken van Yerseke and the oyster reefs of Yerseke. Losses are smaller in the Krabbenkreek and the Zandkreek. In only a few places sedimentation occurs on sheltered tidal flats, as is the case on the tidal flats in the Krabbenkreek or Slikken van Viane.



**Figure 2 Erosion and sedimentation on tidal flats between 1985 and 2001**

### 1.3 What are the effects on salt marshes?

The salt marshes are all situated in the eastern, sheltered part of the Oosterschelde. In a natural situation new salt marshes generate on the lower edge of existing salt marshes if the tides provide adequate sediment. However, since the completion of the Oosterschelde works the supply of sediment from the channels to the tidal flats has almost stopped and the development of young salt marsh does not occur anymore. Existing salt marshes are decreasing as waves exert force on the salt marsh cliffs. Waves also become more powerful as the tidal flats in front of the salt marshes are getting lower.



**Erosion of a salt marsh cliff.**

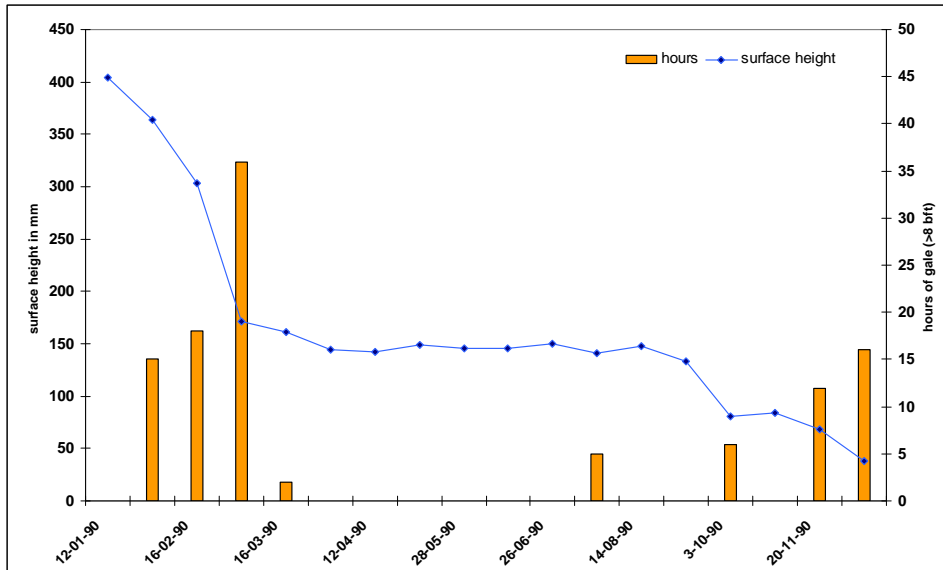
The area of salt marshes in the Oosterschelde amounts to about five hundred ha according to measurements of 2001. Three ha of salt marshes are disappearing annually. All salt marshes are decreasing. The salt marsh near Anna Jacobapolder is eroding most rapidly (2.8 metres per year). The salt marshes near Slaak and Sint Annaland are partly protected with a revetment. Erosion has since stopped there. As part of the project Dike Enforcements Oosterschelde, the salt marshes of the Tweede Bathse polder and Anna Jacobapolder will get revetments in the coming years.

### 1.4 What determines the rate of erosion?

Erosion caused by the sand demand varies from year to year and place to place. A combination of factors is determining the rate of erosion.

#### Gales

Erosion occurs mainly when there is a gale blowing. The direction of the wind and the duration of the gale determine the rate of erosion (Figure 3). Van der Hoeven (2006) has shown that the erosion on the Galgeplaat is largest in forceful, long-lasting gales from the west to southwest.



**Figure 3** The relation between duration of a gale and the rate of erosion for a gauging station on the Galgeplaat in 1990. The longer the gale lasts, the more erosion occurs.

#### Water depth

Waves are causing erosion. Wind force, water depth and fetch determine the height and power of the waves. A wave passing a shallow such as the margin of a tidal flat will break. The breaking will cause the sediment to be stirred. The tide moves the stirred sediment. If the current direction is towards the channel, then the sediment will disappear under water for good. If the elevation of the tidal flat decreases by erosion, then the flat will sink below the range of wave effect and the rate of erosion will decrease. Van der Hoeven (2006) has shown by means of a hydrodynamic model that at wind force 9 the power of the waves to stir the sediment decreases from a water depth of 2.5 to 3 m. If the tidal flats have been lowered to the low water mark by sand demand, the erosion will not stop then, but will continue, although at a lower rate, until a level of some metres below low water has been reached.



**The former shoal of the Vuilbaard, the first victim of the sand demand**

#### Closure of the storm-surge barrier

The storm-surge barrier closes once a year on average. During a closure of the storm-surge barrier the water level is more or less constant during a minimum of one tide. Van der Hoeven (2006) has calculated that during closures erosion occurs as well on the Galgeplaat. The degree of erosion is in those circumstances not exceptional, but comparable to the erosion that takes place during a gale with an open barrier. During a closure the eroding forces of waves attack for a prolonged time on one level, where much sand may be stirred up. On the other hand the tidal currents will be non-existent during a closure and the only transporting force is the wind-driven current. The larger stirring action apparently is balanced by the smaller transporting force of the water.



**A peat bed in the Westerschelde**

#### Resistant layers in the subsoil

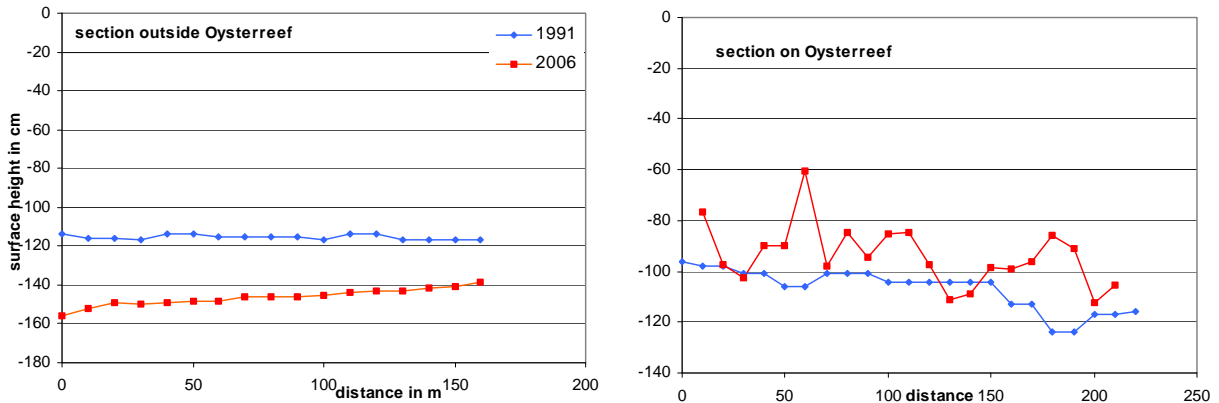
Clay and peat beds offer more resistance to the eroding action of waves than sand and silt do. Under a number of tidal flats in the Oosterschelde such beds are present. As soon as a peat or clay bed surfaces, it will protect the intertidal area behind it against further erosion and levelling out. But where the clay or peat bed surfaces almost all benthic life disappears and the intertidal area loses its ecological function.



