THE PILOT PROJECT "DELFLAND SAND ENGINE" AN INNOVATIVE APPROACH TO SUSTAINABLE DEVELOPMENT OF COASTLINES

M. W. Roelofs[1]

INTRODUCTION

Approximately 3.4 billion people –more than half the world's population– currently live in coastal areas, accounting for only five per cent of inhabited land. It is envisaged that by 2025, as much as 75 per cent of the global population will live in the coastal fringe[1]. The concentration of world population in coastal areas has led to many economic benefits, such as improved transport infrastructure, industrial and urban development, tourism, and food production. The explosive population growth and economic development in coastal areas does however pose a threat to the existing ecosystems in those areas. The increasing economic and demographic importance of the coastal fringe demands higher levels of safety against flooding, whereas climate change and sea-level rise at present cause the exact opposite. To ensure that the population and economic interests are safeguarded in an ecological sustainable manner is one of the biggest challenges in flood protection.

FLOOD PROTECTION CHALLENGES IN THE NETHERLANDS

General

The 350 km long Dutch coast has undisputed value for the Netherlands. Most of the population live in the low-lying areas of the Netherlands; furthermore, this part of the country is the centre of economic activity. At present, roughly 65% of the Dutch GDP is generated "below sea-level"[2]. The important port of Rotterdam, Schiphol airport and vital communication links are located in this area. It is therefore of great importance to protect the low-lying areas of the Netherlands against flooding. In past decades, flood

[1] DRAVOSA.

[1] Nakamura, T (2011). United Nations Environmental Programme (UNEP) – presentation World Water Week, Stockholm, 21-27 August 2011.
[2] Veerman, C.P. et al (2008). Working together with water. Findings of the Delta committee 2008.

protection of Holland has seen various important stages that are highlighted in the next paragraphs.

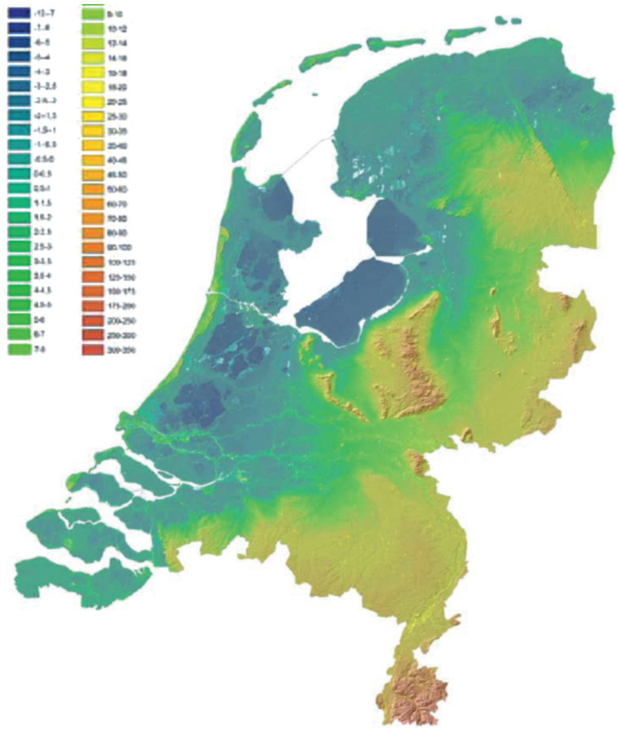


Fig 1. Topography of the Netherlands (Areas in green and blue are below sea level).

Closure "Zuiderzee": 1927-1932

A first important step in the flood protection of the Netherlands is the closure of the so-called "Zuiderzee" (the central lake). The closure of the "Zuiderzee" served both the need of flood protection as well as the need of gaining valuable additional farmland. After the flooding of 1916 and the famine of 1918, a plan was approved to close off the "Zuiderzee" by means of the "afsluitdijk" (closing dam). The closing dam has got a length of 32 km and was constructed between 1927 and 1932. With the construction of the dam, some 320 km of coastline ceased to be exposed directly to North Sea storm surges. Due to the closure of the "Zuiderzee", the salinity of this water mass changed from salt to fresh.

