Engineering: Building with Nature

Case – Sand Motor Delfland

Adapted from the Deltares PublicWiki Case - Sand Motor Delfland by Graciela Nava Guerrero and Prof. Jill H. Slinger for use in the MOOC Engineering: Building with Nature 101x of the Delft University of Technology.

This document provides a synthesis of information on the Sand Engine, the case used as iconic example in the fourth week of the MOOC Engineering: Building with Nature 101x. Please note that as you familiarize yourself with the material, and work through the example case for Assignment 4, you may also need to look for additional information.

Title	Sand Motor Delfland
Location	Coast of Delfland (Netherlands)
Date	March 2011 – November 2011
Main problem owner	Rijkswaterstraat – the operational arm of the Dutch Ministry of Infrastructure and Environment
Companies	Province of South Holland, Ecoshape, DHV, Deltares, Van Oord, Boskalis
Costs	60 million euro for construction, and additional costs for studies and monitoring

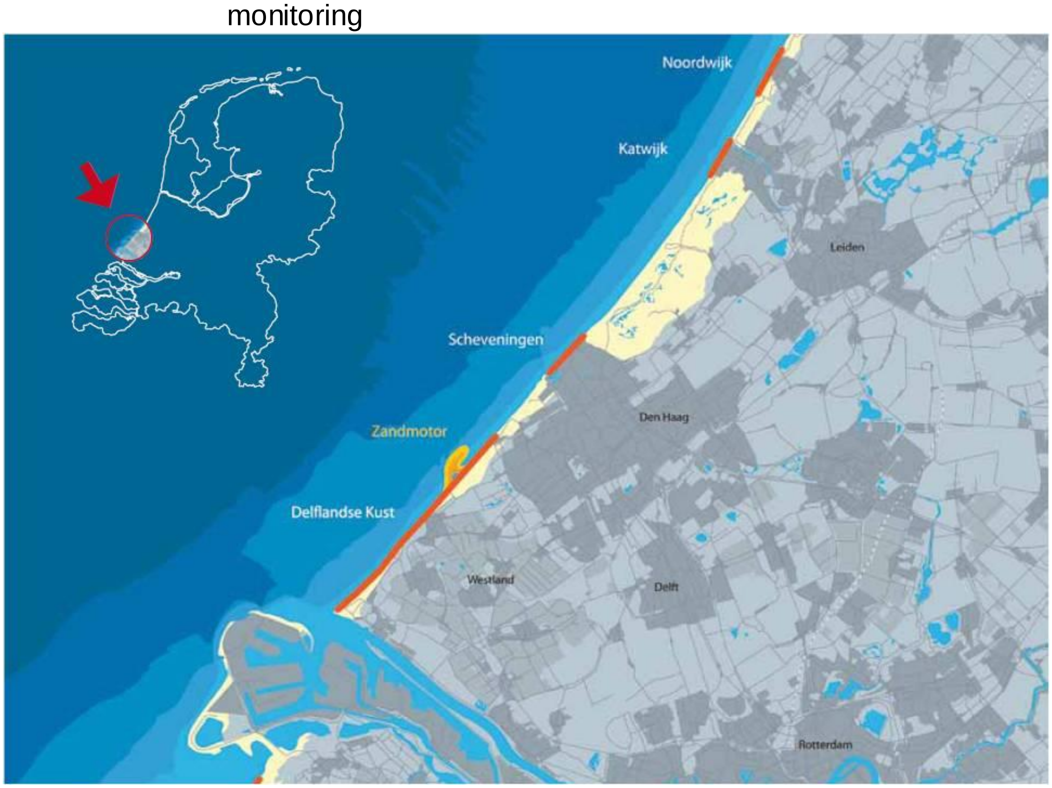

Figure 1 Location of Sand Motor (Source: Projectbureau Pilot Sand Motor)

1. **General description of societal needs**
   a. **Expressed need or required service**

The coast of Delfland, a coastal stretch of about 14 km between Hook of Holland and The Hague (Netherlands), is characterized by dunes, and a net northward longshore transport of sand, driven by predominantly south-westerly winds and waves. The coast is maintained by regular supplies of sand, formerly mostly in the form of beach nourishments, more recently in the form of foreshore nourishments, typically once every 4 or 5 years. The nourishment need for the Delfland coast is in the order of 300.000 to 500.000 m^3 of sediment annually.