**A Japanese oyster reef**

## Shellfish reefs

Mussel reefs and reefs of Japanese oysters are protecting the intertidal area against the eroding action of waves. The sturdy reefs protect the sediment underneath and break the force of the waves. Moreover, shellfish excrete small lumps of indigestible suspended matter, thus raising the soil around the shellfish reef with silty sediment. It appears from research that a reef of Japanese oysters on the Galgeplaat caused a reversal from erosion to sedimentation (Wijsman et al., 2006).



**Figure 4. Soil elevation along two profiles across the Galgeplaat, measured in 1991 and 2006. Between 1991 and 2006 a reef of Japanese oyster developed. Afterwards the relief has increased and the surface has been elevated, while in the neighbouring profile (without an oyster reef) erosion due to sand demand continued.**

## 1.5 What has the future in store?

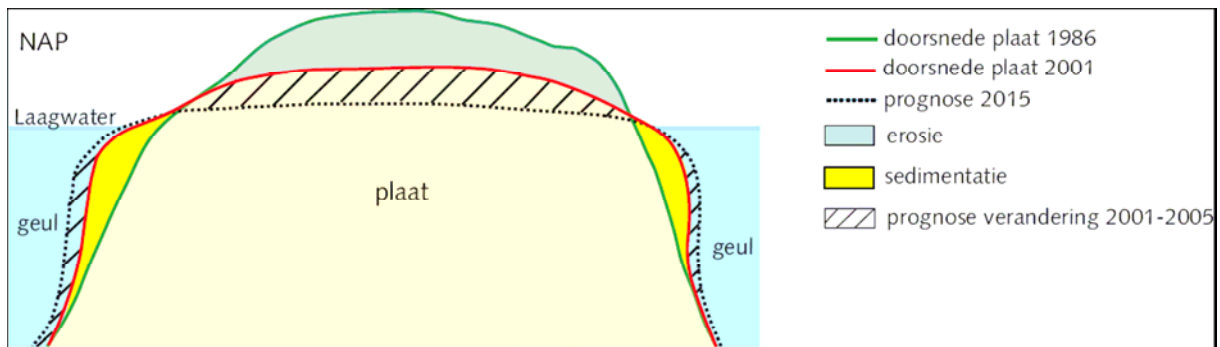
In the future the salt marshes and tidal flats will not only be threatened by the sand demand, but by sea level rise as well. Both low water levels and high water levels will rise due to sea level rise, making the lower elevated parts of the intertidal area to submerge and the lower parts of the salt marshes to get affected by the zone of the daily tidal currents.

### Prediction of erosion

In 1987 Kohnsiek et al. made some predictions on the course of the sand demand. The eventual picture of this prediction has been copied in this survey and it means that 1500 ha will remain in the sheltered areas (see Figure 7).

After 1987, it turned out from analysis from soil elevation data that the reduction of the central parts of tidal flats is the dominant process. Kohnsiek et al (1987) have only taken into account the erosion along the edges of the tidal flats. The pace of erosion therefore is faster than the prediction from 1987 shows and the eventual picture will be reached faster than expected.

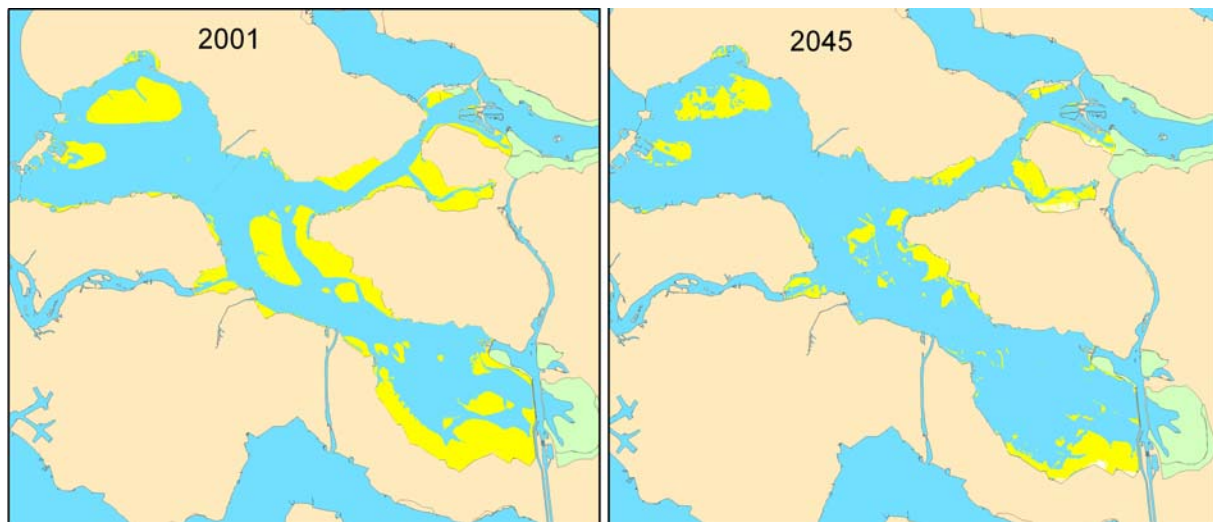
It is not possible to predict exactly how the erosion will develop. Based on measurements from the first fifteen years after closure an estimation has been made of how the process is expected to happen. The changes that occurred in the period 1986-2001 will continue with the same rate in the future (Figure 5). The real changes, however, will depend on storm frequency and water depth, to name but a few and they can change in the course of time. The predictions have produced an indication which, although more reliable than that of 1987, is still very uncertain.



