Development of the Sand Motor

Concise report describing the first four years of the Monitoring and Evaluation Programme (MEP





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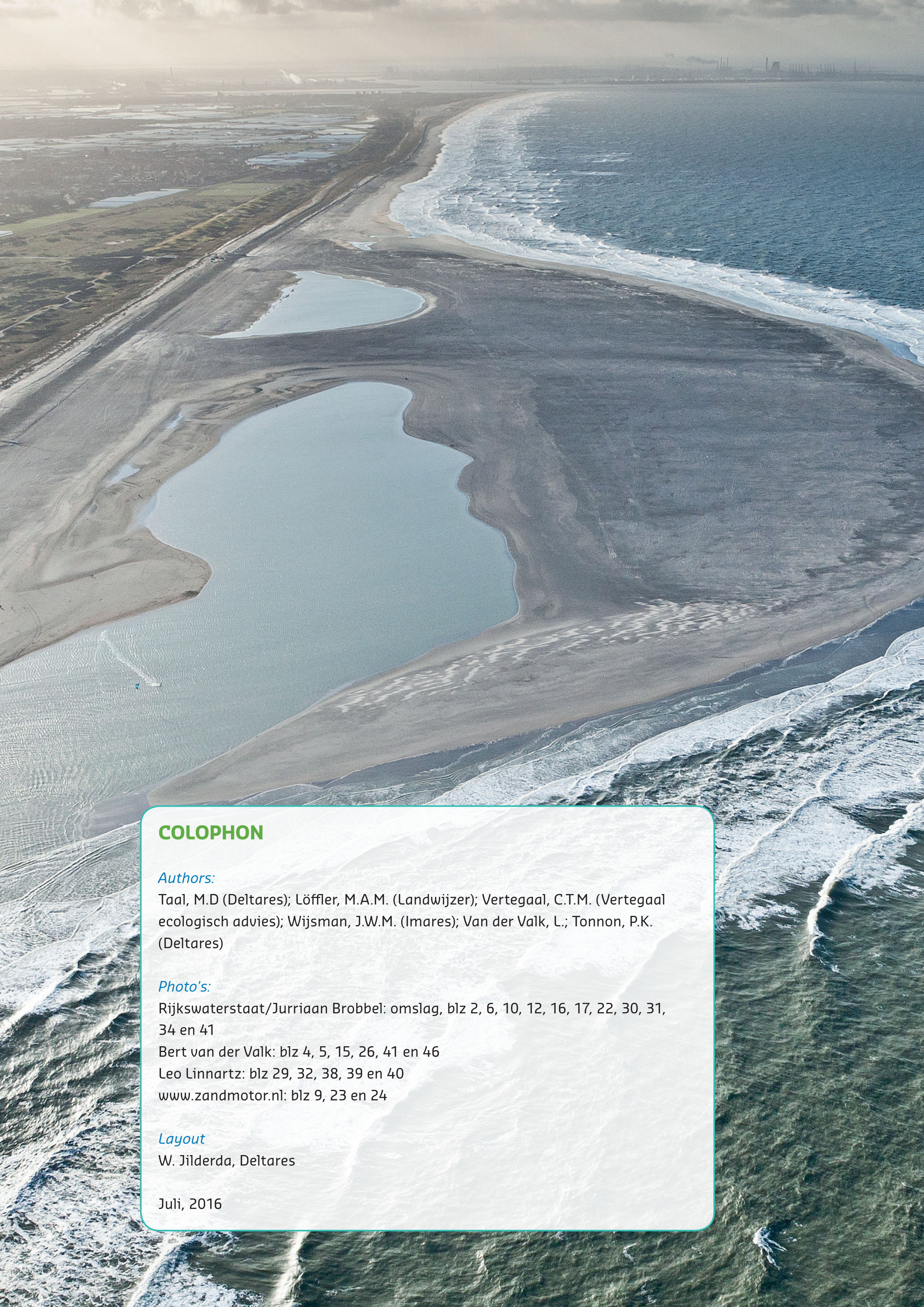

COLOPHON

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Development of the Sand Motor

Concise report describing the first four years of the Monitoring and Evaluation Programme (MEP)

Deltares
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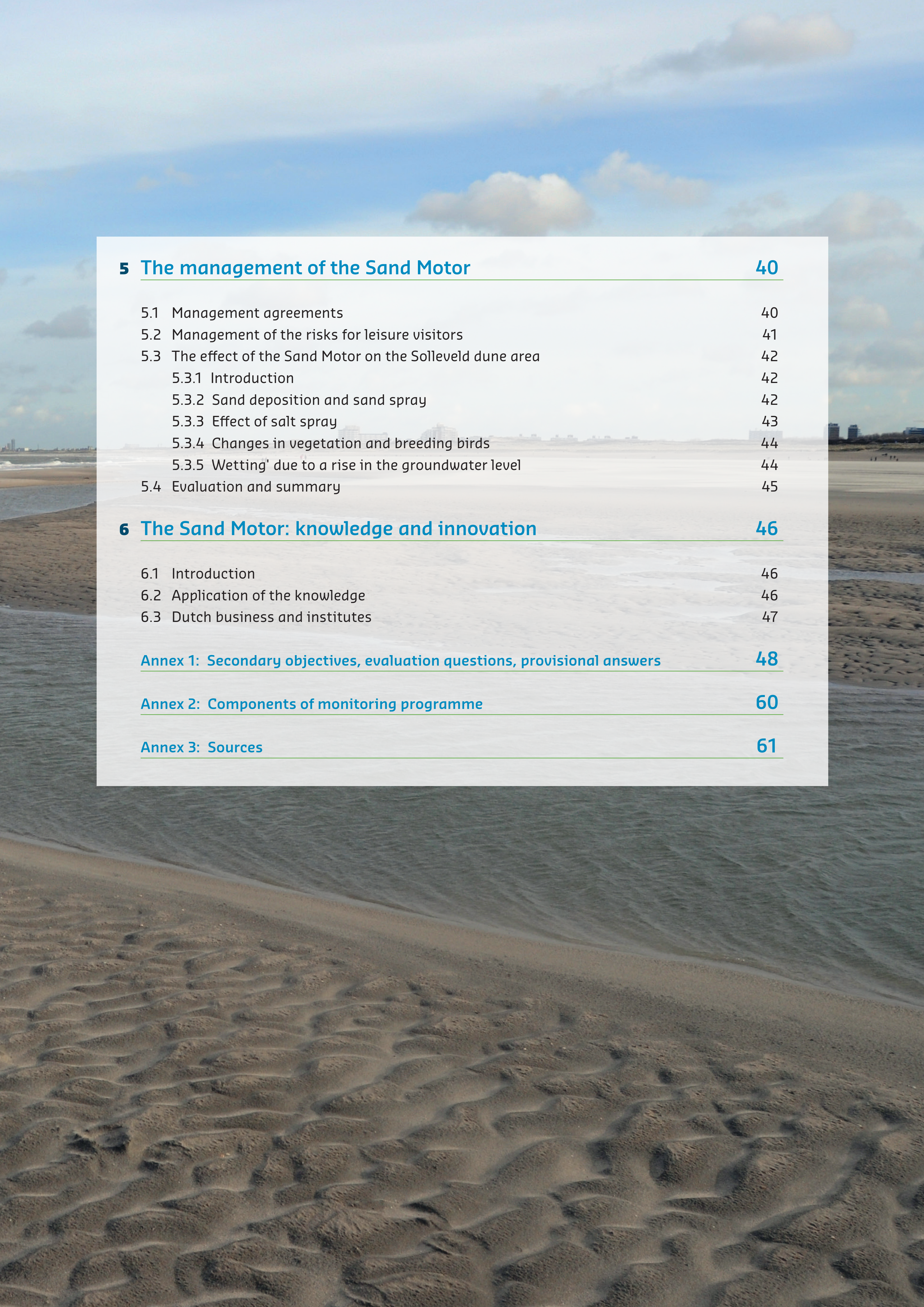


Summary

Introduction

The Sand Motor on the Delfland Coast was created in 2011 as a peninsula covering 128 hectares. It is an innovative pilot project for coastline management intended to contribute to coastal protection in the long term. The intention was also to create an additional appealing area for nature and leisure activities on the Delfland Coast and to boost current knowledge about coastline management. A monitoring programme has been conducted for the purposes of knowledge development and in order to evaluate whether the objectives have been met. This report is a summary of the reports published in the Monitoring and Evaluation Programme (MEP). It provides a broad description of the results, five years after construction, on the basis of four years of monitoring. More information can be found in the underlying, more detailed, reports in the MEP. The MEP reports provide the substantive basis for two other reports on the Sand Motor that were

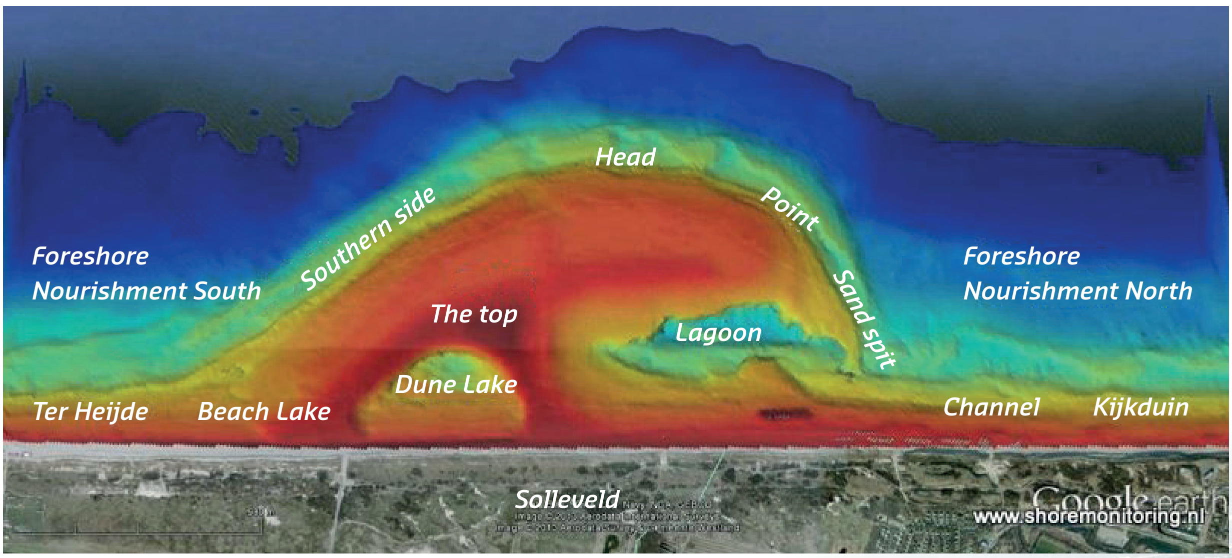


Figure 1: The Sand Motor with names of the different parts: source: Shore, 2013

published at the same time: the 'policy evaluation' and the 'usability study'.

Spread of sand and improved coastal protection
In the first year after construction, the Sand Motor changed shape faster than expected but in line with the expected pattern based on model calculations in the design phase. Changes after that were slower than expected. The sand body extends about 260 meters (a maximum of 350 metres at the Head of the Sand Motor) less into the sea than when it was created in 2011. At the same time, the area where the coast has been extended seaward became 2.2 kilometres longer. After four years, 95% of the sand used for the Sand Motor is still in the monitoring area and 80% of that sand is still within the contours of the sand body created in 2011. On this basis, it is legitimate to conclude that the lifetime of the Sand Motor will exceed twenty years.

Improving coastal protection

The Delfland Coast was safe after it was reinforced in 2010. The Sand Motor provides an additional positive effect. The lifetime of the coastal reinforcement will be extended in the immediate vicinity of the Sand Motor. Without a Sand Motor, regular coastline maintenance would be required. Regular nourishment operations for the maintenance of the Delfland Coast will therefore be needed less during the next twenty years, but probably even longer. This will obviously depend on the distance from the Sand Motor. The volume of sand used to create the Sand Motor corresponds almost exactly to what is needed for the maintenance of the coastal foundation between Hook of Holland and Scheveningen assuming sea-level rise of 3 mm/year over a period of fifty years (the volume of sand used was 18.7 million m^3 net, as opposed to the required 20 million m^3). The actual coastline has moved seaward at the location of the Sand Motor and immediately to the north and south.

A description is given below of the trends in the size of the primary sea-defence dunes after the coastal reinforcement. The reinforcement of the coast in 2010 meant that the defences now complied with the statutory requirement. In the morphological evaluation of the Sand Motor, protection is described on the basis of two variables: 'current dune volume' and 'position of the erosion point' (see section 3.2.3).

Both indicators have developed favourably in recent decades. The dunes between Hook of Holland and Scheveningen have been getting steadily higher and/or wider, mainly due to regular coastline maintenance activities. This process has continued since the construction of the Sand Motor but not as quickly in the monitoring area as before the construction of the Sand Motor. This can be explained to a large extent by the fact that the dune lake and the lagoon capture large amounts of drifting sand and delay dune growth. It is expected that the dunes will continue to grow and that this process will accelerate in the future, particularly once the lagoon and the dune lake have been filled up with sand.

New dynamic area for 'wet' nature

The Sand Motor, with natural features such as the 'sand spit' (the elongated sand shoal on the northern edge of the Sand Motor), rapidly-changing sand banks and the lagoon, is a unique feature on the coast of Holland between Hook of Holland and Den Helder. In terms of the ecology of the shallow sea and the intertidal areas, it is particularly important that there are now many more 'sheltered ecotopes'. There is more fine and nutrient-rich sediment in these locations, making richer benthic life possible. That has a positive impact on other species such as birds and fish.

Only species that can cope with dynamic conditions are found in the dynamic surf zone and the eroding head of the Sand Motor. In deeper water, where the waves have less effect on the sea-bed, diversity and the biomass of benthic fauna are increasing annually. The sheltered, shallow part of the lagoon and the edges around it are currently the most attractive areas for benthic fauna and birds. After four years, the deep part of the lagoon has few ecological values due to the limited exchange of water with the North Sea, and it still has almost no function for young fish any more.

Nature in dunes and dry beach

The area accounted for by new dunes is increasing slightly. Just under one hectare has been formed in the monitoring area. The new dunes are primarily located on the eastern edge of the Sand Motor near the foot of the coastal reinforcement built previously. Furthermore, there are a few small primary dunes on the south-western side of the Sand Motor. Alongside this hectare of new dunes, extra dune volume has been created by the capturing of sand and the raising of the outer slope of the primary sea-defence dunes. This is the area just inland from the actual Sand Motor. The new dune forms are highly dynamic and therefore extremely appealing in terms of the landscape. The fact that new dunes are developing only to a limited extent is probably attributable to:

- The initial situation after construction and the relative short period of four years since then. No dune forms were created initially and no marram grass was planted and so the process of dune formation was left entirely to natural forces. The process is therefore more natural, but slower.
- Intensive shared use. The formation of a new row of dunes in front of the old one is slowed down by traffic on the Sand Motor, particularly vehicles driven by supervisors and researchers. The cleaning of the beach by the city authority of The Hague also prevents dune formation.

The vegetation found on the Sand Motor consists of characteristic sand couch and marram. These habitats are subject to international commitments. Sea holly, a red-list variety, is growing in some locations. Between 2011 and 2015, almost forty species of bird were observed on more than isolated occasions on and around the Sand Motor. The black-headed gull is the most numerous species by far. Other species that have been seen regularly are the common gull, herring gull, grebe and great cormorant. Five species of wader have

The Sand Motor on 16 February 2016, with the breach – one month old at the time – near the lagoon.

been seen. Until now, no birds have been seen nesting on the Sand Motor. As a result of the small number of counts, little can be said about the significance of the Sand Motor for marine mammals such as seals.

During the construction of the Sand Motor, a research question was whether a one-off major nourishment operation would be better for the ecology than several small operations. It is not yet possible to provide an answer to that question because the period of four years since the construction of the Sand Motor is still less than the interval between standard nourishment operations. It will become clear during the coming monitoring period whether or not species that live longer will be able to develop in areas where small layers of sand are deposited regularly due to natural dynamics but that are not covered by thick layers as in standard nourishment operations.

Room for leisure activities

The Sand Motor has clearly resulted in an area with opportunities for leisure activities that was not available previously on the coast of Holland between Hook of Holland and Den Helder. The first leisure study conducted after the construction of the Sand Motor shows that the four main leisure groups are bathers, dog walkers, ramblers and surfers (of all varieties: kite, wave and wind). In conjunction with a range of outdoor activities such as horse-riding, fishing and running, this means that there are more recreational activities on the

beach between Ter Heijde and Kijkduin than before the construction of the Sand Motor.
The general public visiting the area is increasingly familiar with all the different aspects of the Sand Motor. During and immediately after construction, attitudes were slightly critical. An increasingly large group now approves of the Sand Motor and the project enjoys widespread support.

