Eco-engineering in the Netherlands

Soft interventions with a solid impact

Contents

Seals on a concrete jetty block covered with algae

Background and cooperation

At Rijkswaterstaat Eco-engineering is an emerging discipline in regular projects, and part of several knowledge management and innovation management activities, including the eco-engineering flood protection programme. As a major player in the field of water management Rijkswaterstaat is in a position to innovate and to create new ideas and applications by pooling knowledge together with other parties including citizens, companies, authorities and research institutes.

Rijkswaterstaat is responsible for the main waterways, water systems and road networks in the Netherlands. It faces numerous challenges posed by extreme weather conditions, an ageing infrastructure, new technologies and shrinking budgets. Rijkswaterstaat set up an innovation programme to cope with these challenges. The parties in this programme that work on eco-engineering also work on the Building with Nature innovation programme. The programme is being implemented by the business community and consists of several sub-programmes that focus on flood protection. In order to implement the programme, the parties formed a foundation called EcoShape to carry out the eco-engineering work.

Deltares has extensive expertise in eco-engineering and is involved in both innovation programmes as a knowledge partner. The Eco-engineering and Building with Nature programmes both examine how functions of ecosystems with of infrastructure can be integrated in a sustainable, climate-robust and cost-efficient manner. The parties are committed to finding solutions for hydraulic engineering infrastructure development that address the needs and wishes of all involved. Potential innovations and improvements are carefully tested in the field, enabling the parties to determine whether an idea actually delivers improvements.

A reciprocal relationship

In eco-engineering projects we let nature contribute to flood protection. We use the services that ecosystems provide to achieve this, such as plants that dissipate wave energy and oysters that stabilize sediment. We thus create more natural flood defences that meet the strict demands of flood protection in what one might call a soft intervention with a solid impact.

When eco-engineering concepts are applied, natural processes and organisms support the realization and functioning of the hydraulic infrastructure (‘building with nature’). The opposite often works well too, when infrastructural works are adapted in such a way that they benefit nature (‘building for nature’). Dunes are an example of ‘building with nature’. They provide flood protection by forming a buffer between the land and the sea, which can be optimized through optimal management strategies. Without dunes, a solid structure would have to protect the land from the sea, such as dikes or dams. Building for nature entails creating a pool in the toe of a dike for juvenile fish and shrimp, for example. Hydraulic engineering and nature enhance each other in all eco-engineering projects. This reciprocal relationship has numerous advantages. New natural solutions emerge as the sea level rises and other water levels gradually change, which could yield huge savings on the maintenance and strengthening of flood defences. More costs can be cut because most ecosytem services provide several services simultaneously. Dunes, for example, contribute to coastal protection, recreation and water purification. Moreover, eco-engineering solutions appeal more to tourism users than hard structures. And finally, licences are often issued more quickly than usual when the design takes nature and recreation into account. These added values make ▶

‘Eco-engineering, natural hydraulic engineering and building with nature: it can be done, and it works!’

eco-engineering a cost-effective option. In 2009 Rijkswaterstaat, EcoShape and Deltares launched the first eco-engineering pilots, which are described in the booklet published by Rijkswaterstaat in 2009 entitled Harde werken met zachte trekken (‘Solid interventions with soft impact’). The pilot phase has largely been completed in the meantime, and the first applications already have been – or still are being – implemented in the field. The parties are also working on new eco-engineering projects. Eleven of these are described in this short book. They are inspiring examples of why the time is right for the large-scale application of eco-engineering.

Reader's guide

The eco-engineering projects mentioned in this booklet can be applied in different ways. The table below contains short descriptions, an overview of the different ecosystem services and the status of each project.
An application is a functional and permanent structure.
A pilot project, by contrast, is temporary in nature.

Building *with* nature in saltwater

Project name	Status	Description	Ecosystem service	Extra services	Result
Sand Engine	Application	Concentrated mega-nourishment resulting in less disturbance of benthic fauna	Flood protection	Recreation, nature and biodiversity	Sand is spread rapidly along coast, new dune development and more recreational use
Oyster reef	Application	Construction of an oyster reef to counter erosion	Flood protection	Nature and biodiversity, nursery/fishery	Clear increase of silt due to reef and establishment of new oysters
Oesterdam	Application, implemented in 2012	Ecologically designed nourishment and oyster reefs	Flood protection	Natura 2000, nature and biodiversity	*Results not available yet*

Building *with* nature in freshwater

Project name	Status	Description	Ecosystem service	Extra services	Result
Noordwaard	Application under construction, implementation between 2011–2015	Developing a wave-attenuating willow foreshore for a dike	Flood protection	Recreation, nature and biodiversity	*Result not available yet*
Foreshore levee	Pilot project	Building reed marshes to dissipate wave energy and trap sediment	Flood protection	Water quality, nature and biodiversity, nursery/fishery	The reed marshes have a wave-damping effect; their floating ability has to increase
Shoreline dike	Design phase	Constructing a soft dike with marsh zones	Flood protection	Water quality, recreation, Natura 2000, nature and biodiversity	*Result not available yet*
Marsh restoration	Stakeholder participation	Temporary land reclamation to turn open water into marsh again	Flood protection	Nature and biodiversity, nursery/fishery, food, recreation	*Result not available yet*
Soft Sand Engine	Pilot project, implemented in 2011–2012	Allow forelands to grow along with changing water levels by promoting the transport of sand	Flood protection	Nature and biodiversity, recreation	*Result not available yet*

Building *for* nature in saltwater

Project name	Status	Description	Ecosystem service	Extra services	Result
Eco-concrete	Application	Construction of micro and macro structures to existing concrete slabs to promote the establishment of benthic organisms	Natura 2000	Water quality, nursery/fishery, nature and biodiversity	Quicker establishment of algae, mussels and periwinkles
Tidal pools	Application	Construction of small pools at the base of dikes to promote the establishment of organisms	Nature and biodiversity	Nursery/fishery, recreation, Natura 2000	Increased biodiversity by a factor of three
Hanging structures	Pilot project completed	Use rope to hang structures to increase the adhesion surface for shellfish	Nature and biodiversity	Water quality, nursery/fishery, flood protection	Purifying effect and significant increase of biomass

Explanation of the ecosystem services used

Flood protection	The eco-engineering solution creates additional protection against flooding by dissipating wave energy, capturing sediment, stopping erosion increasing seepage length and stabilizing flood defences.
Water quality	The solution promotes water quality, because plants and filter feeders – such as mussels and oysters – remove organic material, silt, nutrients and toxic materials from the water.
Natura 2000	The application makes it easier to achieve the Natura 2000 objectives, for example because it creates a larger living environment or increases the availability of food for Natura 2000 species.
Nature and biodiversity	The application promotes the natural value and biodiversity of the area.
Food	An ecosystem that is part of the solution provides food for humans, such as mussels, shrimp and edible plants and fruits.
Nursery/fishery	The application provides sheltered places where juvenile fish and shellfish can develop, or it promotes the growth of food for fish.
Recreation	The structures that are built offer a pleasant environment for recreational purposes or provide new opportunities for recreational activities.

Sand Engine

01

The beaches and dunes of the sandy Dutch coast protect the hinterland from flooding. Sand nourishment allows natural processes to maintain this sandy coast and 'dynamically' keep it in place. The sand for nourishment is dredged from deep waters (below the 20-metre depth contours). Water and wind distribute this sand naturally along the beach and across the dunes.