**Figure 5 Schematic graph of the erosion and sedimentation as they occurred in the past fifteen years and the continuation of this process in the prediction (the hatched area)**

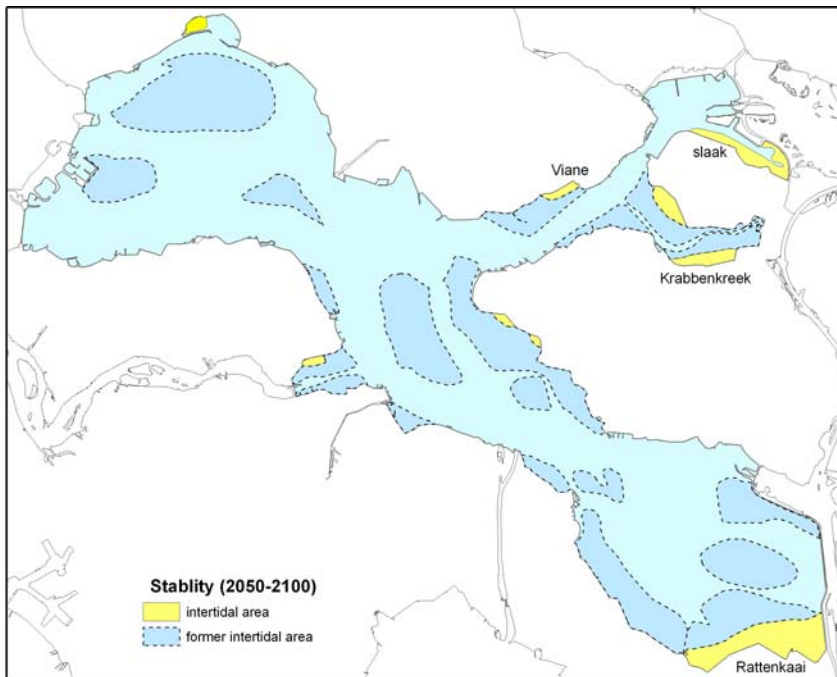
#### Development of tidal flats and salt marshes

Until now, erosion of tidal flats has occurred mainly above the low water mark: the tidal flats have become less elevated, but are still exposed at low water. It turns out from model calculations that the area of intertidal area will decrease rapidly before long. A number of tidal flats will become so low in the coming years that they will not emerge anymore and thus will no longer be part of the intertidal area. Around 2015 the Speelmansplaten will be halved; around 2030 there will only be half left of the Galgeplaat, the Hooghe Kraaijer and Yerseke Oesterbank. Tidal flats that are sheltered, such as in the Krabbenkreek, the Zandkreek and the Slaak, will mainly remain.



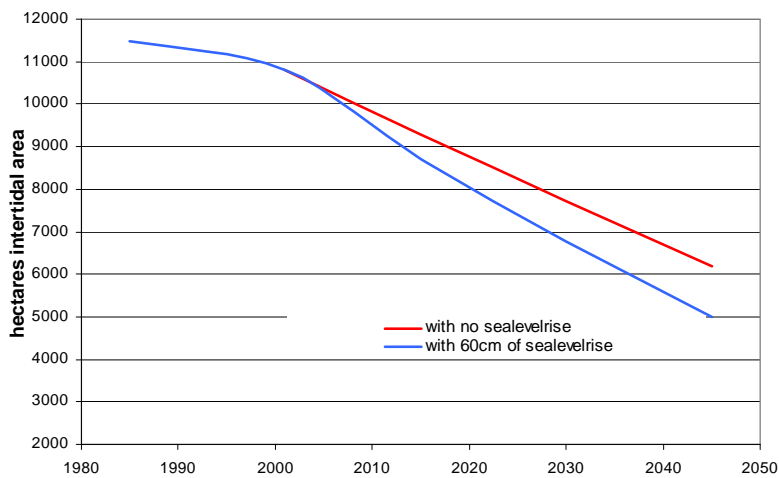
**Figure 6 Prognosis of the development of erosion of intertidal area (yellow in the maps) between 2001 and 2045.**

Around 2045 the total intertidal area in the Oosterschelde will be halved (Figure 6): a loss occurs from 11,300 ha in 1986 to about 5000 ha in 2045. This is the combined effect of sand demand and the expected sea level rise of 60 cm in the coming century. The loss due to sea level rise amounts to about 1200 ha in 2045, the loss due to sand demand 5100 ha (Figure 8). The effect of sand demand therefore is four times that of the effect of sea level rise. Somewhere in the period until 2100 the intertidal area will reach its eventual situation of about 1500 ha (Figure 7).



**Figure 7** Eventual picture of the intertidal area and the channels of the Oosterschelde, as it will be reached in the period 2050-2100.

Cliff erosion of the salt marshes will also not occur at the same rate everywhere in the future. Hordijk (2007) is expecting that salt marshes in sheltered places (Rattenkaai and Krabbenkreek) will be almost completely conserved in 2060 and that salt marshes in unsheltered areas will disappear completely (Slikken van de Dortsman).



**Figure 8** The effect of sea level rise on drowning of the intertidal areas

## 1.6 Sand demand in the Voordelta

The channels in the Voordelta, on the seaward side of the storm-surge barrier, are suffering from sand demand as well. This is due to the fact that the water flow from and into the Oosterschelde has decreased. The higher parts of the Voordelta, that are within the influence of the waves, lose sediment to deeper channels. This means that the area of (middle) deep water increases at the expense of the area of shallow water and intertidal area. (see Figure 9). The extent of this sand demand in the Voordelta has not been calculated. Supply of sand from the Voordelta to the Oosterschelde, can only be expected until the sand demand of the channels in the Voordelta has been met and the storm-surge barrier is adjusted in such a way that sand can pass through it into the Oosterschelde.

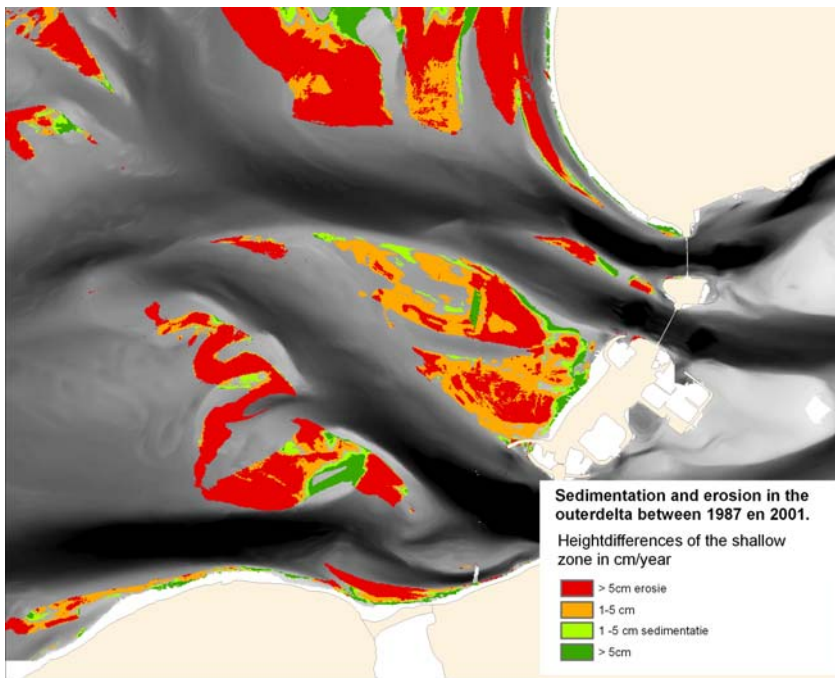


Figure 9 Changes in area of various depth zones in the outer delta. In 1986 the area of shallow, middle deep and deep water amounted to 3650, 10500 and 8250 ha respectively.