Safety for leisure visitors

No safety problems for leisure visitors arose that could not be managed. Since 2013, lifeguards have been using a smartphone application that provides a picture of potentially hazardous bathing situations (the bathing water safety model). The monitoring programme provides information about the seabed that is essential as input for this model.
The evaluation of the 2014 bathing season indicates that the organisation of safety on the beach and for bathers is satisfactory but that further optimisation is possible. Optimisation measures are introduced every year on the basis of the evaluation of the previous year. The recommendations of the team working on safety include projections of changes in the Sand Motor. Because the tidal channel has become increasingly meandering, the risk of bathers being dragged out to sea directly has declined.

Impact on Solleveld

The construction of the Sand Motor led to the creation of a bare sand flat seaward of the existing Solleveld dune area. This meant that there were concerns prior to construction about the possible negative effect on the Solleveld ecological values. The amount of sand blowing into the outer Solleveld dunes would appear to have increased slightly. However, in absolute terms, the amount of sand being blown to Solleveld remains limited. A lot of sand is deposited on the outer slope of the coastal reinforcement, where the sand dynamics have increased considerably.
The amount of salt spray has fallen but this would not seem to have had any effect for the time being. There are no signs that birds have been affected. Monitoring has not identified any effects of the rise in the level of groundwater ('wetting') on the locations sensitive to this phenomenon.

Knowledge development and innovation

A major, long-term, knowledge development programme was established in conjunction with the Sand Motor. Dozens of researchers from a range of universities and research institutes have been monitoring every detail of the development of Sand Motor. The programme is generating new knowledge that can be used for coastline management, for example with respect to the impact of a major nourishment operation on morphology, leisure activities and the ecology. Some of the knowledge development is already being actively used, an example being the app developed for bather safety.
Finally, the Sand Motor pilot project is also explicitly intended to provide businesses and research institutes with the opportunity to acquire knowledge and experience in the area of innovative coastline maintenance. The knowledge developed is passed on to institutes, government authorities and businesses engaged in hydraulic engineering, and it is already being used in other areas.

Effect on water-based infrastructure

The available monitoring results contain no data about effects on the entrance channels leading to the ports of Rotterdam and Scheveningen, or about effects on the outlet of the J.J.J.M. van den Burg pumping station.

01. Introduction

1.1 Background to the Sand Motor

A peninsula measuring 128 hectares was created on the coastline between Ter Heijde and The Hague in 2011: the Delfland Coast Sand Motor. The hook-shaped peninsula was made by depositing sand and it included a dune lake at the foot and a lagoon between the spur of the hook and the existing coast. At the same time, two sand nourishment operations were conducted on either side of the Sand Motor (see Figure 1). The Provincial Authority of South Holland and the 'Zuid-Hollands Landschap' Foundation are jointly responsible for management.

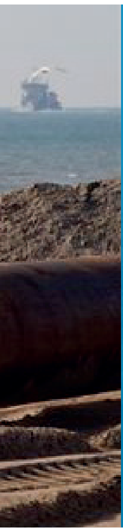
The Sand Motor is a pilot project for an innovative approach to coastal protection and coastline maintenance that involves using nature to provide protection from the sea and to create a temporary area for nature and leisure activities. Wind, waves and the currents spread the sand from the Sand Motor along the Delfland coast, creating additional protection from the sea. The following three objectives were formulated for the Sand Motor:

- The encouragement of natural dune growth on the Delfland Coast between Hook of Holland and Scheveningen. This dune growth will benefit coastal protection, nature and leisure activities.
- Knowledge development and innovation with the aim of determining the extent to which coastline maintenance and added value for leisure and nature can be achieved in conjunction.
- Creating an appealing leisure and nature area on the Delfland Coast.

The fourth objective requiring evaluation is 'the proper management of the Sand Motor and the surrounding area'. This objective relates mainly to safety for leisure visitors and ensuring that the Sand Motor does not have any undesirable effects on ecological values in the existing dune area.

Monitoring

Mega-nourishment operations, including those in which new land is temporarily created, as in the case of the Sand Motor, are an appropriate component of the coastline management of the future. To determine whether the four objectives referred to here have been achieved and in order to make knowledge development possible, a Monitoring and Evaluation Plan was drafted during the preparations for the Sand Motor (MEP, see sources, no. 1). It sets out three monitoring objectives:



You are reading the evaluation of the Sand Motor based on the results of the monitoring and evaluation programme (MEP) and other observations.
The introduction describes the background to this document, how it relates to other evaluations and the structure of this document.

- Research to determine whether the stated objectives from the EIA for the Construction of the Delfland Coast Sand Motor have been achieved. The objectives were accordingly broken down into secondary objectives in the MEP (see Annex 1).
- The collection of sufficient accurate information so that the Sand Motor can be managed properly. These objectives have also been broken down into secondary objectives (see Annex 1).
- Compliance with the permit conditions relating to the delivery of monitoring data.

The MEP was further elaborated in 2011 to produce an implementation programme (see sources, no. 2) formulating the abstract objectives and management objectives as specific and concrete evaluation questions (see Annex 1) and hypotheses. Monitoring programmes were drawn up for the following themes:

- General weather and sea conditions and hydrodynamics (including wave and current measurements). The acquired data have been used as a basis for other studies and to safeguard bather safety.
- Morphology of beach and foreshore (including measurements of bathymetry and sediment composition).
- Ecology of beach and foreshore (including composition and numbers of benthic fauna and bird counts).
- Nature and dunes (including monitoring of sand dynamics, geomorphology, sand deposition, salt spray, habitats, vegetation and birds/breeding birds).
- Leisure (visitor counts and surveys for the Provincial Authority of South Holland).
- Groundwater (as part of the Sand Motor/Solleveld pilot project agreement between the Provincial Authority of South Holland and Dunea).

It was possible to make the MEP more ambitious due to a subsidy from the European Regional Development Fund (ERDF) and to conduct more monitoring of a more scientific nature. A subsidy from the STW Technology Foundation facilitated the appointment of a group of 12 doctorate students and 3 post-doctorate staff to the NatureCoast project. They are also conducting additional monitoring of the Sand Motor that is not covered by the MEP. This area will be discussed further in Chapter 6.
In the meantime, many reports have been produced about the Sand Motor and the developments there. They can be downloaded from: *www.dezandmotor.nl*.

1.2 This document

This final MEP report is both a narrative description of how the Sand Motor works and a substantive evaluation of the Sand Motor. It is based on the monitoring results collected through to late 2015 and it provides, where possible, answers to the evaluation questions in the MEP. Outline descriptions will be given of the changes that have occurred. For more detailed information about the parameters monitored and the results, the reader is referred to the underlying detailed monitoring and evaluation reports (see Annex 3). It should be pointed out emphatically that this is factual information: no assessment is given of whether the developments as a whole are positive or not.

This report is linked to the other reports about the Sand Motor that appeared in the spring of 2016.

- The 'usability study' focuses on the evaluation of the current Sand Motor pilot project (and its building blocks) in a comparison with standard coastline management activities. It also includes a review of existing and desirable functions on the Dutch coast that serves as a basis for the description of opportunities to use the Sand Motor concept elsewhere on the Dutch coast (see sources, no. 4).

- The 'policy evaluation' sets out a final assessment of the degree to which the Sand Motor contributes to the stated policy objectives: flood risk management, added value for nature and leisure activities, and knowledge development in these areas. The policy evaluation also looks at collaboration and context management relating to the Sand Motor (see sources, no. 5).

- 'Framework for development of sandy strategies' (see sources, no. 6). This study was conducted for Ecoshape. It produced a framework for the development of large-scale sandy strategies. That framework was then tested to determine feasibility by applying it fictively to a situation in Jamaica and on the Delfland Coast before the Sand Motor. Ecoshape was established to further develop the concept of 'Building with Nature' and to implement it in practice.

1.3 Document guide

This report is structured as follows:

- Chapter 2 describes the background to the Sand Motor.
- Chapter 3 contains information about the significance of the Sand Motor for coastal protection.
- Chapter 4 looks at the significance of the Sand Motor until now for nature and leisure.
- Chapter 5 describes the management of the Sand Motor. This also includes the impact of the Sand Motor on the existing Solleveld dune area.
- Chapter 6 focuses on the significance of the Sand Motor for knowledge and innovation.

02. Background to the Sand Motor

2.1 'No Netherlands without sand'

The Dutch coast is made of sediment: particularly sand, but also clay, and peat in places. The accretion or erosion of the coast is determined by the balance between the amount of sediment available in the coastal zone (the supply) and the amount of sand required to maintain the equilibrium of the system (the demand). This 'demand' depends on changes in the sea level and on locations where the sand can settle. If the supply of sediment exceeds demand, coastal accretion will be the result: sand shoals will extend and the coastline will move seaward. If less sand is available, the coastline, ebb-tidal deltas, sand shoals and/or gullies will erode.

The natural supply of sand to our coastal zone stopped more than a thousand years ago. This was the result of a number of factors, one being that – as a result of all sorts of human interventions in the catchment area in recent centuries – the rivers now transport only small amounts of sand to the Dutch coast. Furthermore, almost no extra sand is brought in from the sea to the coast because sea-level rise means that the seabed has become deeper. The waves cannot therefore pick up as much sand any more. Another factor is that more sand is needed to compensate for land subsidence resulting from, for example, gas extraction and peatland settlement. The sandy coastal system therefore loses sediment on balance when there is relative sea-level rise and so the natural pattern is for the coastline to erode.

In the Wadden area and in the Eastern Scheldt, for example, the sandy system is not in equilibrium due to the closing off of the Zuiderzee, the Lauwerszee and partial closure as a result of the construction of the Eastern Scheldt barrier. These developments sharply reduce the amount of water flowing in and out during each tidal cycle and the channels became, as it were, too 'roomy'. In order to establish a new equilibrium, the channels attract sand: they suffer from 'sand hunger'. Near the Wadden area, these developments take sand from along the North Sea coast, the ends of the nearby islands and from the ebb-tidal deltas.

The first part of this chapter will look at coastal policy and management, and the role of sand. Different types of sand nourishment, including the Sand Motor as a mega-nourishment pilot project, will be examined.
The second part of this chapter zooms in on the Delfland Coast and on the construction of the Sand Motor on this stretch of the coast.

2.2 Policy for the Dutch coast

Thinking in terms of sediment stocks is central to Dutch coastal policy and management. This policy is set out in the National Water Plan (NWP), the Water Act and in the National Policy Strategy for Infrastructure and Spatial Planning (SVIR).
The main objective of the national coastal policy is the sustainable maintenance of protection for the hinterland against flooding from the sea. It involves three lines that are each intended to maintain safety levels in the hinterland on different time scales:

- Maintaining safe water defences in order to cope with high water levels and waves during storms;
- Maintaining the coastline (with the base coastline as the reference);
- Preserving the equilibrium of the coastal foundation in the context of relative sea-level rise. The coastal foundation is the area within which sand moves over a period of approximately 200 years. The limits of the coastal foundation are determined on the seaward side by the continuous NAP -20m line and on the landward side by the boundary between the dunes and the hinterland (the inner dune margin).

The three lines are interrelated as follows: to protect the hinterland from the sea, the dunes must be strong enough and contain adequate amounts of sand. It is important for there to be enough sand in the coastal zone that can be spread by the wind and sea across the surf zone, beaches and dunes. If there is enough sand in the coastal zone, the structural erosion of the coast will be prevented. Maintaining the equilibrium of the coastal foundation ensures that the Dutch coastal zone will, in the long term, rise with the sea level. Rijkswaterstaat conducts sand nourishment operations every year with this aim in mind. To stimulate natural behaviour, 'dynamic management' is used where possible for different sections of the coast. The effects of wind and sea are left undisturbed or even encouraged.

Working on safe water defences
Dams, dikes and dunes on the coast protect the hinterland from flooding. The Dutch Water Act sets out the safety standards for the dikes and dunes (the primary defences). The implication for the sandy coast is that there needs to be enough sand in the primary sea-defence dunes.
The defences are assessed every six years. Steps are taken when dikes or dunes fail to comply with

the safety requirements. The guiding principle is that these interventions should involve the use of sand as much as possible and hard infrastructure as little as possible ('soft when possible, hard when needed'). This is the best way in the long term to maintain the protection of the hinterland, coastal functions, dynamics and the natural processes in the coastal system.
In recent years, various water defences on the coast have been reinforced as part of the Flood Protection Programme. These 'Weak Links' emerged after an additional assessment in 2003 which showed that the impact of waves on the coast is higher than had been assumed previously. Upgrades were necessary to ensure that the defences complied with the statutory requirements again. However, the Weak Link programme has not prevented the structural erosion of the coast due to sand shortages.
This is the aim of the ‘Coastal Management and Maintenance’ programme (see below).

Coastal Management and Maintenance
In 1990, the government decided that the level of coastal erosion at the time was no longer acceptable and that sand nourishment was required to maintain the coastline in its present position. The base coastline (in broad terms, the coastline in 1990) was therefore adopted as the reference. Its location is stated as a minimum volume of sand that must be present in a particular stretch of coast. If there is a threat of a structural depletion of the base coastline, an assessment takes place to determine whether sand nourishment is necessary and desirable.

Maintaining the equilibrium of the coastal foundation
The policy was extended in 2001 to include the maintenance of the coastal foundation. Since then, the annual volume of sand nourishment has been set at 12 million m³, the amount needed to ensure that the entire Dutch coastal foundation 'grows' in line with the sea-level rise that occurred last century (18 cm /century). If the sea level rises faster in the future, the annual management volume may be increased.

2.3 Sand nourishment

Sand nourishment is an important way of implementing the coastal policy. The sand comes from the deeper areas of the North Sea (outside the coastal foundation and therefore where the water is deeper than 20 metres) and it is deposited so that local erosion of the coastline is tackled directly. The wind, waves and tide then spread the sand on the coastal foundation. Sand that drifts from the beach to the dunes helps to protect the function of the dunes as sea defences. A robust sandy system is therefore a stable basis for water defences in the long term.

Initially, sand nourishment operations consisted of depositing sand directly on the beach. Over the course of time, the sand has been deposited increasingly under water on the foreshore. This approach is much cheaper because it allows natural forces (in other words, waves and currents) to spread the sand in the direction of the beach. Sediment management was also extended to include nourishment on the sides of channels, not only to maintain sand stocks but also to stop the channels moving too far in a landward direction. The strength of innovations of this kind is that they

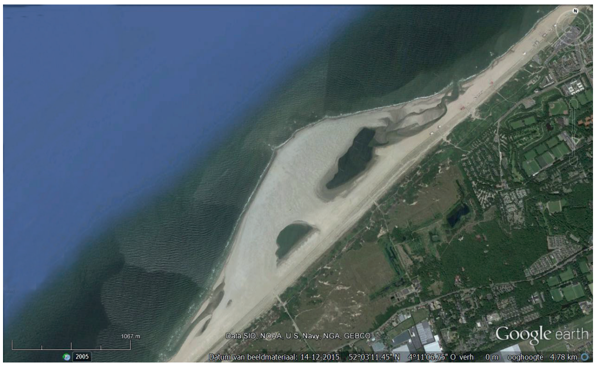


Figure 3. The Sand Motor from the air in about 2013. Source: Google Earth.