Every four or five years, supplementary sand is deposited along the narrow coast between Hoek van Holland and The Hague – known as the Delfland Coast. On average, between 300,000 m^3 and 500,000 m^3 of sand is deposited every year on the beach or in the shallow water near this part of the coast. The faster the sea level rises, the more sand needs to be deposited. Frequent nourishment is unfavourable for the benthic organisms because it traps them under the sand.
It takes three to five years for the benthic community to fully recover. Mega-nourishment – an excess of sand that is gradually spread by the tide, waves and wind – is an alternative to frequent nourishment. This kind of nourishment needs to be repeated much less often and spreads the sand across the contours of the coast as naturally as possible.
This enables us to preserve our natural coastal defence of beaches and dunes, and creates more space for nature and recreation. In 2011, the Delfland Coast Sand Engine pilot experiment was launched to examine the effectiveness of mega-nourishment.

Implementation

Between March 2011 and November 2011, a hook-shaped peninsula was created along the coast at Ter Heijde – the Sand Engine. The peninsula juts out one kilometre into the sea, and when completed it was two kilometres wide. The total surface area was initially more than 100 hectares. In total, 21.5 million m^3 of sand was deposited, 2.5 million m^3 of which was placed on opposite sides of the peninsula as an underwater nourishment to prevent short-term erosion. The Sand Engine is a fairly even 'shoal', containing a small lake about eight to ten hectares large and two metres deep. The lake introduces more variation in bedforms and water levels, which enables nature to develop better.
The Sand Engine's key higher points are a spine about five metres above mean sea level around the lake, a slightly higher point seven metres above sea level and a spine that is four metres above mean sea level straight across the Sand Engine (pointing in a north–south direction).
These parts remain dry when water levels are high, but they are significantly lower than the dunes in Solleveld, an adjacent nature area.

Results

Six months after it was created, the peninsula had already begun to gradually change shape, and the hook is expected to eventually join the beach. The resulting shape will resemble a bell, which over the years will gradually spread to the north and to the south. As a result, the beach will widen and create new dunes. The sand will be blown away from the beach and into ▶

▲ *Jumbo hopper dredger*

Sand Engine

ecosystem service flood protection, recreation, nature and biodiversity

specification
- replenish coastal defence's supply of sand
- preserve coastline
- dredge and deposit sand less frequently
- more recreational options
- ecological potential

system saltwater with pockets of freshwater

organisms benthic fauna, fish, birds, seals

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location Delfland Coast, at Ter Heijde

status application

duration 2011-2021

the dunes, raising them. Part of the sand will vanish in deep water. An extensive monitoring programme will determine whether the Sand Engine creates fewer disturbances than the original sand nourishments and whether it improves the protection of coastal nature and recreation areas. The monitoring programme will enable involved parties to expand their knowledge and nourish the coast more effectively in the future. The researchers will focus on the wind, waves and the tide, the distribution of sand, the groundwater level, the geochemistry, the quality of the water in the dunes, the flora and fauna of the dunes and underwater banks, as well as recreation and nature conservation.

Costs and benefits

The Sand Engine cost €70 million. Basically mega-nourishment is not more cost-effective than regular small-scale nourishment in terms of its primary function (coastal management for flood protection). Indeed, the latter is quicker to yield a return on the investment. Mega-nourishment creates added value mainly for recreation and nature, and potentially also for drinking water supplies.

Other applications
If the principle of mega-nourishments works, then it can be widely applied along the Dutch coast and probably abroad as well.

Partners
Rijkswaterstaat, Province of South-Holland, Delfland District Water Control Board, Borough of Hoek van Holland, Municipality of The Hague, Zuid Hollands Landschap, Municipality of Westland, Deltares, EcoShape, Dutch Lifeguard Association, Dunea, WWF, Delfland Coast Project Office, Van Oord and Boskalis.

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Oyster reef

02

Since the construction of the Eastern Scheldt storm surge barrier, there has been tidal flat erosion in the Eastern Scheldt estuary. Nearly 10% of the intertidal zone has disappeared in the past 20 years. If no measures are taken, the tidal flats could vanish from the Eastern Scheldt by 2075. This would not only adversely affect the fauna, such as seals and many birds, but also the flood defences. The absence of tidal flats would result in higher and longer waves in the deeper, more expansive open water, which would put more pressure on the flood defences.

Erosion is usually reduced by means of solid constructions, such as rubble or concrete dikes and embankments. Natural elements, such as reef-forming shellfish can also fulfil the function of these solid constructions.
The advantage of a natural reef is that it can grow and thus maintains itself. So natural reefs can counter the erosion of the intertidal zones in the Eastern Scheldt and help trap sediment, which contributes to the preservation of the intertidal flats.

Implementation

The first oyster reef was built in 2007. Living oysters were collected and put back in the water along the edge of an intertidal flat. The area turned out to be too dynamic, however, and the oysters vanished following a storm. In 2009, a small reef, was built, 48 m^3 in size, using a steel-wire ungalvanized box (a gabion) filled with dead oyster shells.
The idea was that the steel frame would corrode and the 'organic bio-builders' – in this case the oysters – would take over the stabilizing function. Nature conservation organizations are using similar techniques on a major scale to restore oyster reefs in the United States.
In the Netherlands this technique was used on a larger scale in 2010 to build three large artificial oyster reefs in two different places in the Eastern Scheldt. The boxes in these reefs had an area of six by two metres and were 30 centimetres high. Together, the two reefs are 10 by 200 metres large.

Results

Initial results show that new oysters are quick to attach themselves to the gabions. Moreover, the amount of silt behind the reef is increasing. This coincides with the results from pilot studies on mussel beds, which show that the bed affects the composition of sediments. This impact can be felt hundreds of metres away from the mussel bed. Simulations performed in the lab also show that the beds dissipate wave energy in shallow water.

Costs and benefits

If the design were to be optimized, then an oyster reef could potentially be cheaper than rubble mounds. Money could almost certainly be saved on maintenance costs and oyster reefs could limit the number of sand nourishments in the Eastern Scheldt. In addition to a potential reduction in cost, the oyster reef would provide the following benefits:

- Protect the hinterland against erosion by dissipating wave energy.
- Increase the volume of land outside the dikes by trapping sediment.
- Cultivate oysters for (human) consumption.
- Improve the landscape using natural structures.

Oyster reef

ecosystem service	flood protection, nature and biodiversity, nursery/fishery
specification	• dissipate wave energy • reduce erosion • trap sediment in and behind the reef
system	saltwater/intertidal zone or subtidal
organisms	oysters or mussels (reef-shaped shellfish)
location	Eastern Scheldt
status	application
duration	2006-2012

Other applications

In freshwater systems, floating reed marshes or freshwater mussels can be used to trap and stabilize sediment.

Partners

Rijkswaterstaat, EcoShape, Deltares, Imares, NIOZ, Radboud University Nijmegen.

References

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Oesterdam

03

The Oesterdam is located in the eastern part of the Eastern Scheldt.
This dam separates the freshwater body Volkerak-Zoommeer from the saltwater of the Eastern Scheldt. The dam also creates a non-tidal navigation route between Antwerp and the Rhine.
The building of the Eastern Scheldt storm surge barrier and the Oesterdam diminished the tide in the Eastern Scheldt: less water runs into and out of the Eastern Scheldt. The channels are responding to the decreasing amount of water by filling themselves with sediment from the tidal flats – 'sand hunger' – which is reducing the surface area of the intertidal zone. Due to the erosion of the tidal flats in the intertidal zone, there is less wave dampening larger continuous areas of water, and therefore increasing pressure on the dikes. Moreover, the decreasing size of the intertidal area is unfavourable for birds, which forage on the tidal flats.