## 2 Effects on safety, nature and users

The landscape of tidelands, shallow water and channels is changing because of sand demand. This is causing effects on nature in the Oosterschelde, on wave attack on the dikes and on the various users of the area. What will be the main effects if sand demand continues freely?

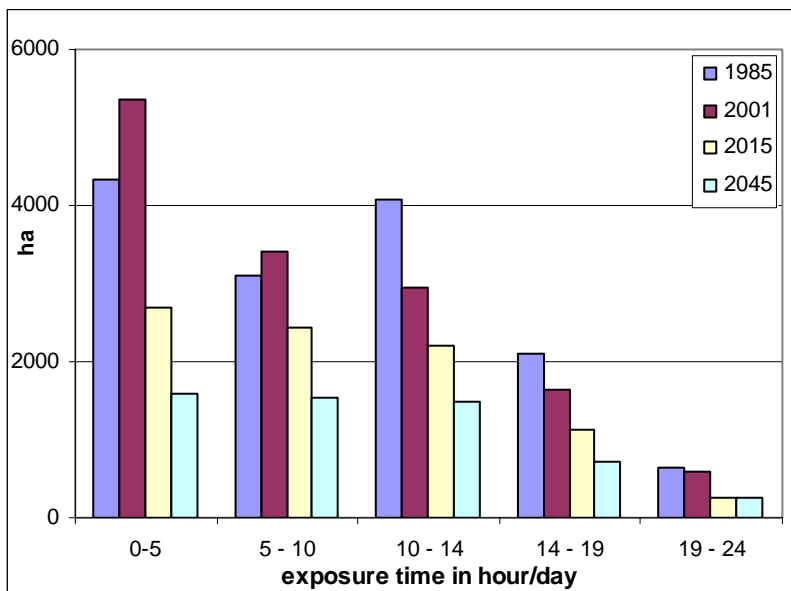
### 2.1 Nature

The ecosystem in the Oosterschelde is for the main part dependent on the intertidal area. The intertidal area is rich in benthic animals that are a food source for higher species such as fish and birds. Seals are using the tidal flats as a resting area. If there is a loss of intertidal area, then the ecosystem will lose one of its main foundations. This will bring about a significant shift in the composition of its species.

At the moment, ten percent of the intertidal area has been lost and the remaining intertidal area has a decreased elevation. Species that have their habitats in the intertidal area have less space per individual available. Firstly, this will effect their condition, but as the decrease continues, their populations will dwindle dramatically.

#### *Duration of exposure*

Most benthic animals have a very specific preference of habitat. They only thrive at a unique combination of soil composition, water dynamics and duration of exposure. The duration of exposure, (the period that the intertidal area emerges during low water), is changing as a consequence of sand demand: the elevation of the tidal flats is decreasing and they will be exposed for a shorter period. The prediction of the duration of exposure is key to the prediction of the development of the benthic animals' communities. Predictions of soil elevation and tidal curve maps of the duration of exposure have been made for 1985, 2001, 2015, 2030 and 2045. A sea level rise of sixty cm in the next one hundred years has been taken into account within the predictions. Figure 10 shows the change in duration of exposure for the entire Oosterschelde. The area of all duration of exposure classes will at least be halved in 2045.



**Figure 10 Development of duration of exposure for the entire Oosterschelde**

The zones that emerge for a long period in particular are important to benthic animals and waders. The area in these higher duration of exposure classes are decreasing gradually during the whole period. The areas that have short durations of exposure (duration 0-5 hours and 5-10 hours) have

increased until 2001, but from that year they are plummeting. The increase in the first years can be explained because of the fact that this zone receives the sediment that eroded from the higher zones at first and because of the fact that the higher zones are becoming less elevated so that they become included in lower classes of duration of exposure.

Between 2001 and 2045 the mean duration of exposure of the intertidal area will drop from almost nine hours per day to less than five hours per day. That is almost halved.

### ***Benthic animals***

Benthic animals that live on the intertidal areas, withstand the alternation of emergence and submergence. Most benthic animals are food for birds and fish and some species are important to shellfish fisheries (mussels, cockles). Densities of young benthic animals are often high (Farke et al., 1979; Günther, 1992). They prefer the intertidal areas as they are safer there from preying fish, crabs and lobsters.

Erosion affects the benthic animals' living conditions. Benthic animals living on the more elevated intertidal area see their habitats decrease. They are mainly smaller benthic animals such as *Peringia ulvae*, scud and cockle. Benthic animals living in the lower intertidal areas see their habitats increase. The Japanese oyster in particular is profiting from it. All benthic animals suffer from a decrease of their nursery grounds; this causes young benthic animals to become more easy prey for fish and shrimps.

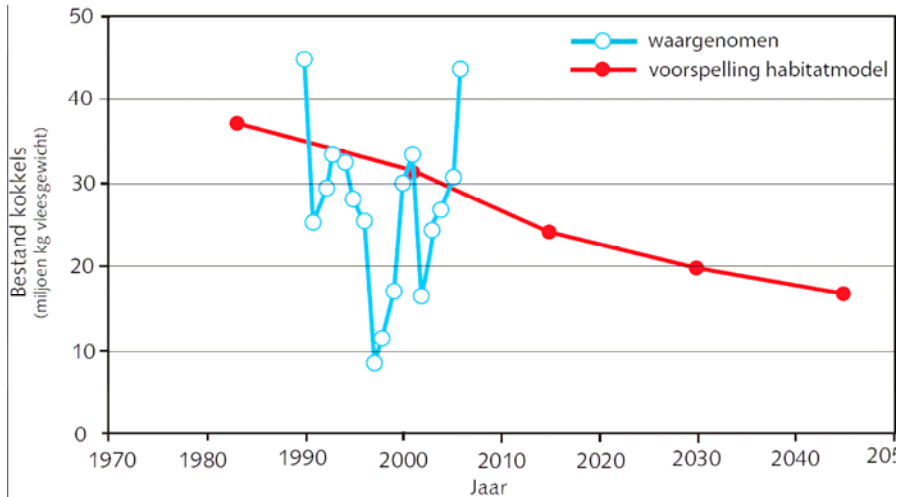
The effects have been elaborated for the cockle and Japanese oyster. The cockle has been selected as this shellfish is fished commercially and it is an important source of food for the oystercatcher, which is a species protected by the Birds Directive and that has a dwindling population. The Japanese oyster has been selected as this shellfish is coming on substantially and covers a considerable area of the intertidal area. This species is competing for food with, for instance, mussels and cockles.

### ***Cockles***

The cockle stock of the Oosterschelde is measured annually during the shellfish survey by Imares in Wageningen. Optimum settling conditions for cockles are generated at mean current velocities of thirty centimetres per second, duration of exposure of about fifty per cent (about MSL) and a soil composition of fine sand (Geurts van Kessel et al., 2003).