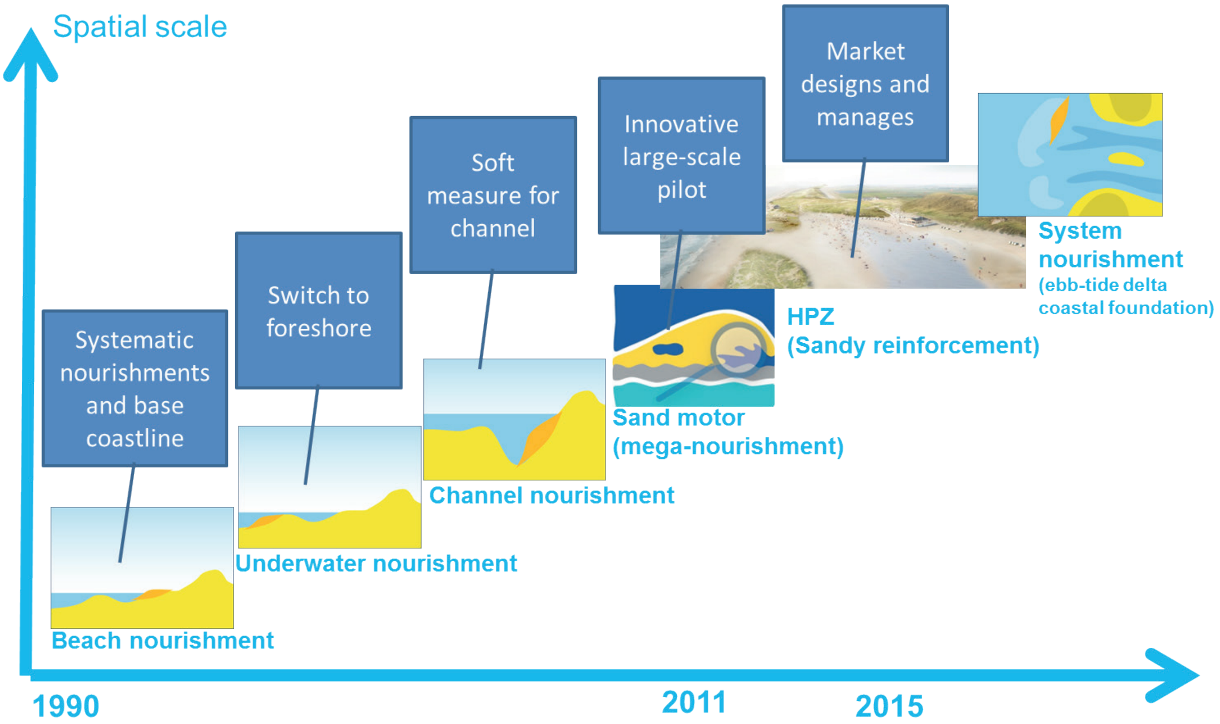


Figure 4: Several types of nourishment have been applied or explored at different spatial scales. The emphasis in 1990 was on beach nourishment but, in later years, sand has also been increasingly deposited on the foreshore. Channel nourishment was also introduced later. The Sand Motor was built in 2011 as a pilot project for mega-nourishment. Together, all the nourishment approaches contribute to maintaining the equilibrium of the coastal foundation.

preclude the need to deposit rock, an approach that is much less appropriate for a sandy system. Rijkswaterstaat is therefore always looking for the most efficient way of maintaining the coast. It was decided to explore the concept of 'mega-nourishment', which involves bringing in an excess volume of sand in a single operation. Wind, waves and currents then spread the sand along the coast over a longer period of time. The Sand Motor is a pilot project for this approach (see Figure 4).

The timing and amounts selected for nourishment depend on an appraisal of the costs and benefits and the characteristics (particularly morphological) of the area (see figure 4). Bringing in an excess volume of sand is, on the one hand, more expensive than 'just in time' nourishment because money has to be spent sooner. On the other hand, a large nourishment operation is cheaper per m^3 of sand because a lot of work is completed in a single operation. The one-off deposition of a large amount of sand rather than smaller nourishment operations on a more frequent basis is expected to be a benefit in that it disrupts nature less and builds more with natural forces. It can also create a temporary area with room for other functions such as nature and leisure activities. This fits in with the government's aim of achieving more for society with the funding available for coastal nourishment.

2.4 The Delfland Coast

The Delfland coast between Ter Heijde and The Hague was selected as the location for a pilot project with a Sand Motor. This was a logical

place given morphological and administrative considerations. As a result of sea-level rise, the amount of sand needed for coastline maintenance is expected to increase sharply in the future. It has also been noted that there is a severe shortage of space for leisure activities in the southern wing of the Randstad urban agglomeration. The coast is one of the possible locations where leisure opportunities can be upgraded. The Provincial Authority of South Holland has therefore been interested for some time in creating an appealing new area on this stretch of the coast.

The pilot location is a part of the Delfland coast, which extends from Wassenaar to Hook of Holland, and that is managed by the Hoogheemraadschap van Delfland water authority. A large section of this coast has traditionally been affected by coastal erosion. As far back as the eleventh century, storm surges led to the failure of what were still low and small dikes on the northern side of what used to be the Meuse estuary. After 1600, attempts were made to stabilise the Westland coast and to restrict the loss of land, for example by building the first 'Delflandse hoofden', the breakwaters along the coast here. In the centuries that followed, more and more were built until the present number of 68 was reached.

However, coastal erosion continued: the maintenance of the sea dike demanded continuous attention and resources. The nineteenth century saw the strengthening of the narrow row of dunes, which was raised to form a sand dike. The missing sections were filled in and low sections were raised. Even so, storm surges eroded the dunes time and time again and, on 1 February 1953, the storm led to a critical situation on the ’s-Gravenzande coast and the defences barely held.
The seaward development of the Rotterdam port and the deepening of the entrance channel meant that sandy dredged material became available. It was decided not to dump this material at sea but to use it to reinforce the Delfland coast to the north of the northern pier of Hook of Holland. This led in the 1970s in the reclamation of an area that would be known as the 'Van Dixhoorn Triangle'. The present Hook of Holland beach is located seaward of that area. This reinforcement operation did not have any effect on the northern section of the Westland coast, which was still affected by erosion. The response here was to pump sand onto the beach starting in the early 1970s (and from 1986 onwards near Ter Heijde). The Van Dixhoorn Triangle and these nourishment operations were therefore the forerunners of coastline maintenance as it would be implemented from 1990 onwards throughout the Netherlands. The Westland coast was extended in the seaward direction in recent decades because some of the nourishment sand drifted to the outermost row of primary sea-defence dunes, where it was captured by the extensively planted and rapidly-growing marram grass.

Figure 5. Location of the Sand Motor on the South Holland coast. In red, the Weak Links: the 'Delfland Coast' was reinforced in 2008-2009. Source: Vertegaal et al., 2016.

Early this century, the Delfland Coast was designated as one of the 'Weak Links' in the coastal defences (Figure 5). This was not because the dunes had got weaker but because it was clear that storms could become more severe in the future. Rijkswaterstaat and the Hoogheemraadschap

Delfland water authority therefore upgraded the defences. That operation was completed in 2011 with the Delfland Coastal Reinforcement, which involved 17.6 million m³ of sand.

The beach and the dunes are important for nature and leisure activities along the entire Delfland coast, which includes various Natura 2000 areas that, in line with the European Habitat directive and the Dutch Nature Conservancy Act, are strictly protected, not only from interventions in the areas themselves but also from undesirable external factors. The same applies to the Solleveld dune area on the landward side of the Sand Motor. It is mainly made up of 'old dunes' which, as the precursors of what we now usually call dunes (the 'young dunes'), were deposited by the sea along the Dutch coast starting in 3000 B.C.

There is a relatively narrow strip of young dunes seaward of Solleveld. This hilly zone is a few hundreds of metres wide and the soil is lime-rich. This part of Solleveld has been very much affected by the coastal reinforcement operations in recent decades: a double foredune dating from the late 1980s (the result of a dune strengthening operation, the 'Zeerepen 1987') and the row of dunes approximately 60 metres wide included in that reinforcement operation in the context of the 'Weak Links'. Solleveld is considered to include all these areas.

2.5 Design and implementation of the Sand Motor

In March 2011, immediately after the Delfland coastal reinforcement, work began on the construction of the Sand Motor, a peninsula measuring 128 hectares in the shape of a hook and with a dune lake at the foot and a lagoon between the spur on the northern side and the existing coast. At the same time, two foreshore nourishment operations were conducted on either side. The final batch of sediment for the Sand Motor was brought in on 29 June. The northern foreshore nourishment (the smaller of the two) was completed at almost the same time. The southern foreshore nourishment was completed in November 2011. It is located a few kilometres to the south of the Sand Motor.

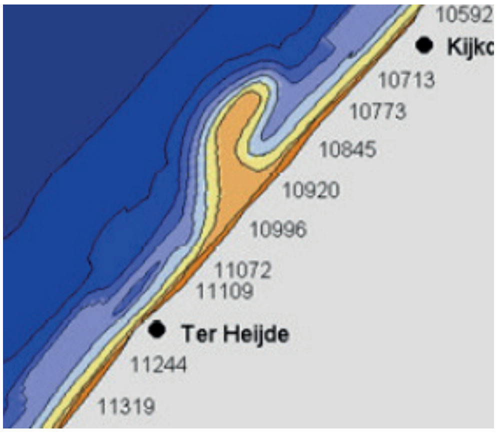


Figure 6. Preferred alternative from the Sand Motor EIA

Dredging vessels picked up the sand ten kilometres offshore and pumped it into the project area. The total net quantity (the amount of sand that was actually deposited in the Sand Motor: there are always sand losses during dredging) was 18.7 million m³. The quantities for the southern and northern foreshore nourishment operations were 1.7 and 0.4 million m³ respectively.

The ultimate design of the Sand Motor is the result of the optimisation of the preferred alternative from the Environmental Impact Assessment (see Figure 6, from sources no. 3). This design complied best with the three objectives: dune growth, the creation of more nature and leisure facilities, and knowledge development. The hook shape results in considerable variation, with the lagoon forming a sheltered area and a highly dynamic area where it points into the sea. A new dune lake was created at the base of the hook. In addition to additional variation in the landscape, this also ensures that the Sand Motor will not have a negative impact on the groundwater flows in the Solleveld drinking-water catchment area on the landward side.

03. The Sand Motor for coastal protection

3.1 Expectations

It is expected that the Sand Motor will, because of the larger amount of sand it contains, enhance the protection of the coast between Hook of Holland and Scheveningen by comparison with the regular nourishment operations conducted prior to the construction of the Sand Motor. It is also assumed that, over the course of twenty years, less sand will be needed to maintain the base coastline on this stretch of coast. It has been calculated that the volume of sand in the Sand Motor and the supplementary foreshore replenishment will be adequate to maintain the sand balance in the coastal foundation of the Delfland Coast for approximately 50 years assuming an average sea-level rise of 3 mm a year.

Model calculations indicated that the head of the Sand Motor would be particularly dynamic and subject to erosion in the initial years after construction, and that the sand would move in the direction of the coast. The calculations indicate that the section of the hook that is attached to the coast at the time of construction will probably still be visible after a period of ten years. The expectation in the long term is that a more or less straight coastline will emerge (see Figure 7, from sources no. 3).

Another assumption was that the dunes on the Delfland coast would grow faster as a result of the construction of the Sand Motor than is the case with standard nourishment operations.

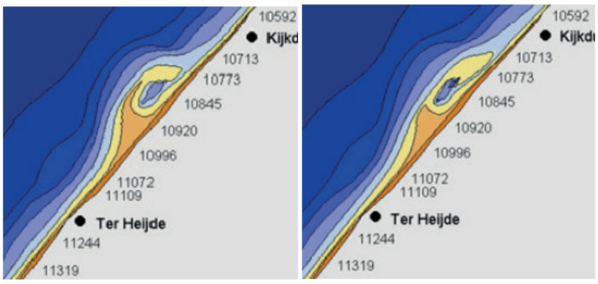


Figure 7. The expected morphological development of the Sand Motor as calculated for the EIA. Calculated development after five years on the left and after ten years on the right. The predicted bed developments have actually occurred but morphological changes were faster than predicted. Sand was not 'lost' faster during this process.

The first objective stated in the EIA for the construction of the Sand Motor was: 'Encouraging natural dune growth in the coastal zone between Hook of Holland and Scheveningen. This dune growth serves different functions: protection, nature and leisure.' This chapter focuses on the first of these objectives: the significance of the Sand Motor for coastal protection. The other two objectives – dune growth for nature and leisure – will be discussed in Chapter 4.

Figure 8: left: aerial photo taken in July 2011; right: aerial photo from May 2015

3.2 Developments

3.2.1 Introduction

Since the construction of the Sand Motor in 2011, the sand has spread along the coast. Coastal accretion has been seen both to the south and the north of the Sand Motor. The spreading of the sand led to a change in the shape of the Sand Motor: from an almost symmetrical bell shape into a more triangular shape with concave arch shapes in the coastline. After four years, the sand body protruded 260 metres less into the sea on average (with a maximum of approximately 350 metres at the Head of the Sand Motor). At the same time, the stretch of coast that has been extended seaward has become 2.2 kilometres longer. The shape changed most in the first two years after construction. The most dynamic conditions were on the northern side, where the lagoon and the channel are located. There were storms in December 2013 and July 2015, the effects of which were closely monitored. Those measurements made it possible to determine in detail how sand is spread during a storm. For example, the December storm of 2013 moved as much sand as had been moved in the previous four months. Without a heavy storm of this kind, the pattern of sand movement would probably have been comparable, but somewhat slower.

3.2.2 *Landscape formation and processes on the Sand Motor*

Since the construction of the Sand Motor, various temporary formations have been created such as the 'sand spit', the channel, the beach plain on the southern side of the Sand Motor, and all sorts of patterns of sand banks. For the names used and the location of these formations, see Error! Reference source not found.1. Some of the sand drifts into the lagoon and the dune lake, which are gradually becoming shallower as a result. Other sand drifts past the lagoon and the dune lake into the dunes behind the Sand Motor.

Sand spit formation

The sand spit is an elongated sand shoal that started to form at the point of the Sand Motor during construction. This form is characteristic of a rapidly expanding coast. Sand transport in the north-easterly direction extended the sand spit by approximately 750 metres along the beach of Kijkduin in less than a year. In late 2015, the sand spit was approximately 2.5 kilometres long and 350 metres wide. It is an elongated area. One part is an intertidal area and another is above the average high-water level. The latter part can also be submerged when water levels are high or when there is intense rainfall.

Development of the channel

The extension of the sand spit has resulted in a channel connecting the North Sea to the lagoon. In the initial years after construction, this channel was narrow, deep and quite short. The water flowed relatively quickly. As the sand spit extended, the channel became longer: from 1.2 kilometres in April 2012 to 2.7 kilometres in late 2015. The channel started to meander and it became increasingly shallow. The flow velocities also declined and the tidal amplitude in the lagoon became smaller. At that time, experts expected that if the spit was submerged during a storm, a new and much shorter channel would be created between the sea and lagoon, resulting in the definitive silting up of the old channel. This expectation came to pass in January 2016 with the formation of a breach channel after a night with a north-westerly storm and a storm surge on the coast. This breach was followed by the rapid development of a new sand spit, and the 'old' channel lost its significance and became shallower. It would appear to be likely that this has resulted in a temporary cyclical process since the new sand spit will be breached and the new channel will silt up. The length of time required for the completion of this cycle is not known but it is probably much less than the four years of the first cycle.

Aerial photo of the Sand Motor with the beach lake in the foreground

Dune Lake and Lagoon
Large amounts of sand drift into the dune lake. In four years, approximately 100,000 m³ of sand blew into the lake, particularly on the western side. As a result, the 'wet circumference' (the circumference of the water plus the intertidal beach around it) declined.
The situation with regard to sand and wind around the dune lake is highly dynamic. Marram grass has grown sparsely. At some distance from the waterline, a ribbon of low vegetation (such as sea sandwort) has been observed. Abundant vegetation is now present in the dune lake itself.

The lagoon has also become steadily smaller since construction in 2011. In the first four years, approximately 300,000 m³ of sand entered the lagoon. By contrast with the dune lake, not all the sand was deposited by the wind; some of it entered the lagoon through the channel. The deepest part of the lagoon is still over four metres deep. Sediment is collecting on the bed.

Beach plain and runnels on the southern side
Large amounts of sand were deposited in the southern part of the monitoring area, particularly in the acute angle present just after construction between the Sand Motor and the original coastline. Soon after construction, this angle was 'sheltered' by sand banks (shallow areas created by the action of the waves) that extended in a landward direction over time and became increasingly higher. That resulted in the creation of a broad beach plain drained by shallow channels (runnels). The profile of this area is continuously changing, with the wind playing an important role because the drifting sand sticks to the wet surface. There are several small sand banks under the water. On the dune side of the beach plain, there is a slightly lower area that is submerged when groundwater levels are higher. Particularly in winter, this results in the formation of a beach lake (alongside the dune lake to the south).

Formation of cliffs on the head
The central section of the Sand Motor is subject to erosion. A maximum level of erosion of approximately 350 metres has been seen at the Head of the Sand Motor in the first four years. Particularly when there is high water in conjunction with a storm, sand is eroded on the seaward side of the Sand Motor in such a way that 'cliffs' form. Sand removed from the head of the Sand Motor enters the surf zone and is transported further along the coast in a northerly or southerly direction by the currents. This has resulted in the formation of a number of large sand banks at angles to the coastline.