Fig 2a. Satellite image of "afsluitdijk".

Fig 2b. Construction.

Delta Plan & Delta Works: 1953-1997

In 1953, a storm tide cause flood and waves to overwhelm sea defences, resulting in extensive flooding of low laying areas of the Netherlands. As a terrible consequence, The Netherlands recorded 1,836 deaths, most of these casualties being in the southern province of Zeeland. After the flooding, the first Delta committee was appointed, resulting in the development and implementation of the "Deltaplan".

Fig 3. The Delta Works.

The plan comprised the closure of the estuary mouths of the Oosterschelde, the Haringvliet and the Grevelingen. As such, the length of the dikes exposed to the sea were reduced by approximately 640 km. Since the entrance to the the ports of Rotterdam and Antwerp were to remain open, the dikes along the waterways "Nieuwe Waterweg" and "Westerschelde" were to be heightened and strengthened. The Deltaplan took half a century to construct and was formally completed with the inauguration of the "Maeslant defence" in 1997.

As part of the development and implementation of the "Delta Plan", the committee pioneered a conceptual framework, called the "Delta norm". This framework comprised:

- Identification of major areas to be protected, called "dike ring areas"
- Assessment of the cost of flooding using statistical modelling
- Calculation of chances of occurrence of significant flooding within dike ring areas

Based on the above framework the following acceptable risks of failure of "dike rings" were defined for various regions in the Netherlands:

- North and South Holland: 1:10,000 years
- Other areas at risk to sea flooding: 1:4000 years
- Transition areas high/low land: 1:2000 years
- South Holland at risk from river flooding: 1:1250 years
- Remaining areas in the Netherlands at risk from river flooding: 1:250 years

The Delta works were designed bearing in mind the above framework. In 1996 the above framework was incorporated in the "Wet op de Waterkering" (water defence act).

Coastal Defence past 1990: "Dynamic Preservation Policy"

Based on the available knowledge in the '50s, the first Delta committee focused on the closure of waterways and assumed that the Dutch coastline as a whole was stable.

Fig 4. "Dike ring" areas and protection levels.

Improved knowledge on coastal genesis however learned that large parts of the coastline were deteriorating due to structural erosion. As a result of the erosion, dune areas – with their important functions of nature, recreation, living and drinking water production- were reducing and safety against flooding could again be at risk. In 1990 therefore, the "dynamic preservation policy" was adopted. This policy comprised the maintenance of the so-called "basic coastline" in the position it held in 1990. The definition of "basic coastline" (BKL) was specified in 1990 as an extrapolation of the momentary coastline (MKL) over the years 1980-1989. The basic coastline is more or less situated at the location of the low water mark in 1990[3].

The term "dynamic" in dynamic preservation policy refers to the fact that although as a principle the 1990 basic coastline will be maintained, localized deviations are possible should those have a beneficial impact on nature development.

The implementation of the dynamic preservation policy resulted in periodical maintenance of the "coastal fundament" (the area between the basic coastline (1990) and the -20m isobath (1990). Areas where too much sand is lost are supplied with sand.

To monitor the condition of the coast, annual inspections are carried out in spring. To this extend, the coast is divided into 17 sections, each containing survey lines ("raaien") at 200-250 m intervals. Through a combination of stereo photogrammetry and bathymetric surveys, the condition of each survey line and the position of the MKL are determined[4]. The position of the MKL is plotted with the MKL positions of past years. By means of extrapolation of the series of MKL s a TKL (benchmarking coastline) is obtained. By comparing the position of the benchmarking coastline (TKL) to the position

---

[3] Ministerie Verkeer en Waterstaat (2010), Project Plan Waterwet – project plan voor de realisatie van de pilot Zandmotor.
[4] Rijksinstituut voor Kust en Zee (1995). rapport 95.022. Jaarlijkse kustmetingen – richtlijnen voor de inwinning, bewerking en opslag van gegevens van jaarlijkse kustmetingen.