Sea level rise will lead to a substantial increase in the nourishment need for two reasons. The first reason is that erosive processes will intensify, meaning that maintaining the present coastline will require more nourishment. The second reason is the Dutch efforts to maintain the entire coastal profile down to the 20-meter depth contour. This concerted effort is in place because the deeper part of the coastal profile (the coastal foundation) is also considered vital for dynamically maintaining the coast, and preventing structural erosion.

In order to maintain the coastline and the coastal foundation of the Delfland stretch while sea level rises during the next 20 years, a sediment volume in the order of 20 million m^3 is needed. The corresponding foreshore nourishments (at intervals of 4 to 5 years) disturb the (underwater) ecosystem significantly. Given that the system is not fully recovered before the next nourishment arrives, the high nourishment frequency means that the system will be in a more or less permanent state of disturbance.

This raises the question of whether the practice of periodic small-scale nourishment is the most suitable or environmentally friendly way of coastal maintenance.

   b. **Stakeholders who react directly with the ecosystem and how they do this**[1]

Inhabitants and tourists of the coast of Delfland who undertake both contact (e.g. swimming) and non-contact recreation (walking, cycling). Certain inhabitants derive their income directly from the beaches and people using the beaches e.g. beach restaurant owners. Inhabitants value living near the beach and this is reflected in higher property values closer to the coast, yet protected from flooding. The dunes also act as flood defence barrier for the hinterland, and much of the water supply for South Holland derives from the groundwater filtering through the dunes. Aesthetic and cultural values are associated with the South Holland coast.

   c. **Interested and affected parties.**

Inhabitants and tourists of the coast of Delfland, Province of South Holland, Water Board of Delfland, Ecoshape, DHV, Deltares, Van Oord, Boskalis, Westland municipality, municipalities of the Hague and of Rotterdam, Milieufederatie Zuid Holland and the World Wildlife Fund.

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[1] The focus of this course lies on integrating between engineering and ecosystem design principles and NOT on the societal aspects of BwN. A full application of the Building with Nature concept would require that the societal context and requirements are included fully from the outset.

- The Province of South-Holland wished to give nature and recreation in the area a boost and to have an icon of innovation.
- The Ministry of Infrastructure and Environment - Rijkswaterstaat is responsible for long-term coastal safety by maintaining the coastline and the sediment volume of the coastal foundation.
- The Water Board of Delfland is responsible for flood defence system maintenance.
- The Westland municipality, the municipalities of The Hague and of Rotterdam, Milieufederatie Zuid Holland, the World Wildlife Fund and Ecoshape were also interested.

d. Sources of ecosystem knowledge and expertise.

Milieufederatie Zuid Holland, the World Wildlife Fund, Research and Education institutions, Inhabitants and tourists of the coast of Delfland, Province of South Holland, Water Board of Delfland, Ecoshape, DHV, Deltares, Van Oord, Boskalis, Westland municipality, municipalities of the Hague and of Rotterdam.

2. Project solutions

An alternative to the periodic nourishments (every 4 or 5 years) is a mega-nourishment applied every 15 to 30 years. The main advantage of a mega-nourishment over periodic smaller-scale nourishment is less ecosystem disturbance. Moreover, the unit price of the large amount of sand is likely to be less than that of smaller amounts at a time. Nature does most of the distribution work and there are additional benefits (recreation, increased nature value, extension of the dune area). Whether this outweighs the costs of the earlier capital investment, however, remains to be seen.

To investigate the effectiveness of a mega-nourishment, a pilot and demonstration project “Sand Motor” was proposed for the Delfland Coast. It involved depositing a large amount of sand (21.5 million m3) on the foreshore and letting the forces of nature (waves, tide, wind) distribute it over the coastal profile and along the shore. In this way, mega-nourishments gradually feed the dune ridge over a long stretch of coast and over a timespan of a few decades, thus contributing to safety against flooding. Large nourishments also create opportunities for nature development and recreation, important supplementary goals of a mega-nourishment.

3. Costs and benefits

Considering only the design and construction costs in the light of the primary function (maintaining the coastal flood defence system), the traditional periodic nourishment practice might be more cost-efficient than a Sand Engine. Yet, there was a strong preference for a mega-nourishment, as additionally, this would create an island or peninsula that would create new possibilities for recreation and nature development. These possibilities, the showcasing of (dredging) expertise, the potential learning experiences and the fact that the area might not need maintenance for the next 20 years and so there would be less frequent disturbance of environment, weighed more heavily than the lower cost-effectiveness for coastal defence (in the short term). Whether the Sand Motor will turn out to be a better deal, economically and ecologically, in the long run is the subject of ongoing research and monitoring.