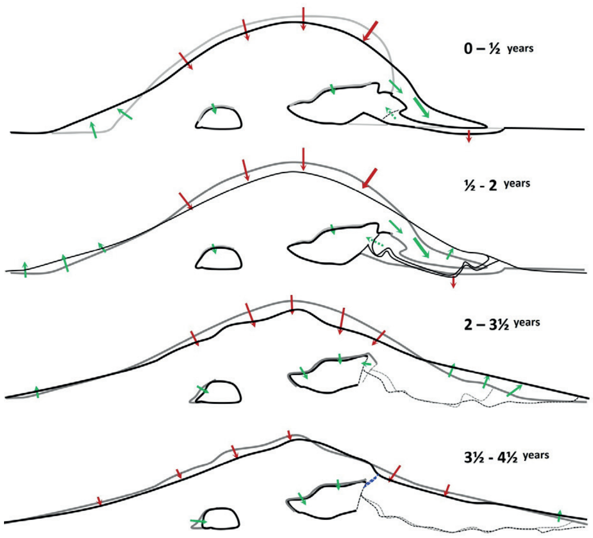


Figure 9: The development of the Sand Motor in four phases: 1) formation of the sand spit and the channel, 2) the extension of the channel and development of a symmetrical form, 3) the stabilisation of the southern side of the peninsula and 4) the formation of a triangular shape. The continuous light-grey line shows the coastline during the previous phase and the dark lines show the new coastline. The main developments in the Sand Motor are shown by arrows. Red arrows indicate erosion; green arrows indicate sedimentation. The short blue line in the bottom figure shows where a new connection between the sea and the lagoon was created in January 2016.

Formation of sand banks on the northern side
Sand banks have formed on the northern side of the Sand Motor. After the December storm of 2013,

the irregular bank patterns were smoothed out, resulting in a virtually uniform, elongated sand bank along the coast. A connection with the bank pattern on the adjoining coast near Kijkduin seems to have been created.

Drifting sand and dune formation
The wind transports the sand on the dry part of the Sand Motor. There are three forms of wind transportation on the Sand Motor:

- Spreading of silt, clay and fine sand. Particularly just after the construction of the Sand Motor, this material was transported to large heights and it resulted in complaints from, among others, people living in flats in Kijkduin. This process is rarely seen now because the fine material has been removed from the upper layers of the Sand Motor. In addition, the 'armour layer' (the hard upper layer of shells) limits wind dispersal.
- Wind dispersal of slightly less fine sand. This sand often comes from the wet part of the beach and it drifts across the beach at low heights. This process of sand transport by saltation is still going on.
- Transport of coarser sand in ridges that slowly migrate. The wind also transports sand located below the shell armour layer.

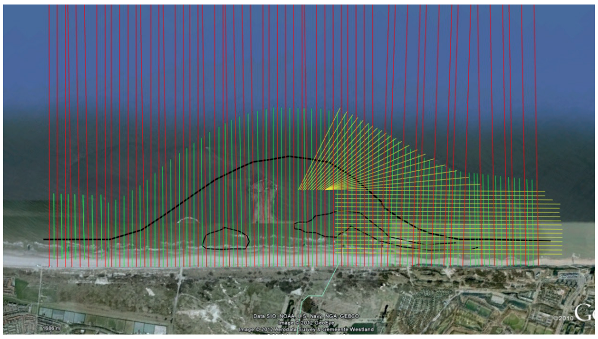


Figure 10: Sand Motor monitoring area where sand volumes are measured

In other words, there is no full shell armour layer. Elevation measurements indicate that the dry part of the Sand Motor fell by approximately 50 centimetres over the course of four years.

The wind takes the sand in a north-easterly direction on average. A sizeable proportion enters the lagoon or the dune lake (see the heading 'dune lake and lagoon'). The elevation charts show that quite a lot of sand also moves to the sheltered areas between the higher ridges on the western side and the dune lake/lagoon on the eastern side. The sand that does not 'encounter any water' is added to the dunes. New primary dunes have also been formed covering an area of approximately one hectare in total. This is less than expected. Section 3.2.3 discusses the reasons for this discrepancy. The new dunes have risen to heights of up to more than two metres in four years.

A lot of sand also enters the coastal reinforcement area completed in 2011 just outside the Sand Motor. Over the past four years, the row of dunes has risen by approximately 2-3 metres over a width of 20-40 metres. The development of new dunes is fastest here (see also Chapter 5). The dune growth in the coastal reinforcement area does not therefore represent an increase in the surface area of the dunes but it is a considerable improvement in terms of quality and volume.

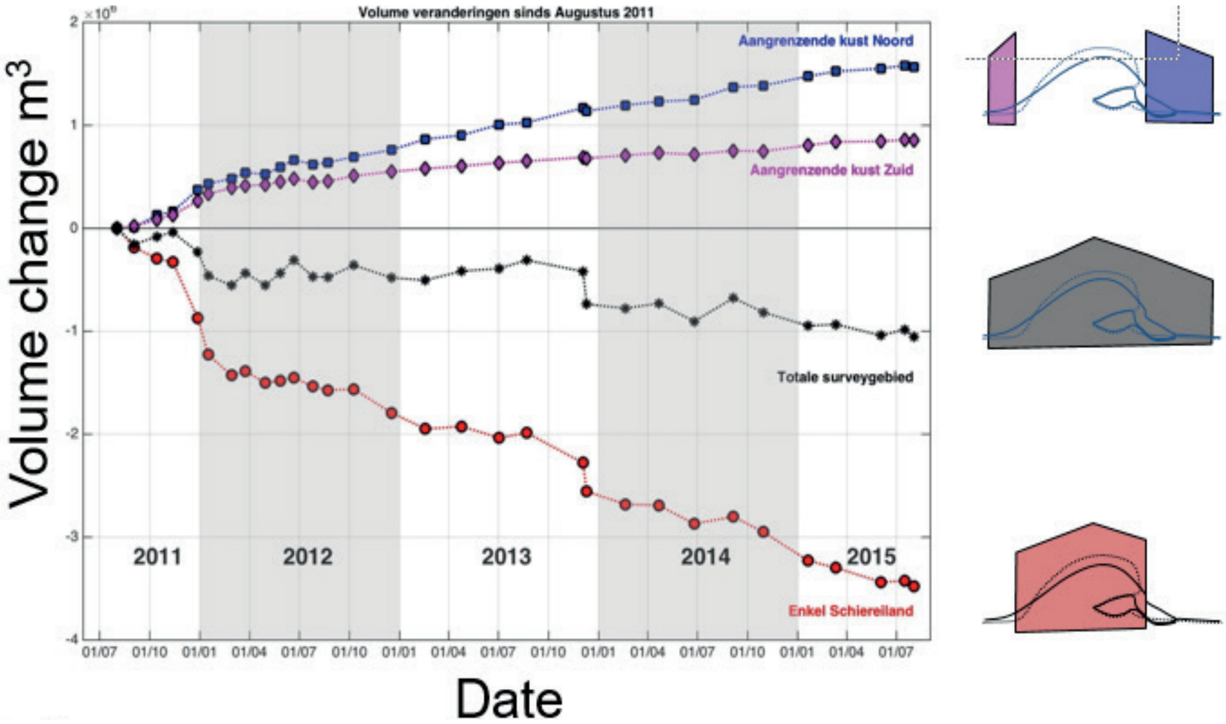


Figure 11: Changes in the volume of sand in the first four years after the construction of the Sand Motor (between August 2011 and August 2015). Source: Shore, 2016.

3.2.3 Development of sand stocks

Sand stocks on and around the Sand Motor
The volumes of sand and their locations around the Sand Motor are being closely monitored. This involves looking at a 'monitoring area' between the NAP -10 m line and the fencing on the boundary between the dune and the beach (in other words, where this boundary was located in August 2011).

The measurements show that the monitoring area still contains, by comparison with the situation prior to the construction of the Sand Motor, an extra quantity of sand amounting to approximately 95% of the volume of sand brought in by the Sand Motor (see Figure 11). This is certainly not all the same sand that was deposited initially: the Delfland Coast is an ‘open system’ in which sand is exchanged with adjoining areas. A prevailing current transports sand along the coast in a northerly direction. It should also be noted that there was an underwater nourishment operation in 2013 involving a volume of 1.5 million m³ to the south of the Sand Motor approximately opposite ’s Gravenzande. That operation had already been planned before the construction of the Sand Motor.

Most of the 5% of the sand volume that is no longer present in the monitoring area can probably be found just outside it, both in the dunes and in deeper water. Here also, this sand is part of the coastal foundation and it will, in the long term, contribute to counteracting erosion.

Sand stocks between Hook of Holland and Scheveningen

The measurements conducted by Rijkswaterstaat every six years (the 'vaklodingen') are needed to establish a picture of the development of the coastal foundation for the Delfland Coast.

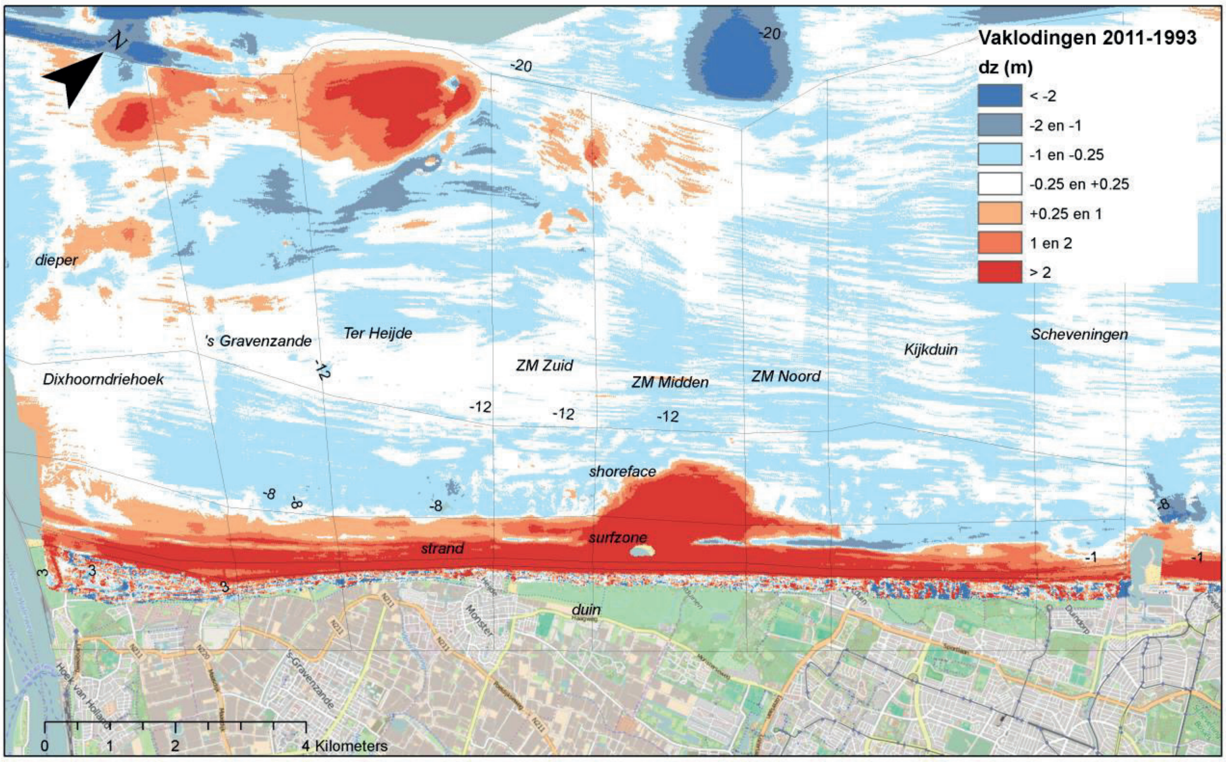


Figure 12A: Sand volumes between Hook of Holland and Scheveningen in the period until just after the construction of the Sand Motor based on the measurements conducted by Rijkswaterstaat every six years of the entire coastal foundation. Red is height increase, blue is height decrease. In addition to the growth of the coastal zone as a result of the successive standard sand nourishment operations, coastal reinforcement and the Sand Motor, we can see the borrow area for the Sand Motor (in blue, upper centre, just outside the -20 metre line) and the locations where dredged sediment from the entrance channel to the port of Rotterdam has been deposited (red, top left, just inside the -20 meter line).

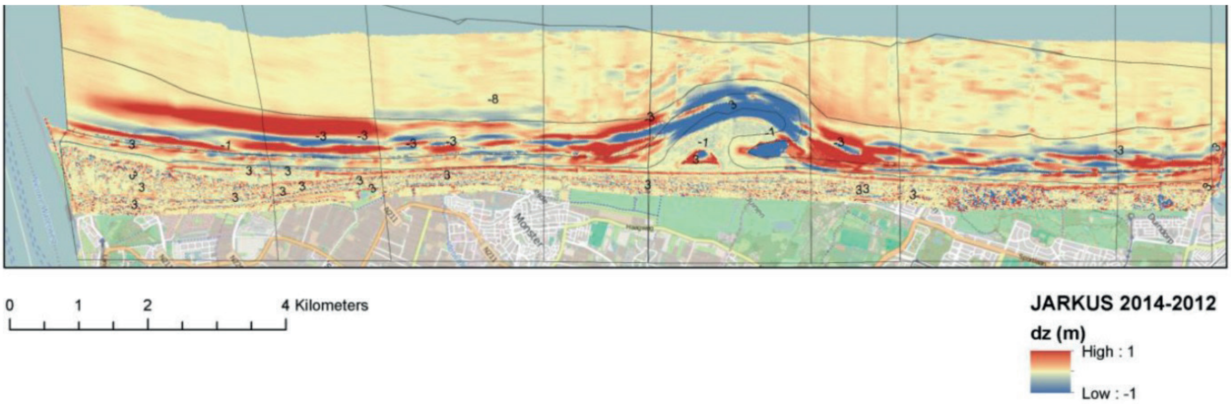


Figure 12B: Development of sand volumes between Hook of Holland and Scheveningen after the construction of the Sand Motor. Red is height increase, blue is height decrease. The erosion of the head of the Sand Motor can be clearly seen, as can accretion to the north (right) and south (left). The underwater nourishment operation in 2013 opposite 's-Gravenzande can be clearly seen on the left of the figure.

Figure 12A shows the most recent measurements (from 2011), as compared with the measurements from 18 years previously.
A clear picture of how the coastal foundation has developed after the construction of the Sand Motor can be obtained only after the following measurements in 2017.

Figure 12B has been added to give an impression of how the entire Delfland coast has developed after the construction of the Sand Motor. It is based on the annual measurements of the shallower part of the coastal foundation (to −8 metres). This figure suggests that there has been a slight increase in the amount of sand in the deeper waters around the Sand Motor (outside the monitoring area shown in Figure 10).

Dune growth
The growth of dunes is established on the basis of the 'current dune volume' and the position of the erosion point (see Figure 13). The current dune volume is a measure for the volume of sand in the primary sea-defence dunes above NAP + 3 m. The sand on the beach (below NAP + 3 m) is not included. The 'current dune volume' informs us that the dunes between Hook of Holland and Scheveningen have been getting steadily higher and/or wider for decades. Initially, this was primarily attributable to beach and dune nourishment operations and the construction of the Van Dixhoorn Triangle. Since 1990, standard nourishment operations have also been a factor. After the construction of the coastal reinforcement and then the Sand Motor, the trend for the 'current dune volume' changed, probably temporarily. The dune foot, the 3-metre line, is moving landwards for example. However, this does not mean that the actual border of the dunes is receding. The 3-metre line was, after the construction of the coastal reinforcement and the Sand Motor, located on the higher part of the beach and no longer at the 'kink' in the profile that is the actual dune foot where vegetation begins. So the dunes are not receding; sand is being redistributed on the higher part of the beach.

The position of the erosion point is also developing favourably and moving seaward.This process is slightly slower on some sections of the coast than it was before the construction of the Sand Motor.