Between 1985 and 2001 the area of intertidal area with an optimum duration of exposure for cockles (ten to fourteen hours) decreased by thirty percent (see Figure 10). The cockle stock does not show a clear decrease yet. Possibly the optimum area of the habitat was not fully used in the Oosterschelde. Another explanation is that other factors determine the cockle stock as well, such as success of spawning, fisheries, predation and availability of food (Wijsman, 2007). When an effect of the continuing decrease of the optimum habitat is to be expected, is uncertain, but a negative effect is surely to be expected.

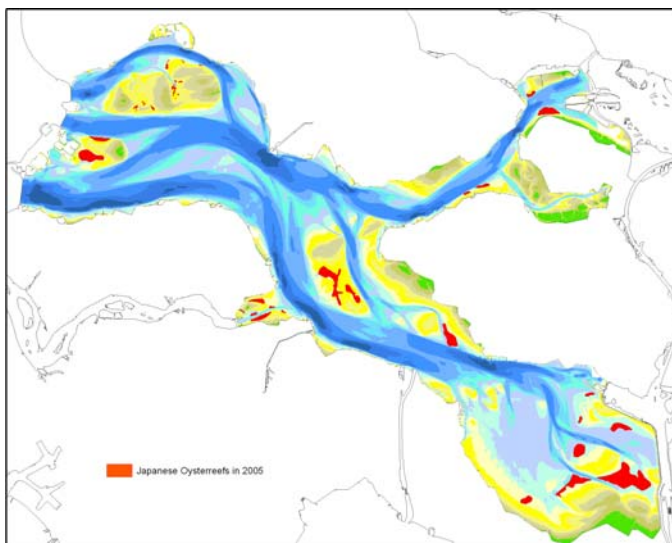
Kater et al. (2003) have set up a habitat model that predicted the number of cockles based on duration of exposure and current velocity. This model was able to predict but 37 per cent of the variation in biomass of cockles. The model results should therefore be regarded as indicative. Wijsman (2007) applied this cockle habitat model to the duration of exposure maps and that way has made a prediction of the cockle stocks in 2015, 2030 and 2045. According to the model the cockle stock will be halved in 2045 compared to 2001 (Figure 11). This halving will mean a decrease of food for waders (the oystercatcher in particular) and fish that live off cockles and decreased catches for the cockle fisheries in the Oosterschelde.



**Figure 11** Development of the cockle stock in the Oosterschelde based on the habitat model (closed circles). The measurements (open circles) show more fluctuation than the habitat model. Not all population-determining factors are incorporated in the habitat model (Wijsman, 2007).

### *Japanese oyster*

The Japanese oyster is an exotic species. Oyster culturists introduced this species in 1964, after the massive mortality of the native oyster in the severe winter of 1962/63. Ever since, the Japanese oyster has been spreading explosively. In the mean time reefs of Japanese oysters cover about eight hundred ha of the intertidal area of the Oosterschelde (Wijsman, 2006). The distribution of Japanese oysters in the Oosterschelde is shown in Figure 12. The Japanese oysters settle just above the low water mark. Fifteen per cent of the area that has a duration of exposure of less than ten per cent of the time is covered by Japanese oysters. It is expected that the area of Japanese oysters will increase both absolutely and relatively due to sand demand. This has two causes. Firstly, the duration of exposure will decrease in the entire intertidal area, generating more suitable habitats. Secondly, the reefs of Japanese oyster will protect the intertidal area against further erosion for some time (Wijsman et al., 2006): while the unprotected zones are submerging gradually the oyster reefs maintain their elevation.



**Figure 12** Japanese oysters in the intertidal area in 2001. The oysters settle in the zone just above MSL. Source: Wijsman, 2007.

The presence of reefs of Japanese oysters cannot be explained by duration of exposure alone. Many of the current oyster reefs are present in the neighbourhood of (former) mussel and oyster plots and cockle reefs. The shells (and remnants) apparently offer a suitable substratum for initial settlement (Wijsman, 2007).

Japanese oyster reefs are having a positive and negative effect on nature. On the one hand the oysters drive away the original benthic fauna. On the other hand the reefs offer a new habitat for algae, snails, shrimps, lobsters, gobies and mussels. Waders are foraging there as well. Most mudflat-dependent waders are foraging on the oyster reefs, even with larger densities than on the tidal flats without reefs (Wijsman et al, 2006).

### ***Birds***

It may be expected that the populations of mudflat-dependent waders will decrease in the Oosterschelde. The sand demand results in deterioration of the living conditions for birds in the following ways:

- The foraging area *decreases* as tidal flats will be submerged. The competition for food will become fiercer in the smaller foraging area.
- The birds have *less time to forage* as the duration of exposure of tidal flats is shorter. Waders must be able to eat long enough during low water to sustain them at high tide. An oystercatcher needs 5.5 hours to achieve this during a cold winter day; a dunlin needs over 6 hours.
- It will become *more difficult to secure food*. Waders can catch benthic fauna more easily if there is a thin layer of water present and therefore they move along with the low water mark. The tidal flats will become more even and therefore the low water mark will move with larger 'jumps'.

Birds with a preference for benthic fauna in the higher parts of the intertidal area in particular, will have less food available. Oystercatchers eating mainly cockles will see their supply of food halved in the period 1980-2045. Shelducks that are eating mostly *Peringia ulvae* and ringed plovers that prefer eating scuds will have to manage with less food.

Preliminary conservation objectives have been determined for fifteen mudflat-dependent waders for Natura 2000. Only the populations of oystercatchers and Kentish plovers are already diminishing (Sovon and CBS, 2005). The populations of the other species are steady or may even increase. Most populations have been able to offset the effects of sand demand up to now (ten percent loss of area and one hour less duration of exposure). It is to be expected, however that more species will get into trouble due to sand demand in the near future. In order to get an idea of future effects the development of the population of oystercatchers has been predicted.

### Oystercatchers

Adequate information is available of the oystercatcher in order to predict how the population will develop as a result of sand demand. In the eighties and nineties there has been a research into selection of prey, intake as food and the way in which energy is used by this species (Rappoldt et al., 2003).

Sand demand has two possible effects on the oystercatchers:

- The main food for oystercatchers is cockles. The expected decrease in duration of exposure will cause the area of optimum habitat for cockles to decrease. The cockle stock is expected to half between 2001 and 2045.
- On a cold winters' day an oystercatcher requires about 5.5 hours duration of intertidal exposure to eat enough cockles for its energy demand. As the duration of intertidal exposure becomes increasingly shorter, the foraging period threatens to become too short. In a period with frost a massive mortality of oystercatchers may occur.