Countering erosion means searching for ways of redistributing the sand in the system, in a way that is consistent with other objectives, such as dike reinforcement.
A pilot project was launched with this idea in mind in order to reinforce the Oesterdam in the Eastern Scheldt, where a large volume of sand dredged from the channels will be deposited in front of the dam. This will ease the wave pressure on the dam and reduce dike erosion. In the long term, this could save on maintenance costs for the dam. Moreover, the mud flat in front of the dam – an important foraging area for birds – will remain intact.
The sand nourishment will be subjected to erosion, so periodic maintenance will be necessary.

Implementation

Rijkswaterstaat and the Scheldestromen District Water Board began reinforcing the Oesterdam in 2012. They now are also conducting a pilot experiment in which the area immediately in front of the Oesterdam is raised with sand for two kilometres.
Measures – for example, the use of artificial oyster reefs – are being taken to slow down the erosion process. In total, approximately 600,000 m^3 of sand will be deposited.
Putting this sand at a slight incline at the right height is creating an intertidal zone with a considerable surface area that is dissipating wave energy and hence decreasing the pressure on the dikes.
Moreover, this area is a valuable habitat for all kinds of organisms, including foraging birds.

Results

The Oesterdam Safety Buffer pilot project is already being conducted and is set to end in 2013.

Costs and benefits

Calculations show that reinforcing the Oesterdam through sand nourishment is cheaper than reinforcing it with rubble.
Although the management and maintenance of the foreshore could initially cost more, in the long term the balance is expected to be positive. Other benefits of the nourishment of the foreland are:
- Preservation of the tidal flats in front of the Oesterdam.

Oesterdam

ecosystem service	flood protection, Natura 2000, nature and biodiversity
specification	• dissipate wave energy • raise tidal flats • create living and foraging area for benthic fauna, fish and birds
system	saltwater
organisms	benthic fauna, fish, birds
location	Eastern Scheldt, Oesterdam
status	application
duration	2012-2013

- Redistributing the sand is consistent with the strategy of mitigating the impact of sand hunger in the Eastern Scheldt. That is important for long-term protection, nature and recreation.
- Adding sand makes it possible to anticipate changing hydraulic demands on the protection of the embankment in a flexible way.

Other applications

A sandy foreshore can strengthen flood defences if the incline at the bottom is not too steep for the defence and not completely muddy. The exact type of foreshore depends on the abiotic conditions at the site in question.

Partners

Rijkswaterstaat Zeeland, Zeeweringen Project Office, Province of Zeeland, Climate Buffer Coalition, Deltares, Imares, Ecoshape.

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Noordwaard

04

Reversing land reclamation in Noordwaard is one of the measures proposed by the Room for River programme. To be able to divert more river water when levels are high, the polder is becoming part of the Nieuwe Merwede flood plain. As a result, twice a year, when there is high river runoff, the polder is temporarily flooded. A new dike needs to be built to protect Fort Steurgat, which is located in Noordwaard.

The initial idea was to build a 'traditional' dike, 5.5 metres above NAP (mean sea level) and lined with stones on the riverside. Inhabitants of Fort Steurgat, however, were strongly opposed because the high dike would restrict their views and tarnish the Dutch Waterline (Hollandse Waterlinie), which the fort is part of. The solution was a partly natural defence. A foreshore with willows was built in front of the dike to dissipate wave energy so that the dike does not need to be raised. Research shows that a strip of willows 100 metres wide can reduce the size of one metre-high waves by 80%. As a result the dike can remain lower and be lined with clay instead of stones. Inhabitants and administrators have responded positively to this innovative solution.

Implementation

The wave-attenuating flood defence is a combination of a dike (4.8 metres above NAP) and a willow foreshore about one hundred metres wide. The willow foreshore will consist of *Salix alba* and *Salix viminalis*, species that thrive in high groundwater levels and can withstand waves. Approximately four trees will be planted per square metre. The dike will be strengthened by lining it with clay. Thanks to the willows, it will not be necessary to strengthen the dike with stone constructions. This will save on construction and maintenance costs. The Rivierenland District Water Board is taking the design into its own hands and is thus responsible for maintaining the willow foreshore as well. Several scenarios for the best possible management were explored and calculations were made with the help of models. Findings suggest that it is best to trim the trees every two or three years to keep the willow foreshore sufficiently thick and healthy. Half of the trees should be trimmed at a time so that the wave-attenuating function of the wooded foreshore remains intact after trimming. The dike itself is low maintenance and only needs to be mowed.

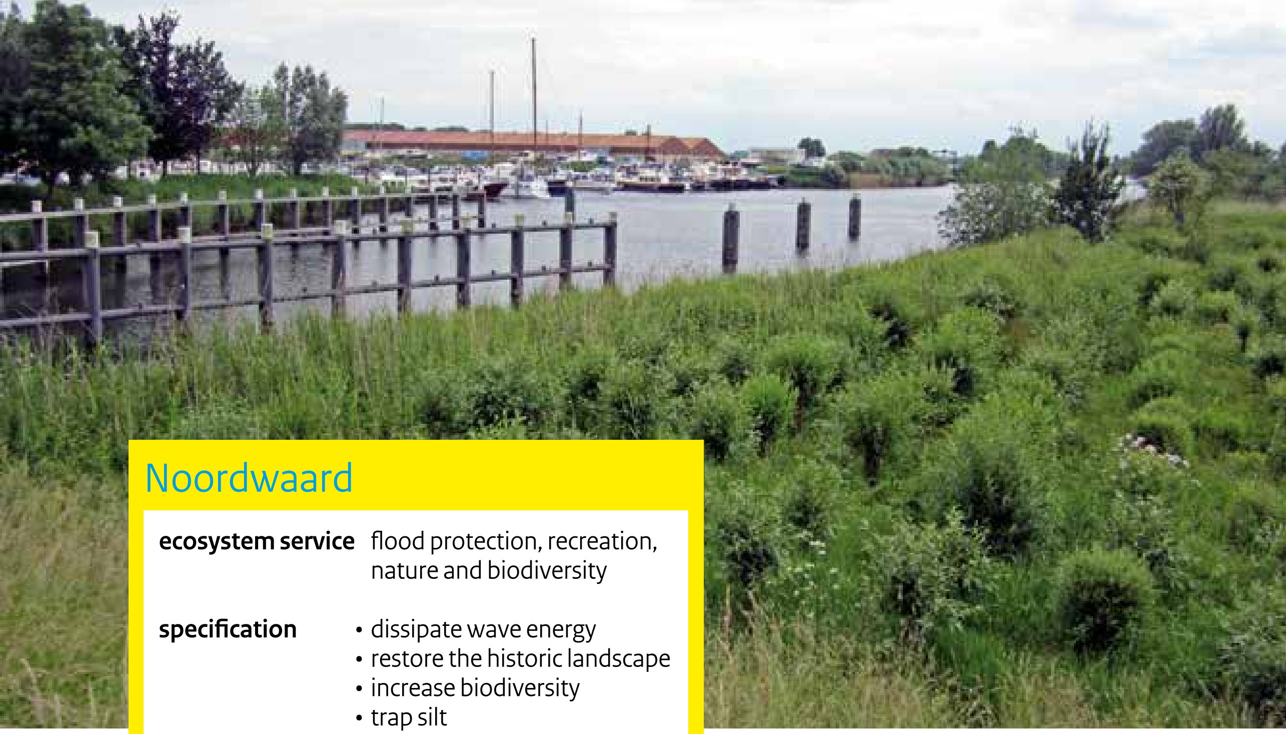
Results

In 2012 the parties developed a method for testing this new dike concept, and subsequently agreed on management and monitoring protocols. The water board will evaluate the project in a later round of testing. Based on model calculations, the parties expect the wave height to be reduced by 80%, as a result of which the dike can remain one metre below the original design. This has not been incorporated yet in an assessment programme, which will eventually evaluate the extent to which the willows reduce wave energy.