4. Planning and Design

a. Initiation

The first ideas for the Sand Motor date back to the beginning of this century. Initiators were the Province of South Holland and the Ministry of Infrastructure and Environment (Rijkswaterstaat). A number of developments were brought together in the initiation phase, which started in 2007:

- The 'Geluk' parliamentary resolution of 2003, requiring the exploration of ‘an integral, multifunctional and sustainable, phased expansion of the coast between Hook of Holland and Scheveningen’.
- The advice of the Tielrooij Committee of the Province South Holland, in their ‘coast booklet’ (In Dutch: ‘kustboekje’) of 2006.
- The development of the idea of mega-nourishments in the Rijkswaterstaat innovation program (WINN), reflecting the ambition of Rijkswaterstaat to explore methods to scale up coastal nourishments.

b. Exploration phase

The Province of South Holland led the exploration phase of the Sand Motor. In a pre-feasibility study (Bruens et al, 2007), different shapes and locations of a Sand Motor were proposed and investigated. Consultant Royal Haskoning was hired to guide the process towards an ambition agreement between the main actors and to design a project development process. In April 2008 the ambition agreement was signed and the planning phase started.

c. Planning phase

The planning phase included the Environmental Impact Assessment (EIA) process. A strategic impact assessment (Grontmij, 2008) and an Environmental Impact Assessment (DHV, 2009) were carried out. In preparation, several alternative designs of a Sand Motor were studied and several scenarios for sustainable long-term nourishment strategies were evaluated (Mulder et al, 2010). The EIA procedure was meant to identify the most feasible and environmentally friendly alternatives for nourishment-based coastal management. Four alternatives were considered, each with a construction volume of 20 million m3 of sand (see Figure 2 to the left):

1. the original nourishment regime (4 to 5 year frequency) with larger amounts of sand,
2. a large foreshore nourishment,
3. a detached island 1 km off the coast, and
4. a peninsula (different locations and shape) attached to the coast.

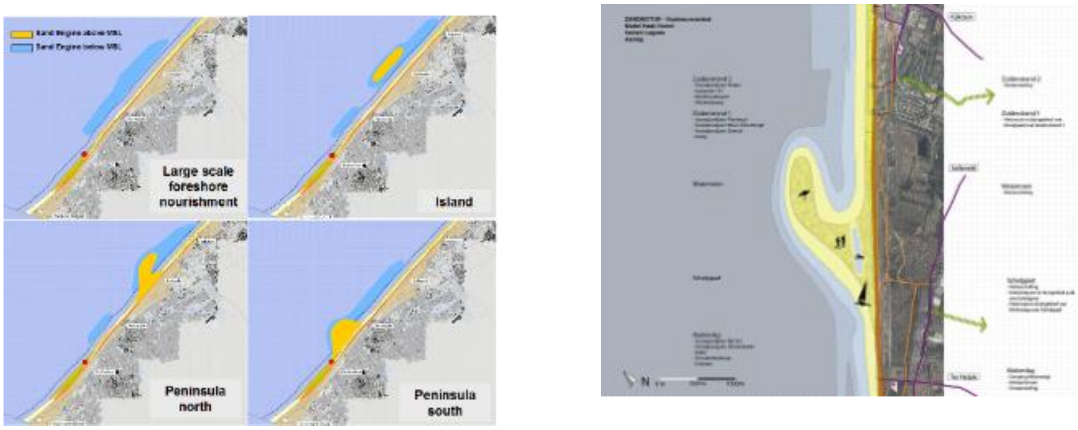

Figure 2 To the left: Alternative nourishment schemes. To the right: preferred alternative, Peninsula.

The design challenge was to locate and design a cost-effective mega nourishment that would serve coastal management and long-term coastal protection, and offer opportunities to nature and recreation, without having negative impacts on existing nature areas and recreation. Morphological and ecological processes were studied in order to assess the costs and the impacts of these alternatives.

The peninsula (see Figure 2 to the right): had the best scores in the EIA as far as aspects such as safety, recreation and knowledge development were concerned. The shape of a shore-attached hook gives more variation than an island or a foreshore nourishment, as a sheltered zone is created between the hook and the beach which is likely to develop into a temporary lagoon.