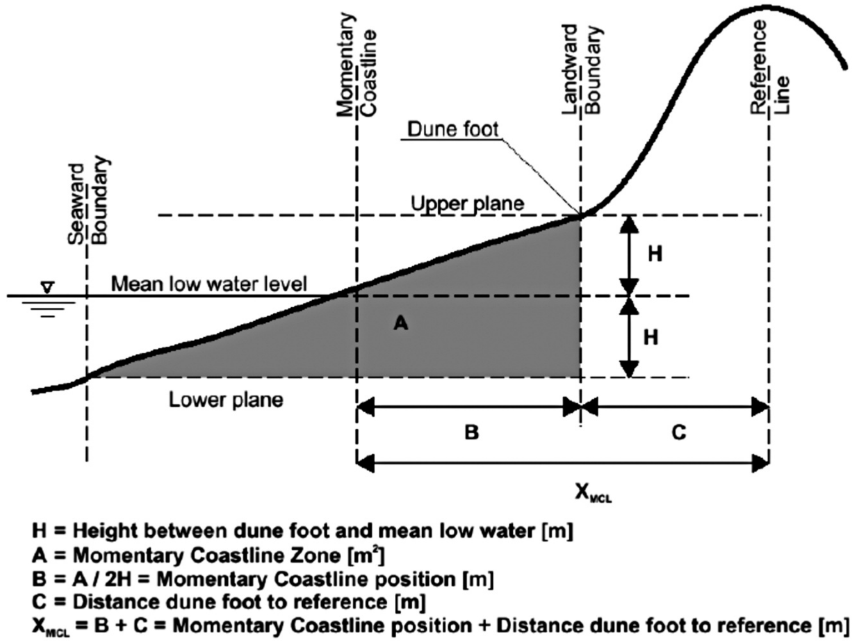


Fig 5. Concept of Momentary Coastline.

of the basic coastline 1990 (BKL), the necessity for intervention is determined.

From 1990 until 2001, each year 6 Mm^3 of sand was supplied. From 2001 onwards, on average 12 Mm^3 of sand is supplied every year to maintain de Dutch coastline in the same position as in 1990. Fig 7 indicates the development of the nourishment volumes and the type of nourishment. As can be seen, after 1997 increasingly sand was supplied into the system by means of so-called foreshore suppletions, rather than beach nourishments [5].

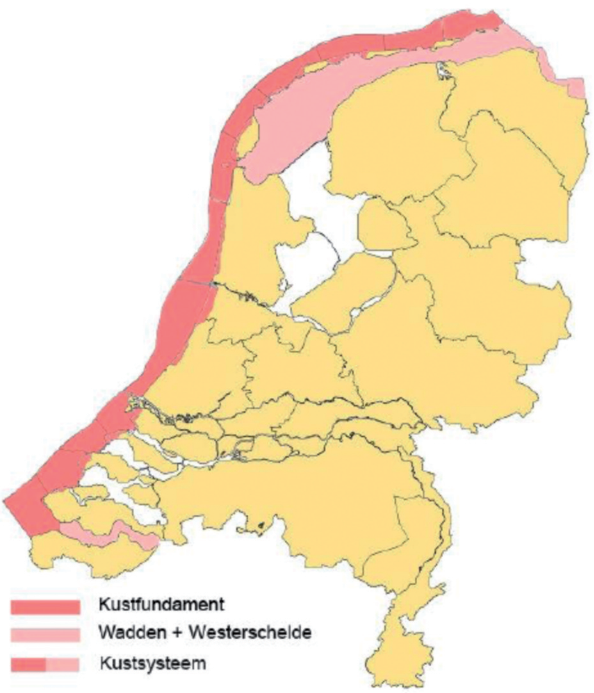


Fig 6. The "Coastal Fundament".

[5] Veerman, C.P. et al (2008). Working together with water. Findings of the Delta committee 2008.