Costs and benefits

The construction costs of the wave-attenuating dike are apparently €1,550 per metre less than they are with a traditional dike; for example, the incline does not need to be clad in stone.

According to calculations, the management and maintenance costs are two euros per metre



Noordwaard

ecosystem service	flood protection, recreation, nature and biodiversity
specification	• dissipate wave energy • restore the historic landscape • increase biodiversity • trap silt
system	freshwater
organisms	willows
location	Noordwaard
status	application
duration	2011-2015

more per year. The wave-attenuating dike provides the following benefits to society:

- Protects Fort Steurgat at high tide.
- Fits in better with the landscape because the dike can remain lower and does not need to be cemented. The inhabitants of Fort Steurgat will still have an unobstructed view.
- The foreshore improves the landscape and has cultural values (ancient tradition in marshy areas).
- The foreshore creates a new habitat for flora and fauna where land and water meet.
- The willows create a reservoir for the storage of the greenhouse gas CO_2.
- The trimmed willow shoots could be used to make fascine mattresses or as a biofuel.

Other applications

- A wave-attenuating willow foreshore is useful in river areas when the height of the waves affects the height of the dikes.
- If the dike lining is insufficient or if there is a risk of internal erosion, a good solution is a foreshore on a clay platform.
- Other sturdy marginal plants can be used instead of willows. Tidal marshes and mangroves provide similar ecosystem services in saltwater and tropical environments.

Partners

Rijkswaterstaat, Room for River programme, Deltares, Noordwaard Project Office, Rivierenland District Water Board.

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Reed marshes

05

Many water bodies in the Netherlands, including major lakes, are bounded by dikes. The by nature gradual transitions between land and water, which have great natural value, are thus replaced by harsh, steep transitions. Few riverbank plants can spontaneously take root along the steep incline or in the deep water. As a result, dikes are directly exposed to waves and currents and require relatively high maintenance. Floating mats with riverbank vegetation could address this problem.

These structures of mats dissipate wave energy, thereby reducing dike maintenance. They also improve the quality of water by converting nutrients and trapping silt. Filter-feeding organisms, such as the zebra mussel, can attach themselves to the bottom of the mats. The idea is that the mats will eventually sink when the reed marsh has developed sufficiently. The reed, rooted in the water, survives. It then takes over the wave-attenuating function of the mats. This principle was tested in a pilot project near the Houtrib locks in Markermeer.

Implementation

The pilot project used mats made of braided willow shoots. These become quickly overgrown with riverbank plants, such as reed. And they create protected, shallow places at the base of the dike where sediment can be trapped. Traditionally fascine mats were used to stabilize underwater hydraulic engineering constructions. The mats were placed near the Houtrib locks in Markermeer in the summer of 2009. They were 30 by 100 metres large, 40 centimetres thick and weighed as much as 80,000 kilograms. Almost 50,000 rhizomes were braided in between the layers of willow. The idea was for the mats to become overgrown with reed and simultaneously trap silt. Then the mats would sink, after which the reed, rooted in water, would create a zone with vegetation at the base of the dike.

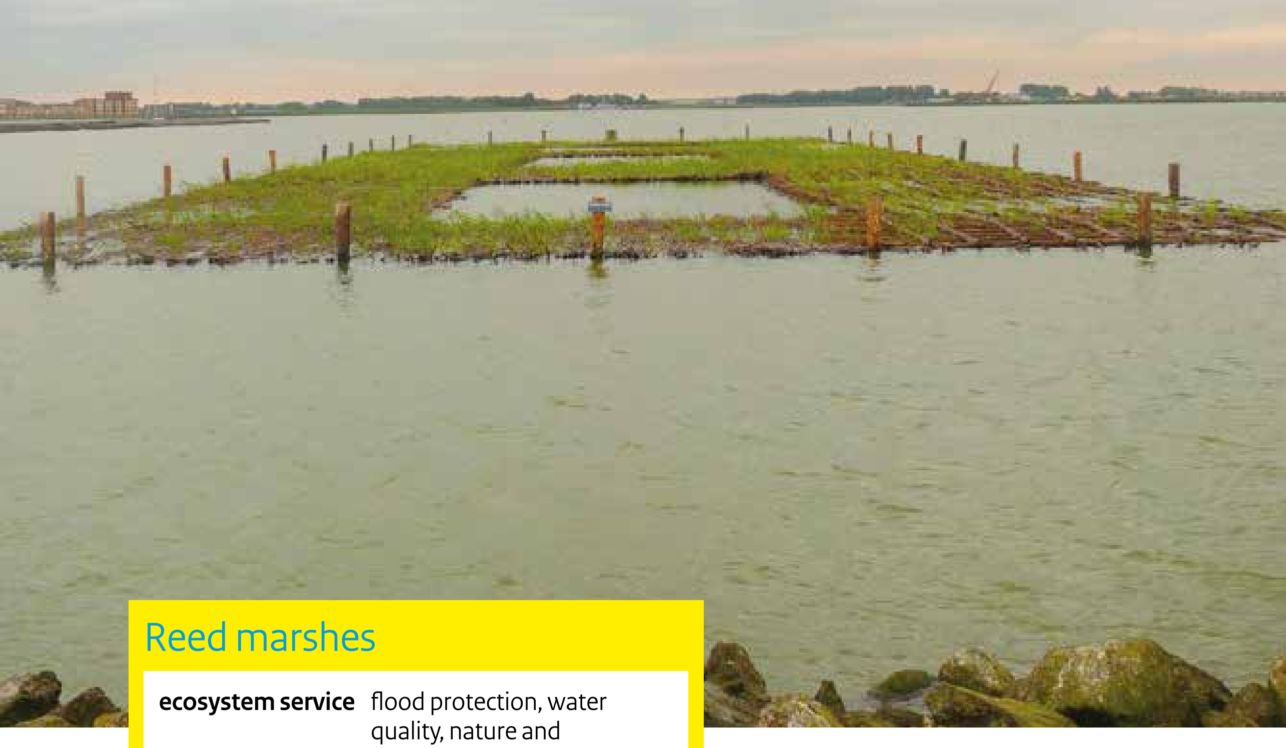
Results

Reed already began to grow three weeks after the floating mats were deployed. Water birds also used the island and the shelter created next to the island. The floating willow mats with reed vegetation did indeed dissipate wave energy. Deltares tested wave attenuation in a wave basin in a separate experiment. Moreover, sedimentation was observed beneath the mats. After several months, the construction was damaged during a storm, which threatened to detach parts of the construction. The pilot experiment was therefore halted prematurely and so only some of the research questions were answered. The results do indicate, however, that these floating constructions are essentially suitable in multifunctional reed banks, which also dissipate wave energy. However the design needs to be further optimized.

Costs and benefits

Outweighing the costs of the floating reed marshes are the following benefits:

- Dissipate wave energy (thereby reducing dike erosion). The mats are capable of dissipating wave energy by 80%, depending on the length of the wave and that of the mats.
- Improve water quality through the purifying effect of vegetation.