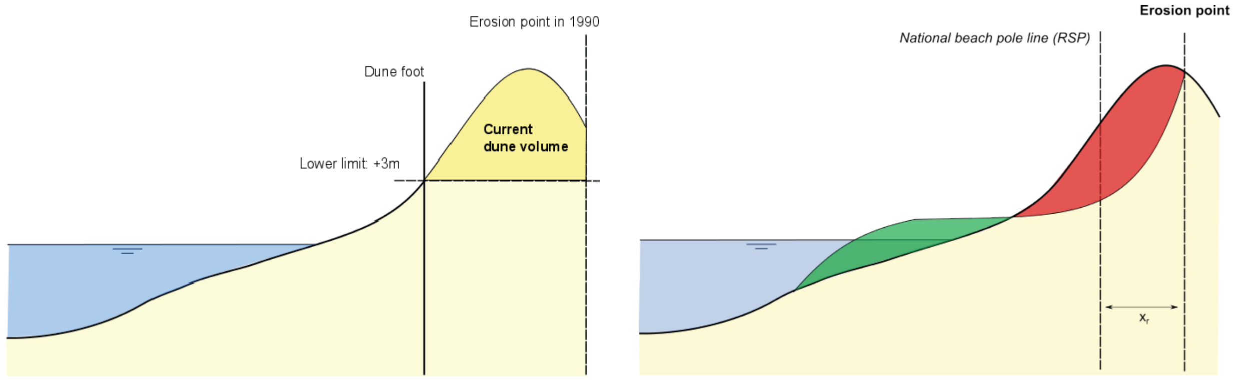


Figure 13: Calculation method to determine the 'current dune volume' and 'position of the erosion point'

The dune volume itself is increasing, but not as quickly as before the construction of the Sand Motor. That seems strange because more sand is now actually available. This can be explained for the central section of the Sand Motor because the dune lake and the lagoon capture large amounts of drifting sand, reducing the amount of sand drifting to the dunes behind the Sand Motor.

On the basis of the observations and existing knowledge about the coast of Holland between Hook of Holland and Den Helder, it is reasonable to expect that the sand from the Sand Motor will spread further along the coast in the years to come, resulting in wider beaches to the north and south that will, in turn, result in increased dune growth. The rate of growth of the dunes immediately behind the dune lake and the lagoon will probably increase only when the dune lake and the lagoon are filled up with sand, a development that, incidentally, does not constitute a problem in terms of coastal protection.

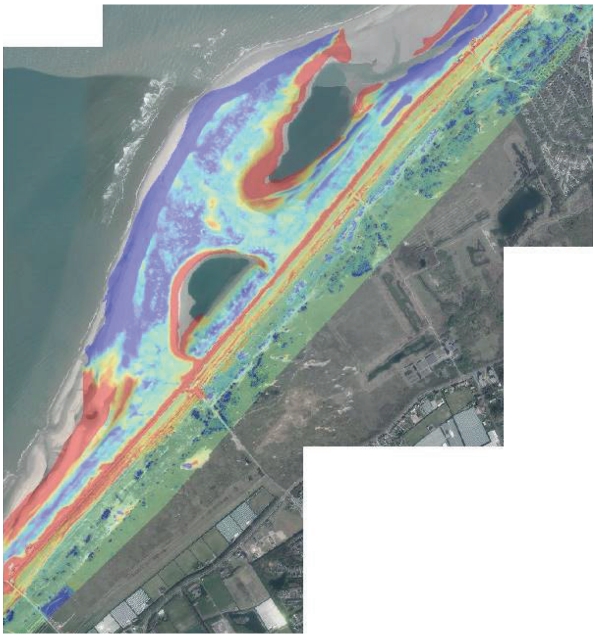


Figure 14: Height changes September 2011 - March 2015. In red: rise of 0.5 m and more, in blue: erosion of 0.5 m and more. Source: Witteveen en Bos et al, 2016.

3.2.4 Impact on long term coastal protection

The dataset of four years is relatively short as a basis for describing the impact of the Sand Motor on long-term coastal protection between Hook of Holland and Scheveningen. It is possible to draw conclusions only about the initial effect of the coastal reinforcement and the Sand Motor in conjunction, and the effects of the two interventions cannot be distinguished from one another.

The results so far indicate that coastal protection has benefited initially, particularly in the vicinity of the Sand Motor. That is not surprising since much more sand has been deposited than would have been required for standard nourishment operations in the last four years. On the other hand, it is also obvious that, over a period of twenty years (the lifetime of the Sand Motor expected initially), less sand in total would have been required to maintain the base coastline using standard management approaches than has been used for the construction of the Sand Motor. In the standard approach, the sand would have been deposited at exactly the right time and in exactly the right place. However, the additional volume used for the Sand Motor does, as a whole, contribute to the maintenance of the coastal foundation between Hook of Holland and Scheveningen. The coastline at the location of the Sand Motor and immediately to the north and south has moved and is, for the time being, located seaward of the base coastline.

3.3 Evaluation and summary

The large amount of sand used for the Sand Motor has a positive impact on coastal protection, particularly in the vicinity of the Sand Motor. That is not surprising since much more sand has been deposited than would have been required for standard nourishment operations in the last four years. The coastline is now located seaward of the base coastline.

The contours of the Sand Motor have changed drastically since 2011. The developments observed have matched expectations.

The Sand Motor has resulted in the creation of a dynamic area where the sea, sand and water have free rein in a way that fits in with the Dutch coastal policy. Waves and currents transport sand from the Sand Motor on the foreshore and to the beaches to the north-east and south-west, where the beach is now much broader. During a period of four years, the sand body became approximately 260 metres narrower and 2.2 kilometres longer. In some places, the waterline has receded even further, for example by approximately 350 metres at the Head of the Sand Motor. An additional amount of sand equal to 95% of the deposited sand is still present in the monitoring area after four years.

04. The Sand Motor as an appealing leisure and nature area

4.1 The Sand Motor as an additional nature area

4.1.1 Background

The coastal zone is home to a large number of plant and animal varieties. One of the aims of the Sand Motor was to create an attractive new area for those plants and animals in the form of a new stretch of dynamic coast. Due to the removal of control measures, waves, currents and wind are given free rein to spread the excess sand and to establish a basis for new nature in the shallow sea (the foreshore), on the beach and in the dunes.

The biodiversity of the shallow coastal zone (the foreshore) and the intertidal beach depends to a large extent on factors such as food abundance, levels of dynamism (bed morphology, flow velocities) and the composition of the sediment. Many of these factors depend on bathymetry and water depth.

The main species present in this zone are benthos (in and on the seabed), fish, birds and mammals. These groups are linked through the 'food chain'. Benthos, for example, are food for birds and fish and (indirectly) for marine mammals. So any effect on benthos will also affect other species.

On the dry beach, the habitat for flora and fauna is determined by local dynamics (and in particular wind dispersal, sand deposition and periodical flooding), bathymetry, soil water balance, salinity, food abundance and human activities. Dune formation is highly dependent upon the potential for the growth of marram grass. The grass is kept in good condition by drifting sand and that allows it to capture even more sand.

4.1.2 Expectations

When the Sand Motor was constructed, it was expected that there would be an increase in habitat variation because of the larger variation in dynamics and sediment composition, in turn resulting in a wider range of species. The expectation for benthos was that the construction of the Sand Motor would create more opportunities for species that live longer because sand nourishment every 3 to 5 years would no longer be required. Benthos are repeatedly buried under a layer of sediment during standard foreshore and beach nourishment operations. Admittedly, the sand continues to spread after construction and across a larger area, mostly in the area to the north of the Sand Motor. However, the extent of sand cover is of a different order. The benthos in

This chapter provides an overview of nature – both the landscape and the flora and fauna – as it has developed in recent years on the Sand Motor and of how leisure activities have developed. This information helps to answer the question of the extent to which the construction of the Sand Motor has resulted in 'the creation of an additional appealing leisure and nature area on the Delfland coast'.

the dynamic foreshore have, in principle, already adapted to this process of being covered by a thin layer of sand as a result of sand transport near the coast.

In addition, it was expected that the erratic morphology of the foreshore and the sheltered location of the lagoon would have a positive impact on the population and development of juvenile fish. Fish in the coastal zone consist largely of juvenile fish, particularly close to the beach. Some of these juvenile fish settle in the coastal zone in the spring/early summer and grow there throughout the summer. The lagoon was also expected to attract waders and seabirds, and to be an appealing feeding and resting place for marine mammals.

4.1.3 Actual developments in the shallow coastal zone and on the intertidal beach

It has emerged that the Sand Motor affects the grading of sediment. That has resulted in more variation in the composition of the bed. For example, areas with relatively fine sediment have been created in the deeper foreshore just to the north and south of the Sand Motor. Sand of a much coarser variety is found on the head of the Sand Motor.

In the lagoon, relatively fine sediment predominates; this is different from the material found on the beach and the foreshores. The edges around the lagoon resemble mud flats and they are rich in benthos and foraging birds.

Benthos and juvenile fish

The benthos communities are highly varied. As is usual in this type of system, composition changes from year to year. The dominant factor determining the composition of the community is water depth. Because the sediment around the Sand Motor varies in terms of grain size, there are local patterns in the benthos community. The areas with relative fine sediment just to the north and south of the Sand Motor are relatively rich in species and they have a high biomass. Benthos are relatively scarce on the Sand Motor itself, where the sand is coarser. There are no indications that the area to the north of the Sand Motor, where some of the sand from the Sand Motor is deposited, is developing differently as a whole from comparable areas on the coast of Holland between Hook of Holland and Den Helder.
The edges of the lagoon are rich in species. Immediately after the construction of the Sand Motor, large numbers of benthos were present in

the deeper water of the lagoon. There were problems subsequently with oxygen levels, very probably as a result of the accumulation of organic matter and the limited exchange of water with the North Sea. As a result, there are only a few species in the deep part of the lagoon at present, and numbers are low. This species do represent added value because they are not often found on the the coast of Holland. In the early days of the Sand Motor, the sheltered lagoon was a suitable location for juvenile plaice in particular. However, water quality has declined here and so this is no longer the case.

It is not yet possible to draw conclusions about the effect of the Sand Motor on the development of benthic species that live longer by comparison with a standard nourishment programme. The Sand Motor has now been in place for five years, a period of time that matches the interval between standard nourishment operations. The benthic communities are therefore still in the same phase of recovery. It is uncertain whether species that live longer can actually develop in the dynamic environment of the Delfland coast.

Birds

Between 2011 and 2015, almost forty species of bird were observed on more than isolated occasions on and around the Sand Motor. Including isolated observations in the count, more than fifty species were seen. The distribution of the number of individuals for each species varies enormously. The black-headed gull is the most numerous species by far. Other seagull varieties such as the common gull and herring gull account for a relatively large proportion of the birds observed. In addition, the grebe and great cormorant have been seen frequently.

Five species of wader were observed. However, the numbers are relatively low, with the exception of the oystercatcher. Sanderlings and bar-tailed godwits are found more in the central section of the Sand Motor, which consists primarily of beaches, than in comparable areas.

On the basis of the number of observed birds in the lagoon it is suspected that the lagoon is a suitable habitat for approximately thirteen species of bird, particularly waders, a few species of seagull and the great cormorant.

The largest numbers of most bird species are observed above the sea. Both the beaches and the sea are important for a fair number of species, whereas there are only a few species that are seen primarily on the beaches. Virtually no birds have been seen in the dune lake.

Until now, no birds have been seen nesting on the Sand Motor. There are indications that the common ringed plover and Kentish plover have attempted to breed here. As a biotope, the Sand Motor would appear to be suitable for coastal breeding birds such as the Kentish plover and common ringed plover. There would also appear to be suitable nesting areas for the oystercatcher, common tern and little tern. Although no studies have been conducted looking at causes, it can be assumed that the relatively intensive use of the area by different groups of visitors and the high numbers of dogs are the main reasons for the virtual absence of these coastal breeding birds, which are easily disturbed.

Marine mammals
Because not many counts have been conducted and because few marine mammals have been observed, no conclusions can be drawn about the effect of the Sand Motor on the harbour seal, grey seal and harbour porpoise in the area. There have been reports of seals on a range of public forums. It would seem obvious that the Sand Motor is hardly used at all by seals during the day, in all probability due to the leisure visitors.

4.1.4 *Actual developments in beach and dunes*

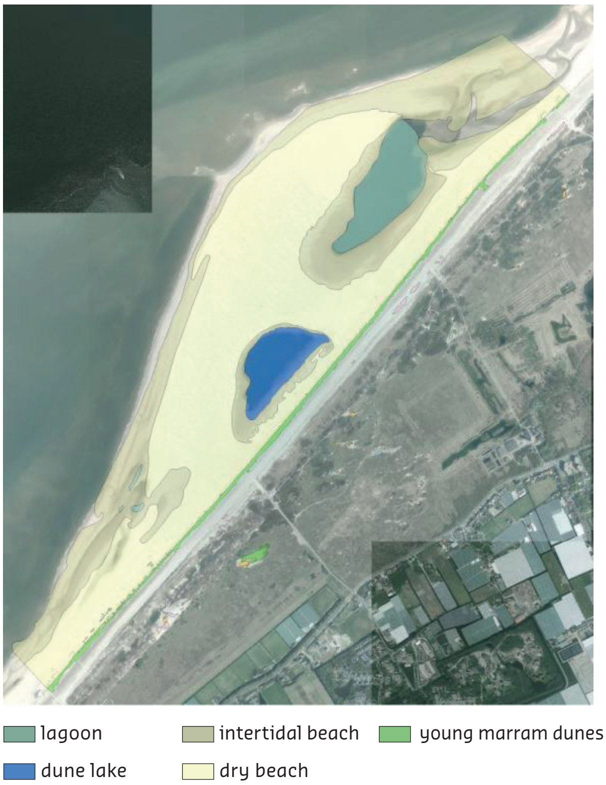


Figure 15: Dynamic geomorphological structures on the Sand Motor

General picture
The sand body of the Sand Motor consists predominantly of broad, relatively flat and very dynamic beaches. Since construction, the area of dry beach has fallen by approximately 40 hectares in favour of the area of intertidal beach. The intertidal beach area around the dune lake increased from less than one hectare in 2011 to more than 5 hectares in 2014. The spread of the Sand Motor to the north and south has resulted predominantly in intertidal beaches. The extent of the dry beaches has increased only marginally, if at all (see Figure 15). The landscape now looks

much more natural than immediately after construction and so the area has come to resemble the very dynamic, open, coastal nature that is seen in the heads of the Frisian Islands.

Dune growth

It has already been explained in Chapter 3 that the development of new dune areas on the Sand Motor has been slow, particularly by comparison with the situation prior to the construction of the Sand Motor and the coastal reinforcement. On the Sand Motor, small new dunes have formed on a modest scale covering a total area of approximately one hectare. Approximately 30% of this area consists of loose dune shapes (embryonic dunes with marram grass or sand couch) scattered around the Sand Motor. The other 70% consists of white dunes on the eastern edge of the Sand Motor next to the foredune (see Figure 16). The height of the latter has increased particularly rapidly by up to more than two metres in four years.

It has emerged that the development of small dunes in the northern and central sections of the Sand Motor is primarily associated with the growth of marram grass; in the southern section, it depends primarily on sand couch. Both grasses can germinate on the beach. As soon as small dunes begin to increase in size, marram is almost always the dominant variety. The stiff leaves of marram grass capture a lot of sand, and their vertical and horizontal rhizomes allow them to spread rapidly. Where there is a lot of drift accumulation, marram is vigorous, and so it flourishes and captures even more sand.

Strongest dune growth is found on the outer slope of the coastal reinforcement, and therefore just outside the actual Sand Motor. In four years, this slope increased in height from one metre to more than 3 metres across a total area of almost 4 hectares. The rapidity of dune development here is, in all probability, due to the fact that marram

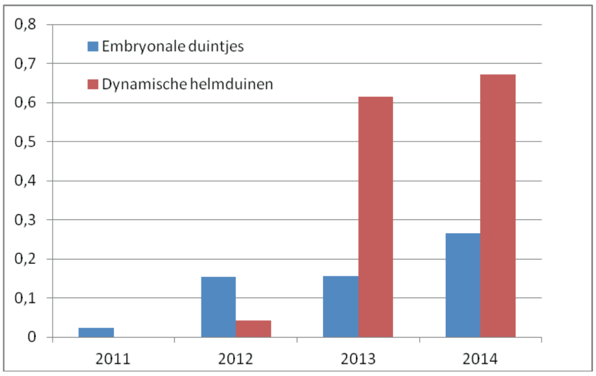


Figure 16: Area of embryonic dunes and young white dunes (in hectares). Source: Vertegaal et al., 2016.

grass was already planted here, resulting in the effective capture of sand. This leads to the replacement of the planted marram grass, which is less valuable in ecological terms, by the 'white dunes' habitat.