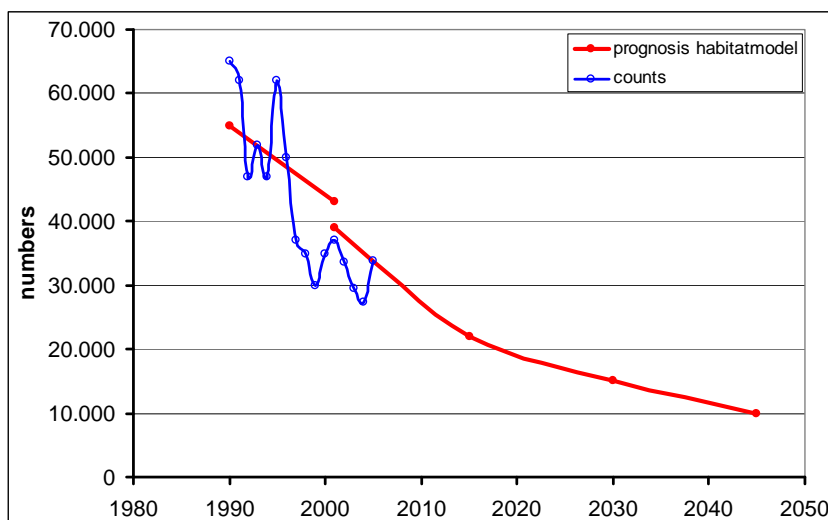
Rappoldt et al. (2003) developed a model for calculating the number of oystercatchers that can survive during wintertime in the Oosterschelde, given energy needs, cockle stock present, foraging time (duration of exposure) and the number of oystercatchers that are competing for food. This model calculates the carrying capacity of the Oosterschelde for oystercatchers: the theoretical number of oystercatchers that is able to forage on the tidal flats. The actual number of birds may differ, as it depends as well on other factors such as breeding success, predation or preying pressure.

The model has estimated the carrying capacity of the Oosterschelde in 2015, 2030 and 2045 (Rappoldt et al., 2006). The calculation is based on the predicted duration of exposure in 2015, 2030 and 2045 and the prediction of the development of the cockle stocks in these years.

The results of this model calculation show that the carrying capacity for oystercatchers will have decreased by eighty per cent in 2045 (Figure 13). In 2001 the Oosterschelde still offered a habitat to 39,000 oystercatchers, in 2045 only 8,000 oystercatchers can be accommodated (confidence interval 5,000 to 14,000). The intertidal area will have halved in that period.

It is improbable that the other delta waters will be able to accommodate the thousands of oystercatchers that cannot be accommodated any longer in the Oosterschelde. This expectation is based on a research into the consequences of the loss of the habitat of oystercatchers in the Krammer-Volkerak. This loss took place when the Krammer-Volkerak was blocked off from the Oosterschelde. The oystercatchers that formerly foraged and rested there had disappeared from the delta within three years after block off (Smaal et al., 1991). Most birds died, part of the group had found substitute foraging grounds elsewhere.

The question remains as to whether the other waders await the same fate as the oystercatchers. It is expected that populations of other waders will dwindle dramatically, as their foraging grounds will disappear beneath the waves as well. The question is not *if* the populations will shrink due to sand demand, but *when* it will happen.



**Figure 13 Prediction of the carrying capacity of the Oosterschelde for oystercatchers based on the prediction of the availability of food and the foraging time (Rappoldt et al., 2006)**

### *Fish*

As a consequence of sand demand the intertidal area will become lower and eventually it will change into shallow water. Species of fish that use the intertidal area during their life cycle, will suffer a negative effect of this change. Species that use shallow water, however, will profit. Rutjes (2007) has worked out the effects on the fish stock in the Oosterschelde and the North Sea.

Juvenile flatfish such as plaice, flounder, turbot and brill and sea bass use the intertidal area as nursery grounds. The production of food for juvenile fish is high here (Van der Veer et al., 2000), the juveniles are less vulnerable to predation than in the deeper zones (Gibson, 1994) and the water warms faster, which stimulates growth.

If the nursery grounds diminish, it will possibly have a negative effect on these flatfish. The density of individuals in the smaller nursery grounds increases and that increases the chance of predation (Van der Veer et al., 1987). The availability of food may also be at risk. It has been established that for plaice in years of large supplies of larvae and juveniles the chance of survival for individual fishes decreases, as the predation success of predators increases (Van der Veer en Bergman, 1987).

The juveniles of sole use the shallow waters as nursery grounds. The area of shallow water increases due to sand demand. This causes the chance of predation and food elimination for juvenile soles to decrease. Years with large supplies of larvae, therefore, may lead to a bigger recruitment. Gobies remain all their lives in this zone and the populations of this species will be able to increase.

After growing up in the nursery grounds the adults join the populations in the North Sea. The contribution by the Oosterschelde to the total stock of the North Sea, however, is small. The majority of the juveniles grow up elsewhere, in particular in the Wadden Sea. As the contribution of the Oosterschelde is small, the effects of sand demand in the Oosterschelde will have little effect on the total fish stocks. The fish stocks in the Oosterschelde itself, eventually will be affected, the gobies in particular. But those effects will pale into insignificance in comparison to the existing fluctuations in fish stocks caused by pressure of fisheries and variations in the strength of age classes by, for instance, weather conditions.

### *Seals*

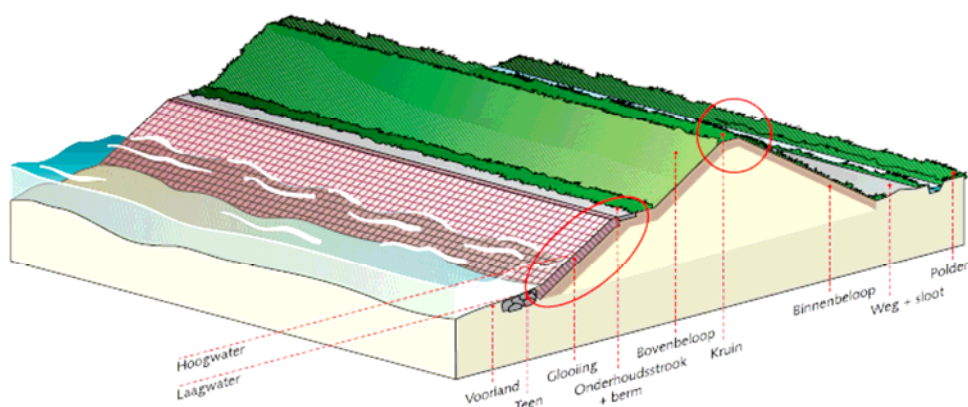
Seals are mainly using the Roggenplaat and of the Galgeplaat to a lesser extent. Sometimes they are spotted at the Noordergaatje near Yerseke. In the season of 2005/2006 37 seals have been counted in August and September, most on the Roggenplaat. The seals are using the shoals as a resting area and to moult and to nurse (May-September). Eventually, sand demand will mean that seals will no longer use the Oosterschelde.

## **2.2 Flood safety**

The dikes along the Oosterschelde have to meet the requirements that are listed in the Dutch Act on Dams. This boils down to the dikes having to withstand safely high water levels and waves that occur only very rarely (a chance of occurrence 1/4000 per year). The required height and strength of the dike needed to achieve this depends on the local circumstances. The managers of the dikes and dams test whether the dikes meet these requirements every five years. If a dike does not suffice, then intervention is needed.