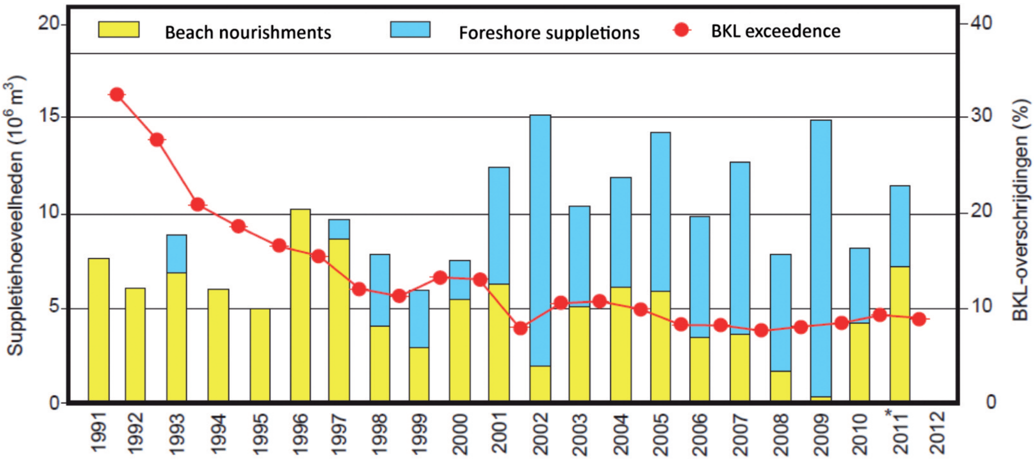


Fig 7. Coastal nourishment volumes 1991-2011.

Sustainable Coastal Development Committee: 2008 Onwards

In 2007 the Dutch Government appointed the 2nd Delta Committee. Their mandate was to come up with recommendations on how to protect the Dutch coast and the low-lying hinterland against the consequences of climate change, whilst letting the Netherlands continue to be an attractive place to live, to reside and work, to recreate and to invest.

The Delta Committee's task was to investigate strategies for the future, long-term development of the coast (2100–2200), paying attention to both safety and environmental (spatial) quality. The Cabinet asked the Committee to consider in particular innovative measures to strengthen the coast and to include the interaction with increased river discharge in its recommendations.

The Committee was also asked to look at other aspects besides safety: possible synergy between flood protection and other societal functions such as life and work, fresh water supply, nature, recreation, landscape, infrastructure and energy.

The main concerns governing the decision to install the 2nd Delta committee were:

- Sea level rise due to climate change
- Land subsidence due to glacial isostacy and subsoil compaction
- Greater fluctuation of river discharges, leading to greater discharges in winter and smaller discharges in summer
- Potential fresh water supply shortages due to warm summers and salination due to salt water intrusion.

The scenarios studied for the year 2050 and 2100 are displayed in below figures.

The committee came up with twelve recommendations for the future e.g. recommendations on flood protection levels, urban development, temporary storage of high