One of the reasons for dune growth lagging behind the expectations is the capture of sand by the dune lake and lagoon. The dunes in the 'wind shadow' of these features are therefore not growing as rapidly as in the adjoining stretches of coast. Other probable causes include:

- The removal of waste from the beach of The Hague (litter can actually result in the formation of new dunes);
- Driving on the beach, reducing or preventing dune formation;
- Walking on the area, hampering the development of new dunes. To limit this effect, a number of areas have now been fenced off. However, this has hardly any effect because the effect is most pronounced in the early stages of dune formation when the dunes are still small (less than a few decimetres). These tiny dunes are not fenced off.

Vegetation

The dry poor ground, the salt sea wind and the intense drifting of the sand make this an extreme environment for plants. Vegetation is slow to settle here.

Figure 17: Two sets of tyre tracks with a central strip of small dunes. Source: Vertegaal et al., 2016.

The plants that do manage to grow are often spaced far apart and, at best, result in sparse patches of vegetation. Due to the highly dynamic environment, some of this vegetation disappears again within one or two years. It is only on the high landward edge of the Sand Motor that there are now more stable and dense areas of vegetation with marram grass.

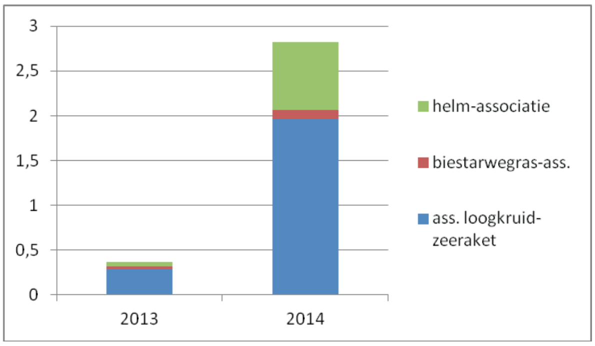


Figure 18: Mapped surface area with types of vegetation in 2013 and 2014 (in hectares). Source: Vertegaal et al., 2016.

Because there were still almost no plants, flora were not monitored in 2011 and 2012. The first integral mapping was conducted in 2013 and 2014. The number of individual plants increased considerably in those two years. In absolute terms, the numbers were still small. Eleven varieties were seen in 2014, including sea holly, a red-list variety.

4.2 Leisure

4.2.1 Background

Many Dutch people appreciate the open landscape of beach and dunes, and enjoy going to the coast for the experience of emptiness, darkness, water, wind, storms, sun, tides, seasons, visible gradients in the landscape and the contrasts with the busy hinterland. Given this, the Provincial Authority of South Holland had, for some time, been on the lookout for opportunities to create an appealing new area on the Delfland coast. It was expected was that the construction of the Sand Motor would create more space for leisure activities.

4.2.2 Developments

Leisure surveys have shown that the four main leisure groups are bathers, dog walkers, ramblers and surfers (of all varieties: kite, wave and wind). The Sand Motor has become a 'hot spot' for kite surfers in particular. The lagoon provides them with both the necessary sea wind and slightly safer, calmer wave conditions. Together with a range of outdoor activities such as such as horse riding, fishing and running, there are now more types of leisure activity than previously on the beach between Ter Heijde and Kijkduin.

Recent counts and surveys have shown that most leisure activity is located on the edges of the Sand Motor. Half of the people stay on the original beach. A number of changes that have emerged with respect to previous studies are:

- fewer bathers
- more people visiting the beach for a day (by car)
- more visitors with a dog
- more kite surfers
- more evening visitors.

The surveys have shown that visitors are increasingly familiar with the various aspects of the Sand Motor. During and immediately after construction, attitudes were slightly critical.

An increasingly large group now approves of the Sand Motor and the project enjoys widespread support.

4.3 Evaluation and summary

The Sand Motor has resulted in the creation of an extra area on the coast with opportunities for nature and leisure that were not available previously on the coast of Holland between Hook of Holland and Den Helder (such as mud-flat environments, a sheltered lagoon and large beach plains).

In broad terms, ecological values have benefited from the construction of the Sand Motor. The sand spit, the rapidly changing sand banks and the lagoon are landscape forms that were virtually absent on this part of the Dutch coast previously. The shape of the Sand Motor has led to an increase in the number of different habitats for benthos, birds and fish. In particular, the sheltered, shallow part of the lagoon and the edges around it are attractive areas for benthos and birds. The deep part of the lagoon had little ecological value in 2015 as a result of the limited exchange of water with the North Sea and the decline in the oxygen content. This area therefore has little value for young fish now.

In 2015, four years after the construction of the Sand Motor, there was still no definite shift towards longer-living benthos by comparison with standard nourishment approaches. It is still questionable whether species that live longer can develop in the dynamic environment of the Delfland coast.

The area covered by newly formed dunes is, at less than one hectare, still very modest in absolute terms. The new dunes are mainly on the eastern edge of the Sand Motor at the foot of the coastal reinforcement, and also to the south-west of the Sand Motor. Most dune formation is located on the outer slope of the coastal reinforcement, where the planted marram grass, which is less valuable in ecological terms, has been replaced by the ‘white dunes’ habitat. The new dunes are highly dynamic and therefore appealing in landscape terms.

The fact that small dunes are developing only on a limited scale is probably due to:

- the capture of sand by the lagoon and dune lake;
- the fact that the Sand Motor has only been here for a relatively short space of time and because no dunes were created initially and no marram grass was planted. The process of dune formation was therefore left entirely to nature and is therefore proceeding naturally, but also relatively slowly;
- management decisions: it is obvious that the motorised traffic on the Sand Motor is slowing down dune development.

The number of plant varieties and the number of areas where plants are growing is increasing but, on the whole, vegetation on the Sand Motor is sparse. It consists of characteristic sand couch and marram grass, habitat types for which the Netherlands has international obligations. Sea holly, a red-list variety, is growing in some locations. Between 2011 and 2015, almost forty species of bird were observed on more than isolated occasions on and around the Sand Motor. The black-headed gull is the most numerous species by far. Other species that have been seen regularly are the common gull, herring gull, grebe and great cormorant. Five species of wader were observed. Until now, no birds have been seen nesting on the Sand Motor. As a result of the small number of official counts, little can be said about the significance of the Sand Motor for marine mammals such as seals.

The Sand Motor has now been in place for almost five years and, in terms of the frequency of sand deposition, there is still hardly any difference from standard nourishment approaches. As a result, the two approaches cannot yet be usefully compared. More time is needed for this purpose.

The four main leisure groups at present are bathers (although there are now fewer bathers than previously), dog walkers, ramblers and kite, wave and wind surfers. There are now more types of leisure activity on the beach between Ter Heijde and Kijkduin than prior to the construction of the Sand Motor. Leisure visitors rate the Sand Motor highly.

05. The management of the Sand Motor

5.1 Management agreements

In the management agreement for the Sand Motor pilot project (June 2010), it was agreed that the Provincial Authority of South Holland would be primarily responsible for day-to-day management on the Sand Motor. The management of the Sand Motor was split up into three components:

1 Supervision and lifeguard service (including zoning involving, for example, bathing bans). Agreements to this effect were made between the Provincial Authority of South Holland, the Haaglanden Safety Region, the Westland municipality, The Hague city authority and the voluntary rescue services of 's-Gravenzande, Monster and The Hague. These agreements were included in a cooperation agreement for Beach and Bather Safety for the Sand Motor Pilot Project.

2 Nature and leisure management on the Sand Motor. The 'Zuid-Hollands Landschap' Foundation is also contributing in this area. Management consists of activities with various frequencies:

- day-to-day management activities such as the supervision of visitors and information;
- periodical management activities such as cleaning and the monitoring of flora and fauna;
- special control measures when necessary, for example if steep channel banks are formed by the dynamics of the Sand Motor.

3 Management of nature outside the Sand Motor. The construction of the Sand Motor affected Solleveld, a Natura 2000 area in the landward direction. The Provincial Authority of South Holland and Dunea entered into a voluntary agreement stating which measures will be implemented to mitigate the possible negative effects of the Sand Motor on nature and drinking-water extraction in Solleveld.

Due to the dynamics of the area and the fact that the Sand Motor is a pilot project, management has to respond to new and unexpected developments. Decisions about any interventions are made at a management meeting that takes place every six months.

During the construction of the Sand Motor, it was decided that 'sufficient accurate information should be collected so that the Sand Motor can be managed properly'. This chapter looks in greater detail at the management of the risks associated with the Sand Motor for leisure visitors and the prevention of undesirable effects on the groundwater and the ecological values in existing dunes.

At the time of the construction of the Sand Motor, it was deliberately decided not to 'zone' the area. In other words, not to designate any specific zones where leisure activities are allowed or not. The idea was to close specific areas only if safety required it. It is known that the development of certain ecological values, such as early dune formation or the settlement of breeding birds, can be affected by leisure activities. At the same time, the development of an appealing landscape can, to a limited extent, be combined with the presence of leisure visitors.

5.2 Management of the risks for leisure visitors

The safety of ramblers and bathers plays an important role in the management of the Sand Motor: the dynamic nature of the Sand Motor may result in unsafe or undesirable situations such as rip currents and other currents, the development of cliffs and the deposition of mud in places that are not desirable for leisure beach activities.

Quicksand has been a feature on several occasions: immediately after construction, for example, but also more recently along the edges of the lagoon and the dune lake as a result of drifting sand.

Figure 19: Warning signs for soft sands were positioned at various locations and times to protect visitors.

Warning signs were positioned accordingly (see Figure 19). There was also a bathing ban during and immediately after construction for the entire Sand Motor. That ban is no longer in place. Bathing is now also permitted in the dune lake.

In the first year after construction, some ramblers got lost (an entire group of schoolchildren on one occasion) because they followed the curved coastline from the south and were unable to cross the opening to the lagoon and continue northwards along the beach. In response, signs were placed at every beach entrance with photographs of high and low water, and a suitable walking route.

In addition to information activities, the involvement of supervisors and well-trained lifeguards is important. Since 2013, the lifeguards have used an application that provides an overview of currents and possibly hazardous situations for bathers. The basis for this application consists of a dedicated, and practical, bathing safety model. It is based on bathymetric information that is used to simulate currents in a computer model. There are numerous sand banks around the Sand Motor and so the lifeguards have been given water scooters in addition to the traditional lifeboats so that they can reach the entire area.

The evaluation conducted in 2015 of the 2014 bathing season showed that the organisational arrangements for beach and bather safety on the Sand Motor were implemented reasonably smoothly. Further optimisation can be achieved by exchanging experiences better and conducting joint exercises. The rescue services and supervisors are getting to know the Sand Motor better and better, and they know when dangerous situations may occur. The rescue services are enthusiastic about the app referred to above that provides them with forecasts for beach and bather safety. The app continues to be developed further.

Because the tidal channel has become increasingly meandering, the risk of bathers being dragged out to sea directly has declined. Furthermore, leisure visitors have also become increasingly familiar with the Sand Motor and this has led to a greater level of social control.

The Sand Motor is extending to the north and to the south. The area requiring supervision is therefore increasing accordingly. Furthermore, inspection rounds now take longer.

The parties involved agree that the current level of supervision and lifeguard service on the Sand Motor must be maintained. The morphological developments, and particularly the formation of sand banks to the north of the Sand Motor, mean that a reduction in the safety level is not desirable. The Sand Motor is changing all the time.

5.3 The effect of the Sand Motor on the Solleveld dune area

5.3.1 Introduction

The Sand Motor is located seaward of Solleveld, the dune area between Kijkduin and Ter Heijde that is a part of the 'Solleveld & Kapittelduinen' Natura 2000 area. Areas of this kind are strictly protected, not only from interventions in the areas themselves but also from undesirable external factors. An 'appropriate assessment' was therefore made prior to the construction of the Sand Motor to identify any possible effects. It was concluded that the Sand Motor would not have any significant impact on protected nature ('conservation objectives') if management in the outer Solleveld dunes was intensified (as a mitigation measure). The permit for the construction of the Sand Motor included the requirement that there should be an effective monitoring of the possible effects of, above all:

- sand deposition and sand spray;
- effect of salt sea wind (salt spray);
- changes in vegetation and breeding birds;
- 'wetting' due to a rise in the groundwater level.

5.3.2 Sand deposition and sand spray

The construction of the Sand Motor led to the formation of a large sand flat seaward of Solleveld that was subject to the effect of the wind. That made it possible for more calcium-rich sand to drift into the Solleveld area.

More intensive drifting can have both positive and negative effects. On the one hand, the 'white dunes' habitat, where marram grass dominates,

benefits from drifting sand. The 'grey dunes' habitat also benefits from some degree of sand deposition. However, excessive amounts of sand that result in the vegetation being covered are detrimental to grey dunes. If so much sand starts to drift that large areas of bare sand are created, that is undesirable from every point of view because these locations cannot be assigned to any habitat type.

In addition to the Sand Motor, there are several factors that affect sand dynamics in this area, such as the coastal reinforcement, the construction of a cycle path, sweeping to clear sand off the cycle path, annual planting of marram grass and grazing in the part of the dunes bordering the sea before the reinforcement.

The total dynamic area in Solleveld in 2011-2015 remained approximately the same. No clear changes in the quality of the habitats in Solleveld emerged from the results. Nevertheless, some of the differences observed are worth mentioning:

- The sand dynamics just outside the Sand Motor, on the coastal reinforcement from 2010, increased considerably. A lot of sand is drifting in the landward direction from the Sand Motor to the coastal reinforcement. As a result, more natural dune forms, with bare areas and a lot of vigorous marram grass, have been created on the man-made profile of the coastal reinforcement. This is comparable with a rapidly-growing foredune. The planted marram (which is not a habitat type) is therefore changing into a 'white dunes' habitat.
- The zone located further landward (Zeerepen 1987) has actually become less dynamic since the construction of the Sand Motor. Here, there are fewer bare areas and locations with high levels of sand deposition. This decline in sand dynamics is probably attributable to the coastal reinforcement rather than the Sand Motor since the reinforcement captures virtually all the sand that drifts from the Sand Motor. The declining dynamics are partially offset by management interventions, particularly to prevent encroachment by shrubs, that include the removal of Hippophae rhamnoides (sea buckthorn).
- The dunes located even further landward are, as previously, not particularly dynamic. In broad terms, the area continues to stabilise, although some blowouts are increasing in size locally. This is probably not attributable to either the Sand Motor or the coastal reinforcement.

Measurements with sand gauges have shown that sand drifts inward when there are strong winds in particular. Since the construction of the Sand Motor, the amount of sand drifting to the outer Solleveld dunes has increased slightly on an annual basis. In absolute terms, however, the amount of sand drifting into the Solleveld area is limited; a great deal of sand ends up on the outer slope of the coastal reinforcement. It is entirely possible that the amount of sand spray will increase in the future if the coastal reinforcement as a whole becomes more dynamic.

5.3.3 Effect of salt spray

Salt spray is the process in which the wind transports salt particles to the outer dunes. These particles interfere with the development of shrubs.

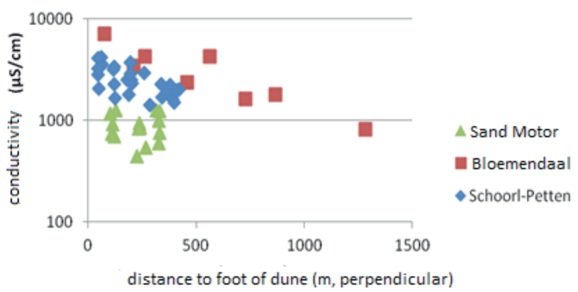


Figure 20: Salt spray at all Sand Motor monitoring locations compared with salt spray measurements during the same period elsewhere on the Dutch coast. Source: Vertegaal et al., 2016.

Salt spray is therefore important in terms of preserving the grey dunes habitat type. Without salt spray, bushy vegetation can grow that is less salt-tolerant than the plants that are characteristic for the dune grasslands belonging to this habitat type.

The surf zone is the main source of the salt. The distance from the surf zone to the outer dune determines how many particles reach the dunes. The construction of the Sand Motor displaced the surf zone in a seaward direction and so a reduction in salt spray was expected.

Measurements have shown that salt spray in the outer Solleveld dune was already relatively low prior to construction by comparison with other monitoring locations on the Dutch coast (Schoorl-Petten and Bloemendaal) (see Figure 20). It has also emerged that the Sand Motor has had a clear, statistically significant, impact on salt spray recently: a reduction of 26-33%. No conclusions can be drawn as yet about the extent to which this has a negative knock-on effect on vegetation (and therefore on the biotope of dune birds). This would require the results of ecological studies, which are still lacking because the data relating to the main parameter (vegetation structure) were not delivered on time.
It is possible that the reduction of salt spray in the dunes as a result of the construction of the Sand Motor is already declining: the Sand Motor has already been eroded on the seaward side and the surf zone has moved closer to the coast again.