Several locations were considered for the peninsula. Given the nature of the pilot, the dynamic character of the Sand Motor and the existing functions and infrastructures, the Solleveld reach (between Kijkduin and Ter Heijde) was selected. At this location the Sand Motor would have a limited (direct) effect on areas with extensive recreational functions, whereas the area is still accessible for recreation and is “central enough” to supply sediment to most of the Delfland Coast.

The Sand Motor is a pilot project. It is the first mega-nourishment of this size and form, with an anticipated functional lifespan of more than 20 years. Until the Sand Motor, the coast was maintained with periodic nourishments parallel to the coast or on the beach. The peninsula-shape is a novelty. The largest periodic nourishments are in the order of 5 to 7 million m^3, with a functional lifespan of 5 to 10 years, at the most.

Final decisions regarding the form, location and volume of the Sand Motor depended on a deep understanding of its anticipated dynamic behaviour over the first 20 years. Accordngly, extensive long term morphological studies were conducted to underpin the initial design, and explore the functioning of the Sand Motor within the first 20 years after construction. An understanding of the bandwidth of uncertainty associated with the dynamic behaviour of the Sand Motor over time was generated. Several aspects critical to beach safety, such as beach development and rip current formation, were handled with smaller-scale morphological models.

Issues that could not be predicted or dealt with in the design were included explicitly in the management and monitoring programmes.

i. Tender request

After the location and volume were determined in the EIA process, the Sand Motor was contracted with a set maximum budget. The Design and Construct contract was awarded to the contractor that could deliver the largest volume of sand for the set price.

ii. Management

Knowledge development in the design phase of the Sand Motor experiment focused on three different activities: design development, design assessment to select the preferred alternative, and the optimization of the preferred design. Integration of the design and assessment activities led to a multifunctional design contributing to coastal safety, nature, recreation and knowledge development.

Important enabling factors for realizing the Sand Motor in the planning phase were:

1. Involvement of a broad representation of actors and stakeholders in the project organization. The Province, national ministries, municipalities, an environmental NGO and the Delfland Waterboard, signed the ambition agreement.

   In the project team, these parties are represented and complemented with consultants and knowledge institutes (Deltares), NGOs and other parties relevant to the process. This broad and intensive involvement of actors and stakeholders turned out to positively influence the general support for the project.

2. The design alternatives for the Sand Motor came from the pre-feasibility study (Bruens et al, 2007) and three design workshops held in the summer of 2008. In addition, experts from several disciplines such as morphology, ecology and dredging operation were also involved.

   During the workshops all identified stakeholders were represented. This integrated approach was instrumental to achieving the necessary multi-functional design.

3. The location of the Sand Motor was subject to few legal restrictions, the only one being that the environment should not be negatively affected.

   Moreover, there were no immediate coastal safety issues and no specific targets concerning nature or recreation. The open formulation of the goals and the absence of legal restrictions contributed to the feasibility of the pilot project, Sand Motor.

5. Construction

a. Detailed design

After selecting the location (the Solleveld reach, a natural dune area between the recreational beach areas of Kijkduin in the North and of Ter Heijde in the South) and the shape (hook-shaped peninsula), the dimensions of the Sand Motor were determined.

The peninsula extends 1 km into the sea, and has a longshore dimension of 2 km. Its maximum level is 5 m above chart datum (NAP), which means that part of the surface remains above sea level even under storm conditions. The total nourishment volume is 21.5 million m^3 of sand, of which 19 million in the Sand Motor itself. The other 2.5 million m^3 was placed in two foreshore nourishments, one on each side. These two foreshore nourishments are designed to supply sand to the parts of the coast that the redistribution of sands from the Sand Motor will not reach in the initial few years.

The 19 million m^3 of sand resulted in an initial exposed sandy area of 100 Ha. The main part of the nourishment lies within the active coastal profile, which extends down to the 10 to 12 m depth contour, i.e. that part of the foreshore where wave-induced sand movement is most active. After redistribution of the sand, eventually the Sand Motor is expected to generate a total of 35 ha of new dunes.

At the base of the peninsula, an 8 Ha lake was created. Apart from creating extra morphological and ecological variation, this lake contributes to maintaining the original groundwater level in the existing dune area, thus safeguarding conditions for the commercially exploited groundwater reservoir in the Solleveld reserve behind the dunes.