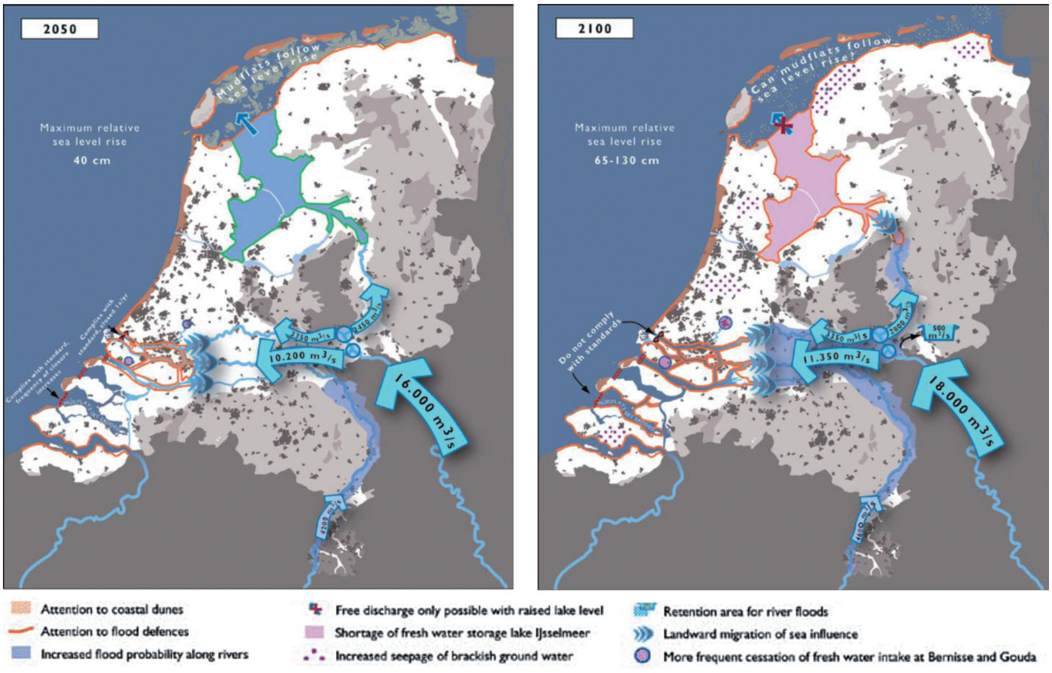


Fig 8a. Scenario 2050.

Fig 8b. Scenario 2100.

river discharges, river delta management, increase of the level of the central lake "IJsselmeer" to provide strategic storage of fresh water and recommendations on the political-administrative, legal and financial framework to be installed. The most important recommendations are provided in fig 9.

On the matter of Coastal defence and maintenance, the Committee concluded the following[6]:

To 2050

The Committee's choice is to 'build the coast with nature'. Coastal safety along the sandy shores of Zeeland, Holland and the Wadden Islands is maintained

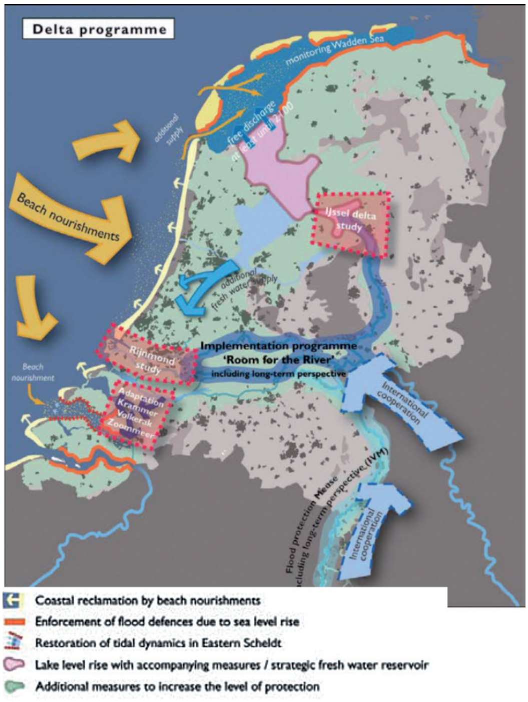


Fig 9. Summary of Recommendations.

---

6 Ministerie van Infrastructuur en Milieu, Rijkswaterstaat (2011), Kustlijnkaarten 2012.

by beach nourishment. Tidal channels will be relocated where necessary. Until 2050 the Committee assumes that 85 million m^3/year of sand will be needed, i.e. that until 2050 sea level will rise by 12 mm/year.

To meet the needs of society, the Committee advises that beach nourishment be conducted on such a scale that the beach will grow in the coming century. This will deliver great added value to Dutch society.

Sand extraction sites will have to be reserved soon. Research must also be conducted soon to determine how such large volumes can be distributed as efficiently as possible in terms of the ecology, economy and energy efficiency.

Post 2050

Beach nourishment will be maintained or reduced, depending on the sea level rise. If it rises by less than 12 mm/year (1.30 m in 2100), then any surplus sand available at that time will contribute to extra coastal space, offering extra safety for the post 2050 period.