5.3.4 Changes in vegetation and breeding birds

Vegetation

Between 2011 and 2015, there was almost no change in the habitat in the outer dunes at a relatively short distance from the Sand Motor. Some changes are apparent at more inland locations. These are changes in habitat types with closely related vegetation. The habitats can therefore consist of all sorts of transitional forms and relatively small changes in species composition can actually result in different classifications.
No clear changes have emerged in terms of the quality of the habitats. It is not yet known whether there has been any change in the total surface area of protected habitats. That is why the development of vegetation is being monitored by analysing aerial photos and comparing the situations in 2009 and 2015. The results of that analysis will become available during the course of 2016.

Breeding birds

Numerous rare birds that are characteristic for open dunes, dune lakes and dune marshes, thickets and woodland breed in the Solleveld dunes. The construction of the Sand Motor may be affecting the breeding bird population of Solleveld by causing changes in the vegetation.

The results of the monitoring of breeding birds in 2010-2013 show that changes in the numbers of some species in Solleveld differ from the national trends. Some species are doing better than the national trend; others are doing worse. The Sand Motor would not seem to be having a negative effect here.
Numbers of the great cormorant are increasing significantly in the central dunes. These birds forage at sea and use the Sand Motor to rest and dry their wings. The increasing numbers may be attributable to the construction of the Sand Motor but the species is also prospering in other dune areas.

5.3.5 'Wetting' due to a rise in the groundwater level

A lot of precipitation falling on the Sand Motor passes through the sand in the direction of the groundwater. Fresh water is lighter than the saline groundwater, resulting in a fresh rainwater lens that floats on the saline groundwater. If this

freshwater lens gets thicker, the groundwater level will rise. Generally speaking, this happens in all dune areas and adjacent beaches. The Sand Motor results in a larger area where a freshwater lens can form and changes the flows in the groundwater. This can result in risks for drinking water stocks. Consequently, shortly after the construction of the Sand Motor, water extraction wells were installed in the new row of dunes in the 2010 coastal reinforcement.

The changes may result in a rise in the water table in Solleveld. The ground may therefore become wet in relatively low locations and this may affect the vegetation in those locations, which include having protected habitats with dry conditions. The vegetation is therefore being monitored at four locations that may be susceptible to this process. That monitoring has shown that there were no changes in the number of species indicating changes in dry and wet conditions between 2012 in 2015. However, it cannot yet be concluded that there will be no effects in the long term. Changes in the water table of this kind are slow and they can also be 'concealed' by annual variations in drinking water production or precipitation. The research did not find any evidence to indicate that breeding birds are being affected by a rising water table.

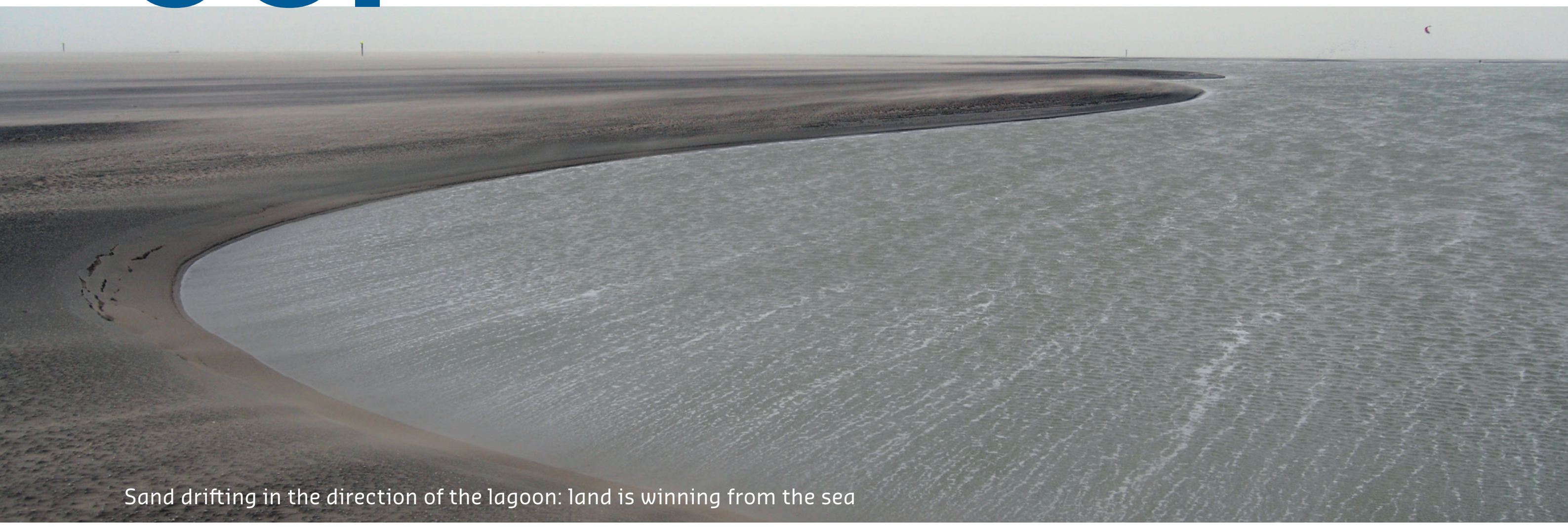
There were no data or reports available for this report relating to developments in groundwater levels as monitored by the Dunea water board. Collaboration between the management authorities was not yet optimal in this respect. It would be advisable to make improvements in this respectcooperation so that it is in order for the final MEP report (10 years after the construction of the Sand Motor).

5.4 Evaluation and summary

No safety problems for leisure visitors arose that could not be managed. The lifeguards have been using a smartphone app since 2013 that was developed for the monitoring and evaluation programme. The app provides information about possibly hazardous situations for bathers (bathing water safety model). Input for this model comes from the monitoring activities. The organisational arrangements for beach and bather safety on the Sand Motor have been implemented well. There is now less danger for bathers because flow velocities in the tidal channel have dropped off.

Proper management of the Sand Motor has proved possible due to the collection of data using Argus, radar, measurement buoys, aerial photographs etc. and there have been no major incidents.
There have been minor effects on existing ecological values in the Solleveld area. There has been a slight increase in the amount of sand (sand spray) blown into the outer dunes. There is now less salt spray landward of the Sand Motor. Only very minor effects on vegetation as a result of these two changes have been observed. No evidence has been found indicating effects on breeding birds as a result of changes in sand and salt spray. The short series of measurements have not yet shown any effects as a result of rising water tables ('wetting') but this possibility cannot yet be excluded.
It is not yet possible to make an adequate assessment of the effects on protected dune habitats because a complete survey of dune vegetation or habitats was not available in time for this evaluation. It is therefore not yet possible to conclude that effects on Solleveld as a result of the Sand Motor have been prevented.

06. The Sand Motor: knowledge and innovation



Sand drifting in the direction of the lagoon: land is winning from the sea

6.1 Introduction

Coastal research in the Netherlands has a long history. Uniquely, the Netherlands has long series of monitoring data. The elevation of sections perpendicular to the coast (JARKUS sections) has been measured annually since 1965 and Rijkswaterstaat has also been measuring the location of the low and high water lines and the dune foot since the mid-19th century.
Coastal research received a boost from the Coastal Genesis (Kustgenese) project, which was the basis for the decision in 1990 to maintain the coastline. That was followed by research programmes with comparable objectives. There is considerable interaction in the Netherlands between research, coastline management and coastal policy. That can be seen, for example, in the use of research results to optimise volumes and design of sand nourishment operations. The Sand Motor fits in with this tradition since it is associated with an extensive and long-term knowledge development programme. It has proven to be a unique 'laboratory' for coastline maintenance. The main research areas are morphological development of the beach and the surf zone, sand transport by the wind, the ecology of the shallow sea and surf zone, and the ecological effects of major nourishment operations.

The three main tracks for knowledge development are:

- the Sand Motor Monitoring and Evaluation Programme (MEP), for which this is the final report after the first four years of monitoring;
- NatureCoast, an STW interdisciplinary research programme with three post-doctorate and twelve doctorate researchers;
- NeMo (Nearshore Monitoring and Modelling), a European research project with three doctorate researchers established to increase our understanding of the interaction between dunes, beaches and the coastal foundation.

6.2 Application of the knowledge

The Sand Motor is generating large amounts of knowledge that can be used in Dutch coastline management. In particular, major advances have been made in terms of our understanding of mega-nourishment operations and the effects of nourishment operations on ecology and dune development. The close monitoring of the effects of the Sand Motor is teaching us a great deal about sediment composition and ecology in the surf zone, and about the area targeted by sand nourishment. Research into the ecological effects of sand nourishment began relatively recently.

An important objective associated with the Sand Motor is the generation of knowledge and innovation with the aim of determining to what extent coastline maintenance, and added value for leisure activities and nature, can be achieved in conjunction. This chapter will look at that objective.

The Sand Motor has led to the establishment of extensive and long data series, and those data can be analysed and used to design other nourishment operations. Other new knowledge and resources that are being developed and that can be used in coastline maintenance include:

- knowledge about measurement techniques (innovations in the Argus and the radar station at Kijkduin);
- the app for safe bathing (see Chapter 5);
- the role of a dune lake/lagoon in terms of capturing sand;
- the effect of storms on the morphological development of the beach and surf zone;
- governance: the administrative arrangements that are appropriate for an approach of this kind to coastline maintenance.

In view of the extensive development of the knowledge tracks referred to above, it is fair to conclude that the objective of 'knowledge development' is being achieved. The question of 'to what extent coastline maintenance, and added value for leisure activities and nature, can be achieved in conjunction' is more difficult to answer. The conclusion from this MEP is that shared added value can certainly be created but that natural values that are susceptible to disruption, and that are often the most highly-prized, cannot be created without zoning leisure activities.

6.3 Dutch business and institutes

The Dutch approach to coastline maintenance has a international reputation and it is therefore an important 'export product' for business. From this point of view, there is considerable national and international interest in the Sand Motor.The Sand Motor pilot project was also intended to give business and research institutes the opportunity to acquire knowledge and experience in the area of innovative coastline maintenance. 'Building with Nature', upon which the Sand Motor is based, is a priority for the hydraulic engineering sector and it is being propagated by, among others, Ecoshape, a joint effort involving dredging and engineering companies, the knowledge sector and government. The hydraulic engineering sector can use the Sand Motor as a case to demonstrate abroad that hydraulic engineering and ecology can go hand in hand to benefit coastal protection, economic development and the living environment. There are several locations outside the Netherlands where Sand Motor-like solutions are being considered, both in Europe (Sweden, United Kingdom, Belgium) and elsewhere (United States, Mexico).

Annex 1 Secondary objectives, evaluation questions, provisional answers

FACT SHEET 1.1	
Policy objective 1: Encouraging natural dune growth in the coastal zone between Hook of Holland and Scheveningen for the purposes of protection, nature and leisure activities	
Secondary objective: coastal protection	
Evaluation question *Does the Sand Motor result, through natural dune growth, in improved coastal protection in the coastal zone between Hook of Holland and Scheveningen?*	***Answer to evaluation question*** *Because of the increase in the sand stocks, all the important variables relating to protection have been improved further. However, without the Sand Motor, the area was already adequately protected and would have remained so using standard coastline maintenance approaches involving sand nourishment.*
Hypothesis EF1-1a The Sand Motor and supplementary nourishment operations provide protection for the coastal zone between Hook of Holland and Scheveningen for 50 years and result in dune growth and therefore improved protection by comparison with the standard nourishment programme between 1990 and 2010.	**Test hypothesis** The dune volume has increased. The coastal reinforcement had already resulted in a dune volume that was adequate to counteract erosion for the next 50 years. That period has now been extended. Flood defences are now developing more strongly, particularly near the Sand Motor, than they would have using the standard nourishment approach.
Hypothesis EF1-1b With the Sand Motor, less sand in total will be required for the maintenance of the base coastline (BKL) on the coast between Hook of Holland and Scheveningen for a period of 20 years.	**Test hypothesis** The total volume of sand used for the Sand Motor (18.7 million m^3) and the nourishment operation in 2013 (1.5 million m^3) near Vlugtenburg already amount to more than 20 times the annual nourishment volume in the standard nourishment programme between 1990 and 2007 (15.6 million m^3).
Hypothesis EF1-1c With the Sand Motor and supplementary nourishment operations, the sand balance for the coastal foundation will be maintained in the coastal zone between Hook of Holland and Scheveningen for at least 50 years assuming sea-level rise of 3 mm a year.	**Test hypothesis** The amount of sand brought in is almost enough for the purposes of matching sea-level rise of 3 mm a year for a period of 50 years (18.7 million m^3 of sand has been brought in, and 20 million m^3 will be needed).

FACT SHEET 1.2

Policy objective 1: Encouraging natural dune growth in the coastal zone between Hook of Holland and Scheveningen for the purposes of protection, nature and leisure activities

Secondary objective: nature

Evaluation question	***Overall development of secondary objective***
No separate evaluation question has been drafted for this secondary objective and there are therefore no hypotheses. New ecological values as a result of the formation of young dunes are discussed under Objective 3 in fact sheet 3.1. *The effects in the existing dunes are discussed under Objective 4 (management, secondary objective 'nature management', in fact sheet 4.2.)*	*There is more space for dynamic management and there is dune growth. However, these results would also have been achieved using regular management approaches such as sand nourishment.*

FACT SHEET 1.3

Policy objective 1: Encouraging natural dune growth in the coastal zone between Hook of Holland and Scheveningen for the purposes of protection, nature and leisure activities

Secondary objective: leisure

Evaluation question	***Overall development of secondary objective***
No separate evaluation question has been drafted for this secondary objective and there are therefore no hypotheses. The effect on leisure activities is evaluated in fact sheet 3.2.	*There are more dry areas and more tidal areas, almost all of which are accessible to leisure visitors. However, this development is not located in 'broader and more robust dunes', which was part of this secondary objective.*

FACT SHEET 2.1

Policy objective 2: Generating knowledge development and innovation to answer the question of the extent to which coastline maintenance can deliver added value for leisure and nature

Secondary objective: development of physical knowledge

Evaluation question	*Answer to evaluation question*
Does the Sand Motor deliver new physical knowledge that will allow the combination of coastline maintenance and added value for nature and leisure activities?	*A great deal of new physical knowledge is being developed through the MEP, NatureCoast and NeMo. It can be used during the design of new coastal interventions to generate added value for nature and leisure activities. There has been little specific research looking at 'the added value for nature and leisure activities in conjunction'. It is possible to draw important conclusions. These have been described in the 'usability study' (see sources no. 4).*
Hypothesis EF 2-1a The Sand Motor is delivering physical knowledge that can explain the morphological changes on the basis of underlying factors, making more efficient coastline management possible.	**Test hypothesis** See the answer to the evaluation question above.
Hypothesis EF 2-1b The Sand Motor pilot project contributes to improved forecasts of hazardous bathing situations, allowing for more effective supervision of bather safety.	**Test hypothesis** See the answers to fact sheet 4.1.

FACT SHEET 2.2

Policy objective 2: Generating knowledge development and innovation to answer the question of the extent to which coastline maintenance can deliver added value for leisure and nature

Secondary objective: ecological knowledge development

Evaluation question *What knowledge is needed to determine the extent to which a Sand Motor generates added value for nature by comparison with standard nourishment operations?*	***Answer to evaluation question*** *See the tested hypotheses below for the answer to this question*
Hypothesis EF 2-2a The construction of the Sand Motor will lead to a change in the gradients in sediment composition.	**Test hypothesis** It is clear that the location of the Sand Motor has an effect on the redistribution of sediment in the area near the Sand Motor.
Hypothesis EF 2-2b The one-off deposition of a large amount of sand results in a different composition of the benthic fauna population in the shallow coastal zone where longer-living species are typically found.	**Test hypothesis** It is expected that any effects on the development of longer-living species will only emerge after a longer period of time (the next 5 to 10 years).
Hypothesis EF 2-2c The relative sheltered location of the area on the northern edge of the Sand Motor has a positive effect on juvenile fish and epibenthos	**Test hypothesis** It cannot be concluded, given the limitations of statistical differentiation, that the sheltered northern area has had a positive effect on the population of juvenile fish.
Hypothesis EF 2-2d Seabirds that feed on shellfish and fish in the shallow coastal zone also benefit from the positive effect of the Sand Motor on benthos and young fish.	**Test hypothesis** There are indications that the area of the Sand Motor is visited more by some species of bird and that there is also potential in that respect. The lagoon, for example, has a positive effect on some species of waders, seagulls and cormorants.
Hypothesis EF 2-2e The Sand Motor has a positive effect on marine mammals in the area.	**Test hypothesis** The available evidence does not confirm this hypothesis. Mammals were already found on this stretch of the coast in the past and their numbers have not risen or fallen measurably.