Reed marshes

ecosystem service	flood protection, water quality, nature and biodiversity, nursery/fishery
specification	• dissipate wave energy • capture sediment • restore gradual transitions from land to water
system	freshwater
organisms	reed, water plants, freshwater mussels
location	Houtrib locks, Markermeer
status	pilot project
duration	2008-2010

- Improve water clarity by trapping sediment.
- Increase the diversity of habitats and species (above and underwater).
- Food source for birds.
- Restore landscape values (transition between land and water).
- Capture the greenhouse gas CO_2 in the marsh.

Other applications

- The reed marsh described above can be used in areas along bodies of freshwater whose banks have a gradual incline. More natural foreshores with a damming function could also be used along small bodies of freshwater, such as water storage areas and large streams.
- Fascine willow mats were still used in 2012 to protect quays and for nature development in Zeeburg in Amsterdam.
- Similar ecosystem services could be provided at an international level using other types of floating materials or vegetation.

Partners

Rijkswaterstaat Water Service and Ijsselmeer Area, Deltares, Hoeksewaard Landscape and Van Schaik BV.

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Foreshore levee

06

Traditionally, dikes that are no longer sufficiently safe are widened and raised. The space needed for these changes often comes at the expense of housing along the dike, infrastructure or nature areas. The people living there are often critical of major landscape interventions. This is particularly true of the dike of the Markermeer between Hoorn and Amsterdam. This reinforcement of this dike is especially tricky due to an instable, settlement-sensitive sub-stratum. An alternative to widening and raising such a dike is to build what is called a foreshore levee.

Foreshore levee

ecosystem service	flood protection, water quality, recreation, Natura 2000, nature and biodiversity
specification	• dissipate wave energy • capture silt to allow growth with rising water level • focus design on Natura 2000 species
system	freshwater
organisms	shoreline vegetation
location	Markermeer between Hoorn and Amsterdam
status	design phase

A foreshore levee is a slightly inclined body of soil that is placed against the outside of an existing dike. This creates a gradual shoreline on the border of land and water, which dissipates wave energy. The foreshore levee is so high and wide that it guarantees protection and fulfils the function of the existing dike. Therefore the latter does not need to be reinforced, and barely any measures need to be taken inside the existing dike. The built-up area is hardly disturbed. The shoreline's shallow areas and inclines also provide a habitat for various plants and animals. They are ideal migration zones for species such as grass snakes, and provide nesting areas and shelter for birds. An additional advantage is the positive effect on water quality as the silt settles both in the new shoreline and in the sand pits that were dug for the construction of the foreshore levee.

Implementation

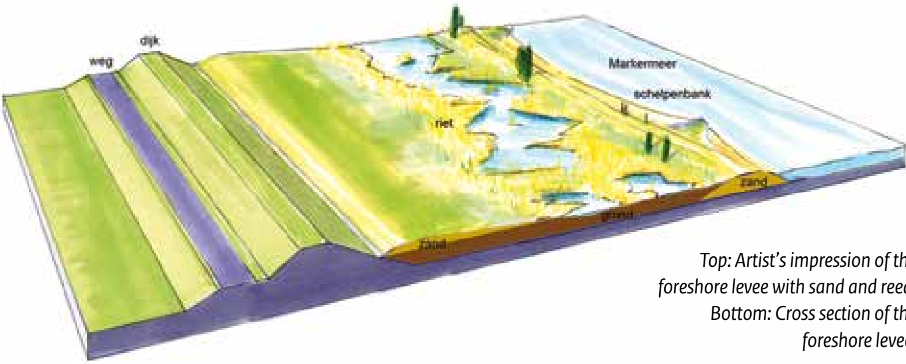
Different versions of the foreshore levee can be implemented:

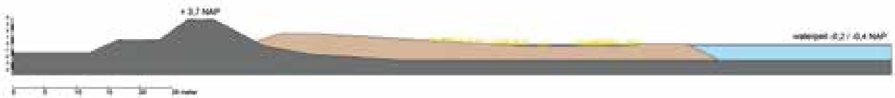
1. A foreshore levee with a large body of sand that remains stable due to the erosion and sedimentation of material.
2. A foreshore levee with sand and reed, in which the reed is protected by a foreshore defence.

The latter is the best ecological alternative. It is an interesting option for certain approaches, including one that incorporates recreational uses.

Results

The foreshore levee was added to the planning study for the reinforcement of the dike of the Markermeer. This variant was further elaborated in 2011, so that it can be tested by means of an environmental impact study.





Top: Artist's impression of the foreshore levee with sand and reed. Bottom: Cross section of the foreshore levee.

A foreshore levee requires intensive monitoring. In particular, settlement, erosion and use need to be carefully monitored.

Costs and benefits

A foreshore levee is likely to be more cost effective than the usual solution. How much more depends on the price of sand and soil. A foreshore levee could cost 30% less at a unit price of €9 per cubic metre. The savings are mostly gained during construction: the management and maintenance of a foreshore levee are expected to be more expensive. Other benefits include:

- Greater dike stability, reducing the likelihood of it weakening due to internal erosion.
- Greater natural value thanks to gradual transitions from land to water, such as from shallow protected water to reedland, marshy woodland and higher grassland. These areas are spawning areas for fish, breeding grounds and foraging areas for birds, and ecological corridors. This contributes to the objectives set out in the European Water Framework Directive and Natura 2000.
- Increase the landscape and recreational values.
- The construction takes place from the water, thereby avoiding the disturbance and damage inflicted by transport across land and by activity on the existing dikes.

Other applications

A foreshore levee is a potential alternative for all places along lakes, where traditional dike strengthening is needed.

Partners

Rijkswaterstaat Flood Protection Programme, Director-General Space and Water, Province of North Holland, Deltares, Arcadis, Haskoning, Hollands Noorderkwartier District Water Board and Ecoshape.

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Marsh restoration 07

The expansive marsh areas along the coast of Louisiana in the United States are eroding at breakneck speed. Every year a marsh area the size of the municipality of The Hague (75 km²–85 km²) vanishes. The erosion has various causes. Since the damming of the Mississippi, the river no longer disposes of sediment along the coast, and more and more marshland is disappearing underwater. Channels also cut across the marshes in many places.

These channels, and the lack of freshwater discharge, give intruding saltwater free rein. Saltwater intrusion in areas that were originally freshwater kills freshwater vegetation and causes the development of large open areas. The wind and wave have free rein along the edges of these large areas of water, thus accelerating erosion. Marshes are economically invaluable to Louisiana. They are the foundation of the state's fishery and shellfish industry, one the most important economic activities in the area. Moreover, the marshes are a soft coastal defence around the most densely populated areas in the state, such as New Orleans. Without the ring of marshes, it would be extremely expensive to protect a city like New Orleans from the destructive tidal waves that accompany hurricanes. And finally, marshes also have great natural value: they attract tourists and are an important factor in capturing and storing CO_2.