BUILDING WITH NATURE

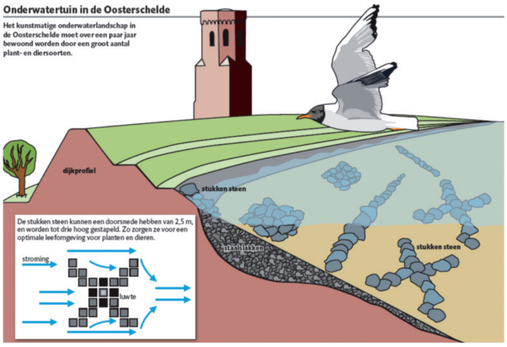
"Building with Nature" refers to the development of new, sustainable design concepts for coastal, delta and river areas that satisfy infrastructure and economic requirements while being based on ecological opportunities. The essence of building with nature is the flexible integration of land-in-sea and of water-in-the-new-land, thereby using the materials, forces and interactions that exist in nature. In building with nature, the existing and potential nature values, as well as the bio-geomorphology and geo-hydrology of the coast and seabed form an integral part of the design.

The BwN concept is further developed by the Ecoshape foundation. The Ecoshape foundation is a public-private initiative; its participants being: the Dutch Ministry of Public Works, universities, academic institutes, consulting engineers, the Port of Rotterdam and dredging contractors. The founding of the programme is 50% public funding / 50% private funding. The approach of the BwN programme involves research and case studies that furnish scientifically proven knowledge and tools. The programme comprises three interdepending pillars, being:

- Interactive case studies
- Generic research
- Ecodynamic design

Programme targets are:

- Ensuring a paradigm shift: from a closed defensive approach (minimise the effects on nature) to an open, offensive approach (maximise the potential of the system)
- Enhance knowledge of ecosystems to facilitate building with nature
- Promote and ensure social awareness of building with nature



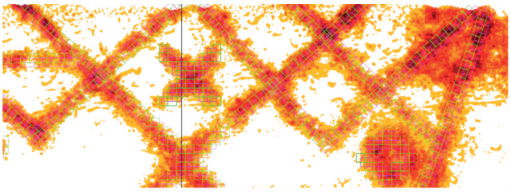


Fig 10. "Submerged garden": shore protection with nature development opportunities. After placement, "Cyclopterus lumpus" was inhabiting newly placed rock.

- Develop scientifically proven design criteria
- Enhance expertise by implementation of the BwN concept on actual pilot projects.

Various case studies and pilot projects have been executed or are under execution, such as:

- "Zeeuwse Delta" – recovery of estuarine dynamics in the south western delta combined with the required safety against flooding and an economical impulse for the local economy.
- "Lake IJssel" – ecodynamic coastal engineering solutions for a long term functioning ecosystem, satisfying the numerous functions of the area, within the complex social context.
- "Sustainable Coastal Development Singapore": in the Singapore area, climate change results in: more severe tropical storms, sea level rise and a more extreme wave climate. To study the safety of Singapore against flooding and the restoration of lost ecological values, the Ecoshape foundation and the Singapore-Delft Water Alliance (SDWA) have started the Joint Singapore Marine Programme (JSMP).
- "Dutch Coast" – Innovative strategies for coastline protection. The Pilot project "Delfland Sand Engine forms part of these strategies.

PILOT PROJECT "DELFLAND SAND ENGINE"

Introduction

The province of "Zuid Holland" in the Netherlands is one of the densest populated areas in the world. Large parts of this province are situated below sea level. To protect these areas a coastal defence system is in place comprising of –predominantly– dunes and beaches. Maintenance of this dynamic "soft" sea defence system has always been nec-