FACT SHEET 2.3

Policy objective 2: Generating knowledge development and innovation to answer the question of the extent to which coastline maintenance can deliver added value for leisure and nature

Secondary objective: spin-off of knowledge and innovation
(This objective was formulated for the policy evaluation as a supplement to the MEP Implementation Programme.)

Evaluation question	Answer to evaluation question
To what extent are the knowledge and methodology that have been developed more widely applicable to the development of sandy strategies?	*The knowledge and methodology can be used, for example in the 'Kustgenese' programme. This applies particularly to the plans and designs for future Sand Motor-like nourishment operations (if morphological response, ecological effects, the increase in the volume of the dune area and so on are applicable criteria). The knowledge and methodology can also be used to 'export' Dutch knowledge about sandy strategies. A picture has been established of how the Sand Motor works and of the success factors in the technical, ecological, managerial organisational and social areas. This will allow better predictions (with models) in the future of the possible success of mega-nourishment operations on the Dutch coast. Our knowledge in this area is being extended all the time and considerable progress was made by late 2015, particularly because the university activities (NeMo, NatureCoast) were now well under way. It is very difficult to quantify to what degree our knowledge will be extended. Only limited research has been conducted into the Sand Motor success factors on the organisational side. It was suggested in the Monitoring and Evaluation Plan that a management survey/interviews would be useful to establish a clearer idea of the quality of collaboration after the preparation phase. This suggestion was implemented on a structural basis for the first time in the policy evaluation (see sources no. 5). It is not known whether there has been an evaluation report looking at the tender procedure for the construction.*
Evaluation question *To what extent is the developed knowledge applied in innovative approaches in the Netherlands and elsewhere*	***Answer to evaluation question*** *See the answer to the last evaluation question.*
Evaluation question *To what extent has knowledge been dissemina-ted, both in the Netherlands and elsewhere?*	***Answer to evaluation question*** *The MEP does not supply any input for this question.*

FACT SHEET 3.1

Policy objective 3: Creating an additional appealing leisure and nature area on the Delfland Coast

Secondary objective: add nature area

Evaluation question	*Answer to evaluation question*
Does the Sand Motor result in the creation of an additional nature area on the Sand Motor itself and in the young dunes alongside the existing dunes?	*This question has been split up into sub-questions (instead of testing hypotheses)*
Sub-question ND1-01 To what extent are wider, more natural and dynamic dunes developing?	**Answer to sub-question** The dune area has hardly got any wider at all in the course of four years. The zone with planted marram grass on the coastal reinforcement is now higher and more natural. Dunes of the 'white dunes' habitat type have formed here. The ‘wider and more robust dunes’ have therefore not formed yet. A ‘high-grade new dune habitat’ is, in effect, only to be found on the former slope of the coastal reinforcement.
Sub-question ND1-02 What is the effect on quality of a dynamic approach to construction and management?	**Answer to sub-question** This question cannot be answered satisfactorily on the basis of monitoring. In addition, Dutch coastline management has had a dynamic approach to construction and management for years. It is clear that the design has contributed to diversity in wet environments. There have only been small-scale improvements in the ecological assets of beaches and dunes. A more focused design and specific management would in all probability result in the creation of more ecological values.
Sub-question ND1-03 What is the effect of leisure management (‘flexible zoning’)?	**Answer to sub-question** No restrictions on access means that nature that is sensitive to disruption is virtually absent from the Sand Motor. No zoning arrangements were made.

Evaluation question *How does temporary new nature develop in the intertidal area and the lagoon on the Sand Motor?*	*Answer to evaluation question* *See the tested hypotheses below for the answer to this question.*
Hypothesis EF3-1b1 As a result of the presence of sheltered areas (lagoon) and exposed areas (on the seaward side), the composition of the sediment of the sand hook varies.	**Test hypothesis** The hypothesis would appear to be supported by the figures.
Hypothesis EF3-1b2 The construction of the Sand Motor will result in an enhancement of ecological values in the intertidal area and the shallow coastal zone as a result of new habitats and habitat variation.	**Test hypothesis** The lagoon resulted in an enhancement of ecological values (specific habitats), particularly in the first year. After that time, the ecological values in the deeper parts of the lagoon declined quickly as water quality worsened. The ecological values in the shallow edges of the lagoon were maintained.
Hypothesis EF3-1b3 The steep gradients (exposed beach and sheltered lagoon) resulting from the creation of the Sand Motor will be seen in a change, and more variation, in the benthic fauna.	**Test hypothesis** There is a clear difference in the benthic fauna in the sheltered lagoon and on the exposed side of the Sand Motor. Diversity in the area as a whole has increased.
Hypothesis EF3-1b4 The relatively sheltered location of the lagoon and the high levels of available food will further enhance the nursery function of the area.	**Test hypothesis** The possible positive effect would only appear to have lasted for a short time.
Hypothesis EF3-1b5 The lagoon will lead to a rise in the wader and seabird populations in the area.	**Test hypothesis** A number of species of bird benefited from the presence of the lagoon (waders, seagulls, cormorants).
Hypothesis EF3-1b6 The sand hook will result in a feeding and resting area for sea mammals.	**Test hypothesis** The available evidence does not confirm this hypothesis.

FACT SHEET 3.2

Policy objective 3: Creating an additional appealing leisure and nature area on the Delfland Coast

Secondary objective: add leisure area

Evaluation question *Does the Sand Motor contribute to the creation of more space for leisure activities?*	***Answer to evaluation question*** *There are more dry areas and tidal areas, almost all of which are accessible to leisure visitors. However, the space for leisure activities is not the result of the growth of dunes.* *Hypotheses were also developed to answer this question. The MEP did not report separately on this area but conclusions can be drawn.*
Hypothesis EF3-2a There will be room on the hook of the Sand Motor for leisure activities immediately upon completion.	**Test hypothesis** This has indeed been the case. There are no restrictions on access to the area.
Hypothesis EF3-2b The dynamics of the Sand Motor will be seen in a changing pattern of leisure activities.	**Test hypothesis** There has been an increase in non-intensive leisure activities and kite surfing on the Sand Motor itself. The number of visitors to the beach has declined on this stretch of coast.
Hypothesis EF3-2c The new area covered by the Sand Motor will encourage non-intensive leisure activities	**Test hypothesis** That is indeed the case; see also hypothesis 3-2b.
Hypothesis EF3-2d As a result of dune growth, more space will be created for leisure activities.	**Test hypothesis** The dunes on the Sand Motor have hardly increased in size at all.

FACT SHEET 4.1

Objective 4 (management): The collection of sufficient accurate information to manage the Sand Motor and the surroundings properly

Secondary objective: managing leisure safety

Evaluation question	*Answer to evaluation question*
Will the Sand Motor have a negative impact on leisure safety and can that be prevented by introducing control measures	*The organisational arrangements for beach and bather safety on the Sand Motor have been implemented well. Hypotheses were also developed to answer this question. The MEP did not report separately on this area but conclusions can be drawn.*
Hypothesis EF4-1a Bather safety can be managed around the Sand Motor by the introduction of rescue services, zoning and information facilities.	**Test hypothesis** No safety problems for leisure visitors arose that could not be managed. There is now less danger for bathers because flow velocities in the tidal channel have dropped off. The lifeguards have been using a smartphone app since 2013 that was developed for the monitoring and evaluation programme. The app provides information about possibly hazardous situations for bathers (bathing water safety model). Input for this model comes from the monitoring activities.
Hypothesis EF4-1b Health risks associated with compromised bathing water quality in the lagoon and/or the dune lake can be prevented by taking steps such as posting warnings and prohibiting bathing.	**Test hypothesis** No problems for leisure visitors arose that could not be managed.
Hypothesis EF4-1c Protecting visitors from the risks of quicksand involves taking steps such as monitoring, clearance and, where appropriate, prohibiting access.	**Test hypothesis** No safety problems for leisure visitors arose that could not be managed.
Hypothesis EF4-1d Protecting visitors from the risks of cliffs and/or steep edges involves taking steps such as monitoring, degrading hazardous features by driving over them and, where appropriate, prohibiting access.	**Test hypothesis** No safety problems for leisure visitors arose that could not be managed.
Hypothesis EF4-1e Siltation in the lagoon is possible and it may result in the development of a beach with vegetation but the appeal for leisure visitors can be maintained by taking the appropriate management steps.	**Test hypothesis** No problems for leisure visitors arose that could not be managed.

FACT SHEET 4.2

Objective 4 (management): The collection of sufficient accurate information to manage the Sand Motor and the surroundings properly

Secondary objective: structuring

Evaluation question	*Answer to evaluation question*
To what extent are leisure and nature objectives on and around the Sand Motor compatible	*It certainly proved possible to create added value for both objectives. However, valuable and disruption-sensitive nature cannot be created without zoning leisure activities. There has been no zoning of this kind.*
Hypothesis EF4-2a The dynamic zoning of leisure and nature on the Sand Motor will allow these two functions to be combined optimally alongside one another.	**Test hypothesis** There has been no dynamic zoning.
Hypothesis EF4-2b Het valt nauwelijks te verwachten dat ten It is hardly to be expected that 'illegal entry' to the Solleveld area will increase as a result of the construction of the Sand Motor, with the resulting disturbance of target species..	**Test hypothesis** It would appear to be the case that this hypothesis can be confirmed. There would, nevertheless, appear to be additional disturbance of breeding birds in the outer Solleveld dunes but this is probably the result of the construction of the cycle path in the coastal reinforcement. There has been no study of the extent to which the presence of the Sand Motor is a factor that determines the number of users of that cycle path.

FACT SHEET 4.3

Objective 4 (management): The collection of sufficient accurate information to manage the Sand Motor and the surroundings properly

Secondary objective: groundwater

Evaluation question	*Answer to evaluation question*
Is it possible to ensure that the Sand Motor will not have any undesirable effects on the groundwater?	*The hypotheses drawn up for this management objective cannot be addressed in adequate detail on the basis of the reports provided for the MEP. However, no effects have yet been observed on vegetation.* *In general terms, the following conclusions can be drawn: The dune lake was introduced in part in order to ensure that the Sand Motor would not have any negative impact on groundwater flows in the Solleveld drinking water catchment area. It has been effective in this respect. Furthermore, a drainage and monitoring system has been installed along the cycle path that will regulate the groundwater level to a considerable extent. The measurement series is still short and so it is not yet possible to identify any impact of rising water tables ('wetting') in locations that are susceptible to this effect.*

FACT SHEET 4.4

Objective 4 (management): The collection of sufficient accurate information to manage the Sand Motor and the surroundings properly

Secondary objective: nature management

Evaluation question *Is it possible to prevent negative effects of the new dune area on ecological values in the existing dune area*	***Answer to evaluation question*** *Answers to sub-questions (rather than hypotheses) for this evaluation question:*
Sub-question ND2-01 What effect will changes in sand spray have on the existing outer dunes?	**Answer to sub-question** There is more sand spray in the outer dunes alongside the Sand Motor and this has a minor impact on existing ecological values in Solleveld. It is unclear whether there has been an increase by comparison with the situation prior to 2010 because the coastal reinforcement in 2010/2011 also plays a role here.
Sub-question ND2-02a What effect will changes in salt spray have on the existing outer dunes?	**Answer to sub-question** There is now less salt spray landward of the Sand Motor and this may have a minor impact on existing ecological values in Solleveld. To prevent negative effects, agreements have been made with site managers and management activities in the Solleveld outer dunes have been intensified.
Sub-question ND2-02b What is the effect of management (grazing) in this respect?	**Answer to sub-question** Grazing is one of the management tools used to offset the negative effects of changes in salt and sand spray, and in particular the spread of vegetation and thickets. The effect on the vegetation structure (encroachment by shrubs) has not yet been studied because the data about vegetation were not delivered in time. Grazing in the 'Zeerepen 1987' area has not yet been documented adequately, but that does not pose major problems.
Sub-question ND2-03 What is the effect of changes in sand and salt spray in the Dunea area behind the current third row of dunes?	**Answer to sub-question** See answers ND2-01 and ND2-02a for the outer dunes. However, this question refers to the 'central dunes', which have hardly been studied at all.
Sub-question ND2-04 What is the effect of changes in water levels in the Dunea area behind the third row of dunes?	**Answer to sub-question** See the comments for management objective 3.

FACT SHEET 4.5

Objective 4 (management): The collection of sufficient accurate information to manage the Sand Motor and the surroundings properly

Secondary objective: water-based infrastructure

Evaluation question	*Answer to evaluation question*
Will the Sand Motor have a negative impact on water-based infrastructure and can that be prevented by introducing control measures?	*See the hypotheses below for the answer to this question.*
Hypothese EF4-5a The Sand Motor will not lead to additional silting up of the entrance channels leading to the ports of Rotterdam and Scheveningen.	**Toets hypothese** The available monitoring results contain no data about effects in this respect.
Hypothese EF4-5b The Sand Motor will not result in the silting up the outlet of the J.J.J.M. van den Burg pumping station.	**Toets hypothese** The available monitoring results contain no data about effects in this respect.

Annex 2 Components of monitoring programme

Theme	Content
Meteorological dynamics and hydrodynamics	Waves and currents Measurements of bathing-water quality Rip tides and rescue operations
Beach and foreshore; morphology	Elevation of hinterland Elevation of dunes and beach Elevation of coast Nourishment data Dredging and deposition data Sediment composition Wave and breaker bar data Elevation of foreshore
Beach and foreshore; ecology	Benthos, coastal zone Benthos, beach Juvenile fish and epibenthos Seabirds Marine mammals Ecotopes
Nature/dunes (report from Witteveen and Bos)	Sand dynamics Dynamic geomorphology Elevation changes Fine sand deposition Salt spray Wind speeds Water levels Vegetation/habitats Vegetation/habitats, locations susceptible to 'wetting' Vegetation uptake of sand spray Higher plants in Solleveld Breeding birds in Solleveld Embryonic dunes on Sand Motor Flora on Sand Motor Breeding birds on Sand Motor
Leisure	Counts and surveys

Annex 3 Sources

Reports quoted in text:

1 DHV, Monitoring- en evaluatieplan Zandmotor, 2010.
2 Tonnon et al. Uitvoeringsprogramma Monitoring en Evaluatie Pilot Zandmotor. Deltares, 2011.
3 DHV, Projectnota/ MER. Aanleg en zandwinning Zandmotor Delflandse kust, 2010.

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4 Oost et al., in prep. Bruikbaarheidsstudie zandmotor. Deltares, 2016.
5 Buitenkamp et al., in prep. Beleidsevaluatie zandmotor. Anantis and RHDHV, 2016.
6 De Boer et al., 'A framework for sandy strategy development - with a quick scan for (co-)financing potential', Ecoshape, 2015.

Basic Reports for MEP:

- Shore, Morfologische ontwikkeling van de Zandmotor pilot in de periode 2 tot 4,5 jaar na aanleg, 2016.
- Tonnon en Nederhoff, Monitoring en Evaluatie Pilot Zandmotor, eindevaluatie onderdeel morfologie 2015. Deltares, 2016.
- Wijsman et al., Monitoring en Evaluatie Pilot Zandmotor Fase 2; evaluatie benthos, vis, vogels en zeezoogdieren 2010-2014. IMARES and Deltares, 2015.
- Witteveen en Bos et al., Monitoring Pilot Zandmotor, onderdeel duinen. Evaluatierapport 2011-2015, 2016.
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- Boon, Tonnon, Swinkels en Stolte, Pilot Monitoring en Evaluatie-programma Zandmotor - fase 2. Analyses, Hypothesen en Evaluatie, Werkdocument
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- Dulfer et al., Hoe bruikbaar is de Zandmotor? Eerste tussentijdse verkenning naar de haalbaarheid en bruikbaarheid van de pilot Zandmotor 2011-2013. Published by Rijkswaterstaat, 2014.
- Ebbens, E. and Fiselier J., Monitoring- en evaluatieplan Zandmotor. DHV, Report, 38 pages. 2010
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IMARES WAGENINGEN UR

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Vertegaal Ecologisch Advies

Bureau Landwijzer
tekst - water - kust - landschap