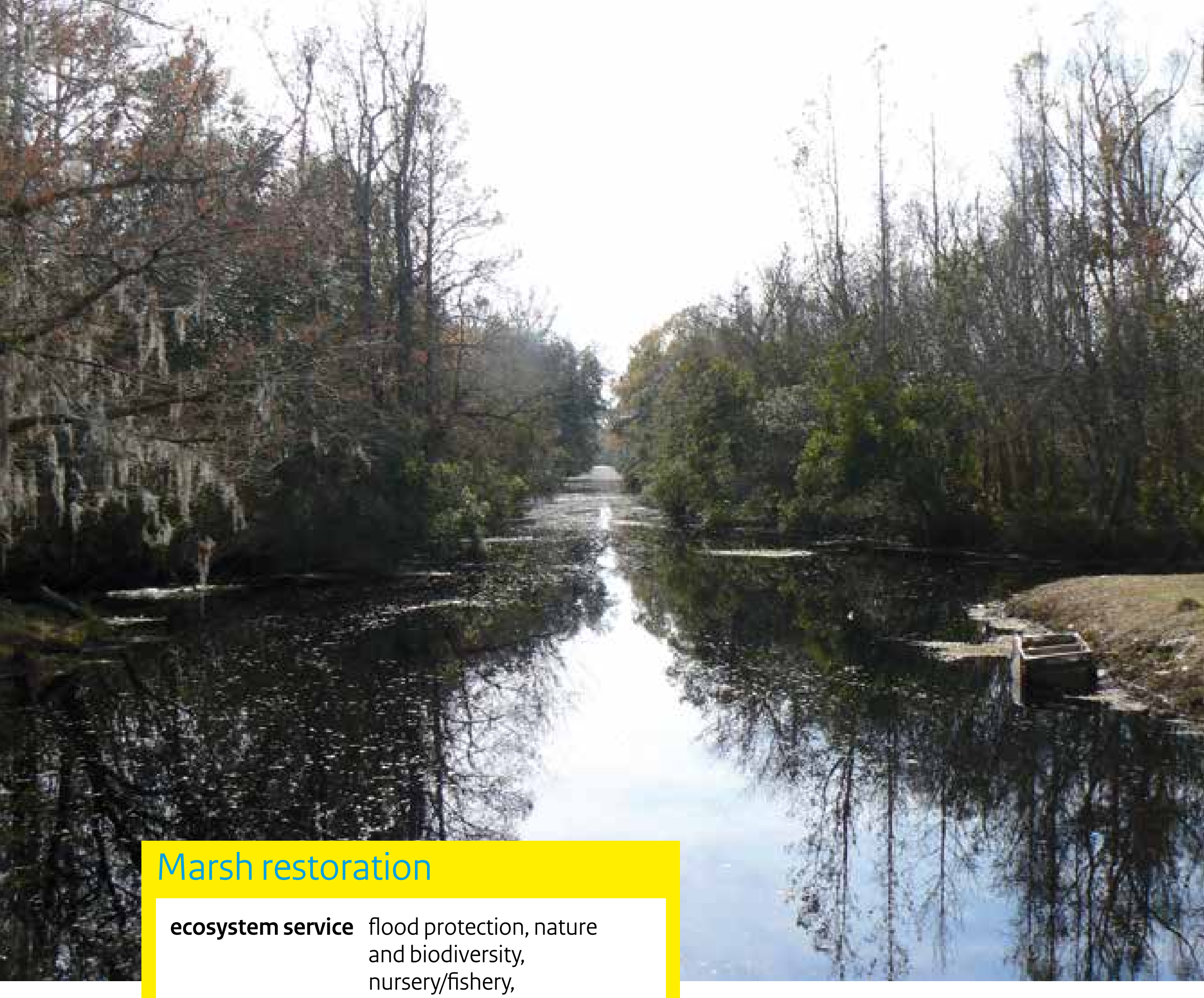
There are different techniques for restoring marshes, such as raising an area with dredged sediment. However, there are hardly any techniques that encourage the development of marshes in open water areas, which is where most erosion occurs. One potential technique is the temporary creation of an enclosed hydraulic engineering unit by damming the area. Water management in this type of units would focus on regenerating marsh vegetation and capturing sediment, or on developing peat.

Implementation

To create a temporary hydraulic engineering unit, parts of the open water have to be surrounded by a dike and drained. Draining land promotes the germination of seeds in the soil. As soon as vegetation has established itself, peat formation has to be set into motion. Soil saturated with water is needed for this. Peat formation and sedimentation cause the low-lying polder to grow naturally again. How quickly this process occurs under specific local conditions is unknown, but in more moderate climates peat forms at a rate of seven centimetres per year. Within 10 years peat deposits should emerge that are thick enough to float independently. Subsequently the water level can slowly be raised again, so that the peat deposit will float and reach the same height as the floating marshes surrounding it. Then the dike can be broken down in stages, and the marsh can be reconnected with its environment. Aids such as floating mats made of willow shoots or other natural materials can help fill the holes more quickly.

Results

This special technique may be tested in a pilot project near New Orleans. To gain broad support for the idea and the pilot



Marsh restoration

ecosystem service	flood protection, nature and biodiversity, nursery/fishery, food, recreation
specification	• restore marsh for coastal protection • reduce erosion of marsh • preserve nursery function
system	freshwater
organisms	marsh vegetation
location	Yankee Pond, to the south-west of New Orleans
status	stakeholder participation

project, the parties involved are working intensively with nature conservation organizations, the estate manager and authorities on a bottom-up participation process. The Jean Lafitte National Historical Park and Reserve chose a location for the pilot project: a lake no more than one and a half metres deep, where there used to be a peat bog enclosed by a dike used for agricultural purposes. As a result of drainage, this peat bog settled, and the land was abandoned. The lake was created when the small dikes burst. The rest of the old dikes can still be seen along the edges of the lake. The pilot project has not started yet, because funding for the implementation has not been secured yet. ▶

Costs and benefits

Restoring the marsh and encouraging its development by enclosing it with a dike is an affordable option, certainly compared to the ongoing initiatives for the restoration of the marsh, which are having limited success. Moreover, this technique can be used in large open-water areas. The initial investment is relatively high for Louisiana, partly because it concerns such a large area. In addition it will take years for a layer of peat to develop naturally, and the process needs to be managed and monitored.
The marsh areas are so important for the economy and for hurricane protection, that a cost–benefit analysis would surely show the restoration and protection of these areas to be a favourable solution.

Other applications

A good example of marsh development through reclamation and an enclosing dike

are the Oostvaardersplassen in the Netherlands. A rich marsh area developed here following reclamation. This principle can probably be used elsewhere for other types of marshland. Further, on a smaller scale, holes in the marsh in Louisiana are being filled with floating mats. Until now, these mats have been largely made from artificial materials, but they can be made from natural mate rials that are available locally as well.

Partners

Rijkswaterstaat Water Service, Deltares, Imares, DHV, EVD, and US Army Corps of Engineers.

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Soft Sand Engine

08

Plans are underway to raise the water level of the IJsselmeer and reinforce the dikes along its shoreline. Raising the dikes means interfering with the area's landscape and cultural qualities. An overgrown area outside the dike, a 'foreland', could provide a solution here, because a foreland dissipates wave energy and creates a protective buffer for the dike. This reduces dike maintenance and makes it more solid when water levels are high, as a result of which the dike will need to be adapted less often.

Forelands also function as breeding grounds for birds, and recreational users can enjoy the nature outside the breeding season. The forelands grow along with the rising water level, providing there is a sufficient supply of sediment. To create or maintain forelands, sand is deposited in strategic places along the coast (nourishment). The waves and currents subsequently spread the sand. The sand will be moved less quickly here than in open sea, as is the case with the Sand Engine on the Holland coast (see project 1 on page 10). That is why we call this one a soft Sand Engine. In the summer of 2011 sand was deposited at the Workumerwaard foreland. A pilot project is also being prepared along the coast at Oudemirdum. These pilot projects are part of the Natural Climate Buffers and Building with Nature (IJsselmeer case study) programmes.