If a dike borders a deep channel or an extensive water area, then waves can get very high. The revetment and the height of the dike must be able to withstand these. If a tidal flat or salt marsh is present in front of the dike, then the waves will be reduced and will exert less force on the dike.

The effects of sand demand make extra demands on the height and strength of the dikes. Salt marshes and tidal flats will get lower or will disappear completely. Dikes that are now protected by an elevated foreland will be subject to more waves and currents in the future.



**Figure 14 Profile of a dike. Sand demand causes the foreland to become lower and wave attack to increase. This demands a stronger revetment on the pitchings and a higher crest.**

### Reinforcement of stone revetments

The project bureau of Sea Defence Works is reinforcing the stone revetments of most dikes around the Oosterschelde at the moment. The project bureau is taking into account the lowering of the intertidal foreland due to sand demand, departing from a measurement from 1989/1991 and a prediction of the future elevation of the intertidal flats from 1998 in the design of the new stone revetments (Roelse, 1998). In the mean time, judgements of the future elevation of the intertidal flats have been adjusted. In 2001, Rijkswaterstaat carried out a second measurement and in 2006 new predictions of erosion in 2015, 2030, 2045 and 2060 were based on it (Jacobse et al., 2006). (see also section 1.5). In this latest prediction it turns out that the foreland of most dikes will become lower due to sand demand. For each scenario, the extent to which wave attack on dikes increases due to a lower foreland has been calculated (Jacobse et al., 2006).

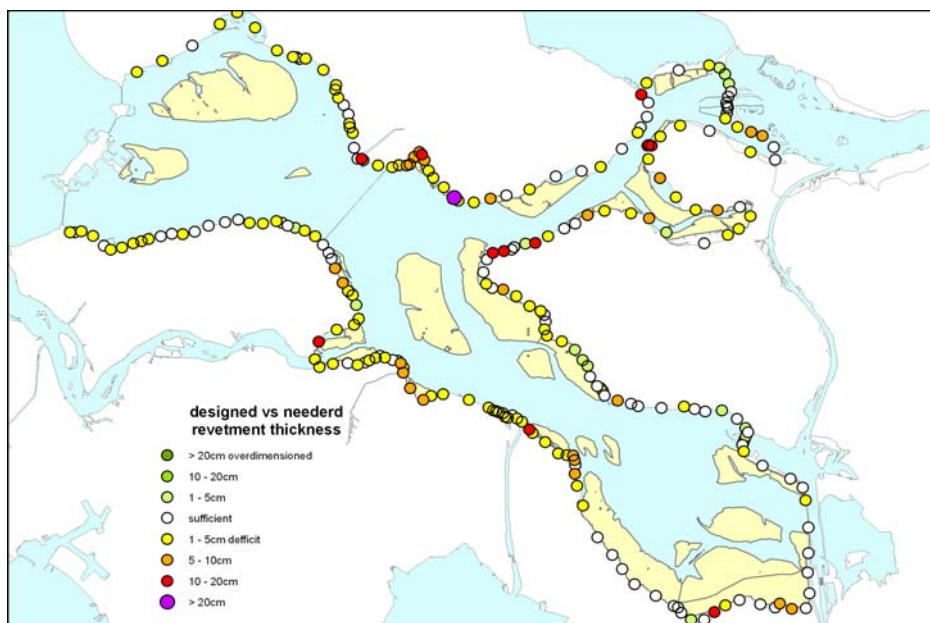
### Checks and design

Every five years the manager checks whether a dike offers the safety that is required. The load is as precisely described as possible based on Hydraulic Preconditions. Recently, the Hydraulic Preconditions 2006 (HR 2006) has been published. It includes the water levels and waves that the manager has to use in the next inspection. The inspection shows whether or not the dike is strong enough and high enough to withstand those water levels and wave attacks in the coming five years. At the construction of a new dike or the reinforcement of an existing one, the design is calculated based on a period of fifty years. In those fifty years the circumstances can change, for instance due to climate change and sand demand. That is why heavier demands apply for design than for checking. In addition to the Hydraulic Preconditions some additions apply for uncertainties in the design, such as a possible longer duration of a gale, uncertainties in the wave period and wave amplitude, settling of the sea defence and settling of the underlying ground. Within those fifty years a change of circumstances does not actually need to lead to a new dike reinforcement. The design standards have been chosen in such a way that reinforcement will not be necessary before fifty years, departing from the current opinions in the uncertainties.

### New opinions

In setting up the Hydraulic Preconditions 2006 a new way of calculations has been applied. From it, it turns out that most dikes along the Oosterschelde will have to withstand a less heavy load than was thought earlier, while the safety remains the same. The dike reinforcements that are carried out by the project bureau Sea defence Works, are based on the old preconditions. They offer more strength than would be strictly needed: the designs have become more robust.

Against this stroke of luck there is a setback as well: in the design, too small an allowance has been made for the future effects of sand demand. It turns out from the new calculations that the wave load in the next fifty years caused by sand demand will increase more than was previously taken into account. In 2060 the wave load on 79 per cent of the dikes will be larger than what they were designed for. Whether the dikes will offer the required safety then depends on how the other circumstances will develop, such as climate change. A worst-case scenario arises when in 2060 all allowances are necessary to meet the developments. A number of dikes will not be adequately robust to allow for the greater effects of sand demand. There, reinforcements will have to take place earlier than planned. The average life span of the revetment then decreases from 50 to 30 years. The dike sections on which the stone revetment is not thick enough in the worst-case scenario before 2060, are distributed over the Oosterschelde. Most problems will occur around the Gouwveerse polder near Zierikzee, the tidal flats of Kats, the tidal flats of Kattendijke, the tidal flats of Yerseke, Krabbenkreek and Zandkreek and the Kempenhofstedepolder at Tholen. The problems with the stone revetment mainly develop where a narrow foreland exists and that is getting even narrower due to sand demand. An exception is the dike sections along the Zandkreek and the Krabbenkreek that will get problems with the stone revetment despite the broad intertidal foreland.



**Figure 15 Design of the stone revetment compared to the required thickness of the revetment with the wave load predicted in 2060**

In the worst-case scenario all these dikes will have to be reinforced or replaced earlier than was anticipated. Costs amount from €90 to 100 million in the case of reinforcement with, for instance, stone and liquid asphalt, to €215 to 260 million in the case of total replacement.

A very favourable scenario develops if only the effects of sand demand occur, and the other circumstances remain the same in the next fifty years. This means that no effect of, for instance, climate change will occur. In that case only a small part of the dikes will have to be reinforced before 2060. The investments will then be lower and will amount probably from €25 to 45 million.