At a late stage, some initially underestimated potential problems related to the commercial drinking water exploitation in the Solleveld dune area arose. Generally speaking, the gradual extension of the dune area induced by the Sand Motor will increase the fresh water reservoir of the dunes. At first sight, this appeared positive for drinking water exploitation. Yet, the very specific conditions at Solleveld made this problematic. In the existing dunes north of the Sand Motor, polluted rubble was dumped and buried after the war. Widening of the dunes will lead to a seaward expansion of the exploited watershed and may bring the groundwater into contact with the polluted rubble. To prevent this, a system of groundwater pumps was installed around the polluted area, in order to artificially lower the groundwater table and to prevent groundwater flow from the polluted area into the exploited watershed.

b. Project delivery

By November 2011, the total of 21.5 million cubic meters of sand had been dredged and placed in position. The Sand Motor was officially opened on November 24th, 2011.

c. Management

Before construction started slight adjustments were made to the position of the Sand Motor, based on discussions with the municipalities of Westland and The Hague. This resulted in a slight northward shift of the location, so that the Sand Motor is located in both municipalities. They agreed, however, that the management of the entire Sand Motor will be in the hands of the municipality of Westland.

During construction regular management and user meeting were organized to inform the stakeholders. To ensure swimmer and beach safety, the lifeguard brigade was closely involved and organized information meetings.

6. Operation and Maintenance

a. Delivered project

In November 2011 the construction of the Sand Motor was completed. A total amount of 21,5 million m3 of sand had been placed in front of the Delfland coast, with the objectives to provide long-term safety, to create extra space for recreation and natural development and to learn as much as possible from this pilot project. Are mega-nourishments a good alternative for smaller-scale periodic nourishments? The first results of the experiment will be assessed 5 years after construction. To this end an extensive monitoring program is in place (see below).

During the first year after construction the Dutch coast was exposed to a number of heavy south-westerly storms. As a consequence, the morphological evolution of the Sand Motor proceeded faster than expected, but the shape developed as anticipated, with the tip of the initial hook extending northward and bending towards the shore, creating a tidal lagoon.

In spring 2012, the tip of the Sand Motor extended to enclose a lagoon, and a channel formed running parallel to the beach with its mouth towards the north. The lagoon filled and emptied with the tides. Worried about the further development of this channel, its effects on beach slopes and swimmer safety owing to strong currents, the Province of South Holland decided to close it off with rocks and create another channel, more remote from the beach. During the summer, dynamic coastal processes drastically altered the lay-out of the channels. As the channels were no longer threatening swimmer safety, the majority of the rock was removed again in September 2012.

b. Strategies

In view of the pilot character of the project an extensive program was set up to monitor the morphological and ecological development of the Sand Motor (RWS, Province Zuid Holland et al. (2013).

Considering that the Sand Motor is meant to redistribute sand along the stretch of coast between Hook of Holland and Scheveningen, additional maintenance of this stretch by sand nourishment is expected to be limited over the coming 20 years (Mulder and Tonnon, 2010).

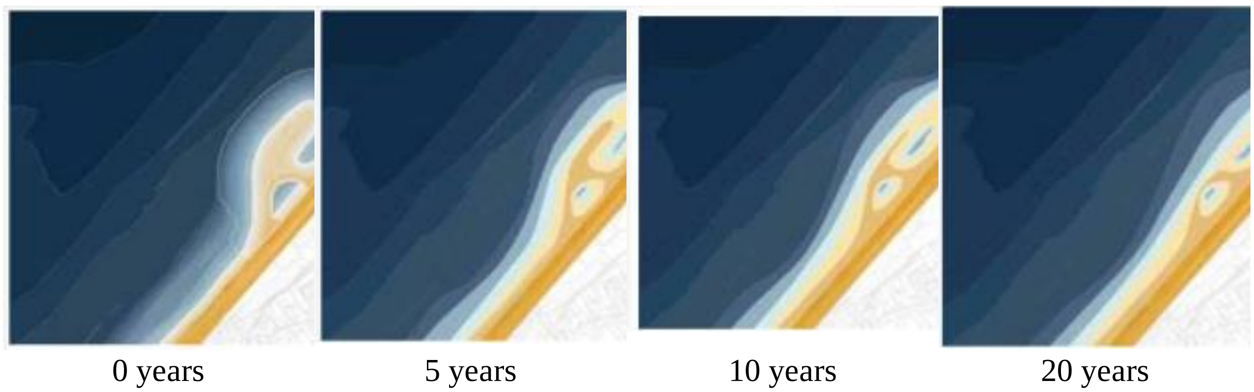

Figure 3 Impression of the predicted evolution of the Sand Engine (Source: Projectbureau Pilot Sand Engine)