Implementation

The first pilot project was conducted in the Workumerwaard nature reserve in the province of Friesland, not far to the south of the Afsluitdijk causeway. Along the edge of the expansive shallows in front of Workumerwaard, 25,000 m³ of sand was deposited, mostly from the IJsselmeer, in the form of an elongated sandbank. Waves, currents and – in the winter – floating ice carry this sand gradually to the coast. Perpendicular to the coast, a 500-metre-long row of poles was built that captures part of the sand and prevents it from flowing towards the Afsluitdijk. In Workumerwaard, planning and monitoring focuses on developing nature, while the emphasis in Oudemirdum is on protecting the coastal defence.

Results

The Soft Sand Engine at Workumerwaard was constructed in 2011. The spreading of sand is carefully monitored. Researchers determine the baseline on jet skis equipped with echo sounding and Differential GPS. This system uses radio stations on the ground to improve the positioning accuracy of the GPS. Until 2013, new soil maps were made twice a year to chart sand movements. In addition, a fibre-glass cable four kilometres long – resembling a snake on the bottom – is charting the distribution of sand. The turbidity of the water and direction of the current are measured, and the development of vegetation is mapped from a helicopter. The researchers monitor the ecological impact by periodically taking samples of the flora and fauna in a number of fixed areas.

Costs and benefits

The costs of this project have not been specified. Compared to alternative interventions, this Sand Engine is the most environmentally friendly. Reinforcing the dikes, besides inflicting damage to the landscape and cultivation, also leads to the

Soft Sand Engine

ecosystem service	flood protection, nature and biodiversity, recreation
specification	• dissipate wave energy • raise the land outside the dike • preserve unique freshwater habitats
system	freshwater
organisms	pioneer vegetation
location	IJsselmeer, Workumerwaard, Oudemirdumerklif
status	pilot
construction	2011-2012

loss of shore areas outside the dike. Directly raising the dike with sand gives the ecosystems insufficient time to adapt.

Other applications

The principle of allowing wave-attenuating forelands to grow by adding sediment is also applicable in saltwater and along rivers. However, the use of forelands does require space between the deep channels and the water defences.

Partners

Province of Fryslân, Wetterskip Fryslân, It Fryske Gea, Climate Buffer Coalition, Responsible Management Foundation IJsselmeer, EcoShape, Deltares, Arcadis and Alterra.

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Eco-concrete

09

Much marine life, such as mussels, barnacles and seaweed, need a hard surface to survive. In the Netherlands, they find this surface on hydraulic engineering constructions, such as harbour piers and seawalls. But modern concrete is becoming increasingly smooth and therefore less suitable for these organisms to establish themselves. The use of special 'eco-concrete' during the construction or renovation of hydraulic engineering structures appears to significantly speed up the process by which these species establish themselves and their diversity.

This is especially important in areas that take Natura 2000 species into account, where the rapid return of these species can speed up work. Eco-concrete is concrete with a special texture and geometric shapes that enable organisms such as algae, seaweed, periwinkles and mussels to attach themselves more easily. These organisms, in turn, are a source of food for birds and fish. And mosquito larvae, which live among the algae, are a source of food for protected bird species such as the ruddy turnstone and the purple sandpiper.

Implementation

Slabs of eco-concrete with different structures, such as horizontal and vertical ridges, hollows and holes, were used in the pilot project at Zuiderhavenpier in IJmuiden. Tests were conducted to assess the impact of these structures on the speed of colonization and the ultimate biomass of algae, mussels and periwinkles. 'Eco-Xblocks' were also used, which are craggy concrete blocks with a rough surface that resemble natural rocks.

Results

The use of eco-concrete in sea defences provides the same protection as 'regular' concrete. A first pilot project with eco-concrete was started in 2008. After two years of monitoring, the pilot project was successfully completed, and in principle eco-concrete was deemed a success.
The rough surface of the eco-concrete with a rough surface became overgrown with algae much more quickly than smooth concrete. Within two and a half years, mussels and periwinkles barely established themselves on smooth structures but did on eco-concrete slabs with macro-structures such as grooves, recesses and holes, where water lingers longer during ebb tide. The success of the pilot project led to the large-scale production in 2011 of concrete blocks with macro-structures for IJmuiden's harbour piers.

Costs and benefits

The production of concrete with special textures and geometric shapes is expected to cost 2% to 3% more than the production of traditional 'smooth' concrete. However, there are many benefits that outweigh these marginally higher costs. The use of eco-concrete encourages various marine flora and fauna to establish themselves, and after renovations species appear to return more quickly. These species are a source of food for birds and therefore marine life. Eco-concrete can speed up save money on replacement work, which has to take these species into account. In addition, eco-concrete could be used as a mitigating measure for negative effects on Natura 2000 objectives. And finally, eco-concrete improves water quality because more

Eco-concrete

ecosystem service	Natura 2000, water quality, nursery/fishery, nature and biodiversity
specification	• encourage colonization by algae and larvae • algae and larvae attract fish • increase filtering capacity of water
system	freshwater/intertidal zone
organisms	algae, seaweed, mosquito larvae, birds (ruddy turnstones and sandpipers), mussels, periwinkles
location	Zuiderhavenpier IJmuiden
status	application
construction	2008 and 2011

mussels establish themselves. Mussels filter water, making it cleaner and clearer.

Other applications

- Eco-concrete can be used along the coast when hard coastal defence structures, such as piers and breakwaters, are constructed or renovated, or when existing structures are raised.
- Eco-concrete can be used along rivers and lakes when solid structures, such as groynes, banks and breakwaters, are constructed or renovated.
- Eco-concrete can be used along regional water courses when solid defence structures along water storage areas and streams are constructed or renovated.

Partners

Rijkswaterstaat Water Service, Rijkswaterstaat Board North Holland, Deltares, BAM-DMC, Microbeton and Ecoconsult.

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Tidal pools

10

Solid constructions along the coast, such as dikes, harbour piers and dams, are the habitat of various marine species. Many of them live exclusively in places that are continuously underwater. By making simple and inexpensive adjustments to solid structures, water in higher parts of the intertidal zone will linger longer. This can be a huge boost to biodiversity and biomass and can be used as a mitigating measure for Natura 2000 objectives.

In order to achieve this, small pools can be built at the base of dikes. These dikes thus have added value for marine species, without endangering the primary function of flood protection. The shape, height, design and placement of the pools affect which species will eventually establish themselves there.

Implementation

In 2008, a number of small pools were developed along the Eastern Scheldt near Yerseke in the toe of the dike. These pools were a few metres to 15 metres long and were filled with different-size rocks. As a result, good living environments were created in these places for various marine species. A second project followed in 2010 between Wemeldinge and Kattendijke, where large pools (15 x 150 metres) were built. These pools were lined with concrete to make them waterproof so that water would remain during ebb tide. By filling the pools with different kinds of rock, such as lava rock, there is sufficient substratum for algae and other organisms to attach themselves, and it simultaneously provides sheltering opportunities for macrobenthos and juvenile fish.

Results

Monitoring revealed that significantly more species are found in the pools than in the rocks around them. Different seaweeds grow there, and there are also different kinds of sponges and ascidians. The biodiversity in the pools are approximately three times greater than in the standard situation without pools. Juvenile fish and the common prawn also like to stay there. To prevent them from falling prey to foraging birds during low tide, there have to be sufficient sheltering options, for example rocks. The pools probably have a positive effect on the surrounding ecosystems as well.