#### Crest height

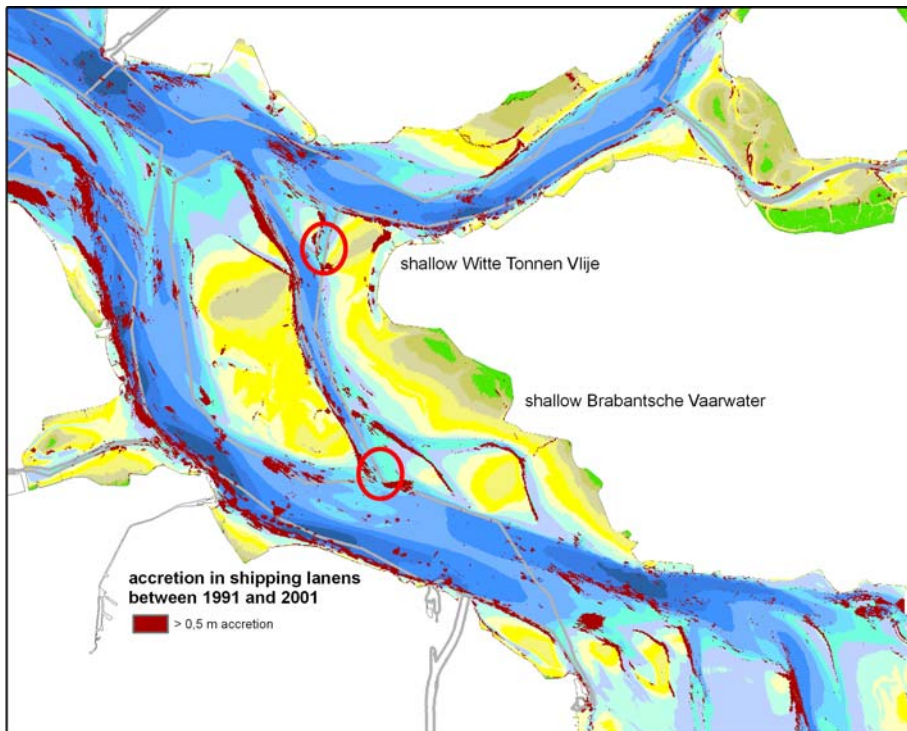
Wave load determines both the required strength of the stone revetment and the required crest height of the dike. The relation between crest height and wave load is almost linear. To withstand the increasing wave attack caused by sand demand, the crest height in 2060 has to be on average 20 centimetres higher than in 2001 (Jacobse et al., 2006). The dikes around the Oosterschelde were based in the seventies on water heights that occur at a gale with a 1/500 chance of occurrence, without the storm-surge barrier. Those water heights are higher than the current normative water levels. The dikes are therefore on average 1.6 metres higher than necessary, enough to absorb the extra 20 centimetres. Only on a few dike sections will the crest height be inadequate before 2060. The project bureau Sea Defence Works will bring these dike sections to the right height in the next few years, simultaneously with the reinforcement of the stone revetment.

#### Uncertainties

Predictions of the way in which sand demand affects the wave load on the dikes have been used for these calculations. The predictions are based only on two measurements of the soil elevation and they hold for the far future. The results are only an indication. In 2008 a new measurement of soil elevation will become available and then a new prediction will be made. It is expected, however, that erosion will continue relentlessly. Intermediate measurements on the Galgeplaat and in the Zandkreek confirm that point of view.

## 2.3 Shipping

Two natural bars are present in the main north-south shipping route: one in the Witte Tonnen Vlije and one in the Brabantsch Vaarwater (Figure 16). Between 1991 and 2001 a maximum of two metres of sand has been deposited on these bars. As a consequence of sand demand a continuing supply of sand from the intertidal area into the channels is taking place. It requires that the two bars will have to be dredged once in a decade.



**Figure 16 Sedimentation on two bars in the main shipping route between 1991 and 2001**

In the smaller channels that are present near large intertidal areas, the silting will be much greater. In the first years after the construction of the storm-surge barrier these channels have become much narrower, because the sediment remains on the channel walls. In the Krabbenkreek, the channels in the Dortsman and the Mosselkreek there has been a silting up of three metres on the channel walls in some places. This sand will spread gradually and in a few decades smaller channels will be more than one metre shallower.

## 2.4 Shellfish fisheries

The Oosterschelde is an important area for mussel and oyster culture and for cockle fisheries.

The mussel fishers catch seed mussels in the Wadden Sea and dump them on mussel plots in the Oosterschelde. After two to three years the mussels are available for consumption. The plots together have an area of about four thousand ha, eleven per cent of the Oosterschelde. The plots are situated on the edges of the tidal flats, in shallow water from a depth of about six metres below MSL to the low water mark. Sand demand means that the area that is suitable for mussel culture increases (Wijsman, 2006). On the other hand a number of existing plots that are now on the leese side of tidal flats will become less suitable as circumstances roughen. The mussels will suffer from an increased competition for food from the Japanese Oyster as the habitat of this species increases due to the drop of the intertidal area. It is still unclear what the net effect of sand demand on mussel fisheries will be.



**Fisheries**

Cockle fisheries take place on the intertidal areas. Only permit holders are allowed to fish and they are restricted to the Roggenplaat, the Galgeplaat and the Slikken van den Dortsman. Moreover, cockle fisheries are only allowed in years when there are more cockles than the waders need for food. The sand demand causes the habitat of cockles to decrease and it is expected that the cockle stock will be halved in 2045. In the short run, there will be more years when waders will need all the cockles and cockle fisheries will not be allowed.

**2.5 Recreation**

Holiday-makers that visit the Oosterschelde, are seeking mainly the wind, the quiet, the space, the birds and the scenery. The main types of recreation are recreational shipping (sailing), scuba diving and small-scale beach recreation. The main part of the intertidal areas is off limits to prevent vulnerable bird populations from disturbance. The Noordergaatje, a shoal near Yerseke, is open to recreation. On warm summer days beach holiday-makers sail to it from the neighbouring marinas.



**Holiday-makers on the tidal flats of the Krabbenkreek**

Recreational shipping  
The Oosterschelde is a unique and much-loved shipping water for pleasure yachts and charter boats, because of the tide, the change of scenery of the periodically emerging tidal flats and the damped waves. A trip around a shoal, with sightseeing of birds and seals is an important attraction of the

Oosterschelde (Houtekamer, 2007), for holiday-makers from other parts of The Netherlands and from abroad as well. Loss of the intertidal area will make the Oosterschelde less valuable, but it is expected that the area remains attractive. An underload of fixed moorings is not to be expected.

#### Diving

The Oosterschelde is a favourite diving region as the water is clear and as colourful plant and animal life has developed on the large area of stone revetments. The intertidal area is less interesting to divers. The loss of intertidal area will therefore have little effect on the use of the Oosterschelde as diving water.



**Diving between suspended mussel lines**

#### One-day outings

In a number of locations along the Oosterschelde sandy beaches have been constructed. These beaches are popular with beach holiday-makers. The local authorities or recreational companies that manage the beaches are now already replenishing those beaches frequently. This maintenance will increase due to sand demand.