c. Monitoring

The time-evolution of the Sand Motor is carefully monitored year-round. The first step was to map the shape of the seabed, and the existing ecosystem components, before construction. The Sand Motor was monitored during construction and is being monitored after construction, for both management and operational purposes, and to evaluate whether this innovative method of coastal protection actually works. The monitoring program focuses on six areas:

1. Weather, waves and currents
2. Sand distribution
3. Groundwater table and quality
4. Flora and fauna
5. Recreation
6. Management.

Early in October 2012, a 40 m high Argus-mast was placed on the Sand Motor. It is equipped with video cameras to register changes of the Sand Motor continuously; directly by visual monitoring of the exposed parts, and indirectly by monitoring wave behaviour (propagation, breaking).

The research program is divided into two phases: 2011-2016 and 2016-2021. This program is coordinated jointly by the Ministry of Public Works and EcoShape and is funded partly by the European Union under the European Program for Regional Development (EFRO).

7. End of life

Eventually the sand of the Sand Motor will be redistributed along the coast by wind, waves and currents. It will induce gradual dune formation along a stretch of coast over a few decades, thus contributing to flood safety and dune nature. Since the Sand Motor is designed to disappear, no significant long term maintenance is foreseen.

a. Lessons learned

- Mega-nourishments need to be tailor-made; to be successful the relevant site-specific coastal processes, such as hydrodynamics, morphodynamics and ecosystem dynamics, need to be understood.

- The specific properties of a particular location will also determine the design of a mega-nourishment.

- Understanding of the ecological and social functions, and the relevant stakeholders, is a prerequisite to a mega-nourishment initiative. These are crucial to the various project phases, as the selection of alternatives is seldom based on cost-effectiveness alone. Instead ecological, socio-economic and political considerations always play a role.

- When considering a mega-nourishment it is important to compare the merits, costs and effects of various alternative strategies. Compare the option of a mega nourishment with more traditional alternatives (periodic small-scale nourishments) and identify the pro's and cons of each alternative.

- When considering a mega-nourishment it is best to evaluate design (location, position and volume), implementation and management as one comprehensive set, including the way in which monitoring and risk management can take place.

- Mega-nourishments are generally not the most cost-effective means of getting sand onto the beach, and only become a preferred strategy when other benefits are taken into account, such as recreational potential and avoidance of frequent ecosystem disturbances.

- The form of a mega-nourishment is a matter of choice, governed by a combination of preferences. On the one hand, a temporary island is less suitable for recreation, since it is difficult to reach, very dynamic, and may create conditions that are unsafe for swimmers. On the other hand, an island is ideal for birds and sea mammals, as it cannot be reached by terrestrial predators like foxes. A peninsula helps in forming a lagoon, which is an asset for recreation as well as nature development. Foreshore nourishment is ideal if the condition of the existing beach is already sufficient. Beach nourishment may be the preferred option if beach sports are to be facilitated that require wide open beaches, but also in situations where tidal currents close to shore make offshore alternatives less cost-effective.

- Morphologically, nourishment within the active coastal profile is advocated, as sand within this zone is most likely to be transported shorewards. If the costs of foreshore and beach nourishment do not differ much, then beach nourishment is to be preferred from a morphological point of view as the sediment losses to deeper water are less.

- Sand properties: using readily available sand is financially often the most attractive. If a choice between different grain sizes is possible, the use of coarser sand below the low water mark is preferred as it will create a steeper stable slope and a smaller total volume is then required. The finer fractions then can be kept for dune formation. If wind-blown sand constitutes problems, e.g. because of nearby roads and houses, coarser fractions may then be preferred.

- Most mega-nourishments will be quite dynamic, so their longer-term development is difficult to predict. Close monitoring, adaptive management, scientific supervision and a clear communication strategy with the stakeholder community are necessary to deal wit the associated uncertainties.

- To use and learn effectively from such a large-scale experiment, monitoring, data management and generic research need to be specified, arranged and funded before construction.

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