Costs and benefits

The toe of a 'regular' dike about five metres wide costs about €100 per linear metre.
In the pilot project the toe of a dike with tidal pools costs about €400 per linear metre.
This higher price is primarily due to the cost of making the pools waterproof. This can be done less expensively by developing a better method, or perhaps by including the pools in their entirety in the assignment. The pools do not have any management costs.
The overall conclusion is that the accompanying costs for the construction of these kinds of small pools are marginal compared to the total costs of constructing or renovating a dike. Various benefits outweigh the costs:

- The organisms present in the tidal pools are a source of food for birds (including species on the Red List) and other marine life.
- 'Rich' dikes increase the recreational and educational value of the area.
- Opportunities are being created for nature compensation and mitigation.

Tidal pools

ecosystem service	nature and biodiversity, nursery/fishery, recreation, Natura 2000
specification	• establishment opportunities in the toe of the dike • good measure as mitigation under Natura 2000 • shelter for juvenile fish
system	saltwater/base of dike
organisms	seaweeds, sponges, sea anemones, crabs, common prawn, juvenile fish
location	Eastern Scheldt dike
status	application
construction	2008 and 2010

Other applications

With a ‘rich’ dike, pools are created in solid structures to retain water during low tide. As a result, habitats are developed for various species that live in water.

This principle can be applied to the construction or renovation of solid hydraulic engineering constructions and is therefore mainly suitable in national waterways.

Partners

Rijkswaterstaat Sea Defence Project Office, Scheldestromen District Water Board, Ecoconsult and Deltares.

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▲ *Tidal pool*

Hanging structures

11

Ports are built to accommodate economic activities, such as shipping, industry and transport. You could say that there is little room for nature in this environment of steel and concrete constructions. Nevertheless, even here simple measures, such as introducing artificial substrate, could increase biological productivity and diversity.

If this substrate is then populated by shellfish that filters the water to gather food, known as filter feeders, then this can benefit water quality. The effects of several artificial substrate designs was examined in the Hanging Structures pilot project in the Port of Rotterdam. For that purpose, 'polehulas'– pieces of nylon rope resembling Hawaiian skirts – were attached to poles. Floating PVC structures , from which large amounts of rope hung down (pontoonhulas), like an upside-down underwater forest, were also placed in the port.

Implementation

Two types of structures were used for the pilot project:
1. Polehulas: approximately 300 nylon ropes 55 centimetres long with a diameter of 6 millimetres. These polehulas were tied around five wooden and two metal poles.
2. Pontoonhulas: floating constructions made of PVC and nylon nets, from which nylon ropes, hang down with a diameter of 12 millimetres. The size varied with each pontoon (two to three square metres), as did the number of ropes (40 to 200) and their length (20 to 150 centimetres).

Results

The pilot project and accompanying monitoring process have been completed. The pilot project revealed that the structures worked well and the biomass was increasingly rapidly. The nylon ropes were soon colonized by mussels, barnacles and various algae and other creatures. Within several months a single, one and a half metre-long hula rope produced two to three kilos of mussels. On average, 8.5 times more biomass attaches itself to polehulas than to a regular pole. The pontoonhulas are larger and provide space for about 350 kilos of mussels. Calculations suggest that 35 pontoonhulas per port basin would be enough for mussels to clean the entire volume of water in the Port of Rotterdam every month. The hula structures were removed in 2010. Some pontoonhulas were transported to Deltares, where the hulas' ability to dissipate wave energy was studied in the Delta Basin. Findings showed that hulas are effective wave-attenuating structures for dampening waves in ports.

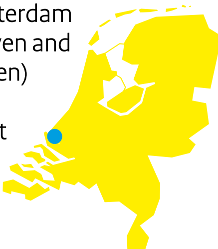
Costs and benefits

The construction costs are higher than in a traditional design, with no additional three-dimensional structures. The necessary material, however, is relatively inexpensive. The pilot project required more maintenance than expected because the structures became much heavier as a result of the unexpectedly large amounts of mussels. These costs can be kept down by optimizing the buoyancy. The structures have the following benefits:

- Improved water quality. The mussels' filtering capacity reduces the amount of organic and inorganic material in the water,

Hanging structures

ecosystem service	nature and biodiversity, water quality, nursery/fishery, flood protection
specification	• filter water by means of mussels • increase biodiversity • provide shelter for fish • reduce wave strength
system	freshwater/port
organisms	mussels, seaweed, ascidians, sponges, eel, mullet
location	Port of Rotterdam (Scheurhaven and Pistoolhaven)
status	pilot project
construction	2007–2010



the water becomes clearer and more light penetrates through the water. Mussels can also remove toxic substances from the water.
- Increase biodiversity by constructing a new habitat.
- The port structures act as stepping stones to ecologically connect areas.
- Reduce growth on poles.
- Positive effect on fish stocks, as a result of shelter.
- According to pilot studies, pontoonhulas dissipate wave energy.

Other applications

- The hula structures from this pilot project are mainly applicable in national waterways. The concept can, if implemented on a smaller scale, also be effectively used in regional waters where mussels exist.
- The structures could be used at an international level. Plants such as seagrass and kelp in port structures could provide similar ecosystem services.

- Similar structures can also be designed for freshwater mussels. These can be used in inland harbours, recreational lakes and locks.
- Pontoonhulas are also suitable for dissipating wave energy. The structures could probably be used to protect banks from waves.

Partners

Deltares, Ecoconsult, Port of Rotterdam, Loodswezen, Smit bv and Van Oord.

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▲ *Overgrown pontoonhula rope*

Applications of eco-engineering: looking ahead

Incorporating ecosystems and their services into flood protection has attracted a great deal of interest in recent years. This short book presents eleven examples of eco-engineering concepts in action.

With help from nature, flood protection can be guaranteed in a cost-effective way. Moreover, the designs for these interventions offer other services as well, such as improving water quality, achieving nature conservation objectives and creating a pleasant environment to live in and use for recreational purposes.
The surplus of water in the Netherlands provides many more opportunities for eco-engineering than described here.
The time is right for us to start building with and for nature on project and landscape scales. Successfully applying eco-engineering concepts depends on good cooperation between government, the business community and the knowledge sector: the 'golden triangle'. The government needs the business community and the knowledge sector to develop and deliver products and services. Conversely, businesses and knowledge institutes need the government to buy innovative products and services.
It was this notion that prompted the Association of Regional Water Authorities, Rijkswaterstaat and EcoShape to sign a covenant on 4 October 2011 to promote the application of eco-engineering principles and building with nature in flood risk management. Building with nature is also a case study within the 'top sector' of water at the Ministry of Economic Affairs, Agriculture and Innovation. Thus the Dutch government is underscoring the importance of this subject. For the structural implementation of eco-engineering solutions in hydraulic

engineering projects, it is important that – in addition to the scientific basis that has now been laid – there is process innovation. For example, by adapting asset management, making uniform the sustainable procurement policy and making a uniform sustainable for flood protection. The parties want to facilitate the implementation and started to do so by setting up a guideline in 2012 for the application of eco-engineering. Distilling generic principles and rules, however, still requires considerable effort, and for now every new project that uses eco-engineering provides new knowledge and insights. Indeed, traditional engineering expertise remains subject to change. In the short term, experience is being gained in the field during implementation processes in projects such as Oesterdam Protection Buffer and Sandy Solution of the Hondsbossche and Pettemer Sea Defences. The government, business community and knowledge institutes can apply the knowledge they have gained both in the Netherlands and abroad.

If reading this book has aroused your interest in one of the solutions, or if you see an opportunity to use eco-engineering in your field, then please contact: innovatie@rws.nl or international@deltares.nl completely free of obligation so that we can work together towards a safe and natural world.

Rijkswaterstaat
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Colophon

With the cooperation of

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