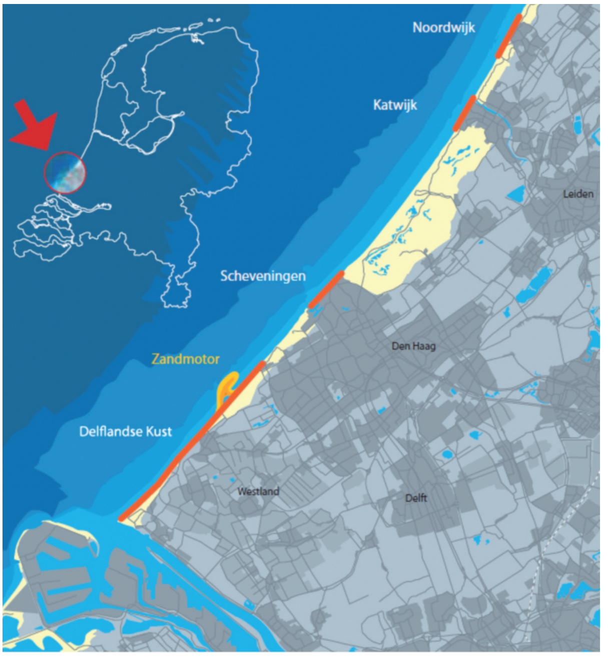


Fig 11. Location Sand Engine.

essary to ensure the required level of safety against flooding. This maintenance of the "Delfland coastline" is usually undertaken by means of periodical foreshore suppletions and beach nourishments.

As mentioned in chapter 2, sea level rise of the North Sea will result in a significant increase of maintenance interventions. In order to avoid more frequent interventions alternatives for maintenance were studied; resulting in mega suppletion denominated "Pilot Delfland Sand Engine".

Of the present yearly averaged nourishment volume of the entire Dutch coastline of 12 million m^3 of sand, 0.4 Mm^3/year is required to maintain the Delfland coastline. The maintenance of the Delfland coastline is usually executed in 1 campaign of 2 Mm^3 every 5 years. Two thirds of the maintenance is executed as beach nourishments, 1 third is executed as underwater foreshore suppletions[7].

Due to climate change and taking into account the results and recommendations of the 2nd Delta Committee, Dutch Coastal authorities foresee an increase of the Delfland coastline nourishment requirement from 0.4 Mm^3 per year to –on average– 1.1 Mm^3 per year over the next 20 years. To avoid more frequent interventions and to facilitate nature development, it was decided to execute a mega nourishment of 21.5 Mm^3: the Building with Nature pilot project "Sand Engine".

Framework & Stakeholders

The programming and execution of a mega beach nourishment pilot project involves a great number of stakeholders. The initiative for the programming of the works was taken by the Province of Zuid Holland. The responsibility for the execution was in the hands of the Ministry of Infrastructure (Rijkswaterstaat) – department "Zuid Holland". At an early stage it was decided to seek co-operation of the most important stakeholders, to be able to jointly take the decision to go-ahead with the pilot. These stakeholders are:

[7] Ministerie Verkeer en Waterstaat (2010), Project Plan Waterwet – project plan voor de realisatie van de pilot Zandmotor.

- Province of Zuid Holland
- Ministry of Infrastructure – directorate Zuid Holland
- Municipalities of: The Hague, Delfland, Rotterdam
- Waterboard of Delfland
- Environmental federation of Zuid Holland

The legal framework under which the execution of the pilot project resides is the water-act 2009 (waterwet) as well as the environmental-act (wet milieubeheer). Under the requisites of the environmental-act, an environmental impact assessment (EIA) was carried out, in which various alternative solutions were weighted on environmental and other merits.

Alternatives

Thirteen alternatives were studied. After pre-selection, four alternatives were considered worthy of a detailed evaluation in the EIA, being[8]:

- *Reference alternative:* to continue the existing nourishment regime. Additional sand will be supplied to improve the "coastal fundament" as well as to accommodate the effects of sea-level rise. This alternative was studies as 5 year interval foreshore nourishments of 5.5 Mm³ each (over a time frame of 20 years).

- *Mega underwater nourishment:* a one-time only mega underwater foreshore suppletion of 20 Mm³.

- *Island:* a mega nourishment in the shape of an island, located 1 km of the coast, approximately 2 km long and 0,5 km wide.

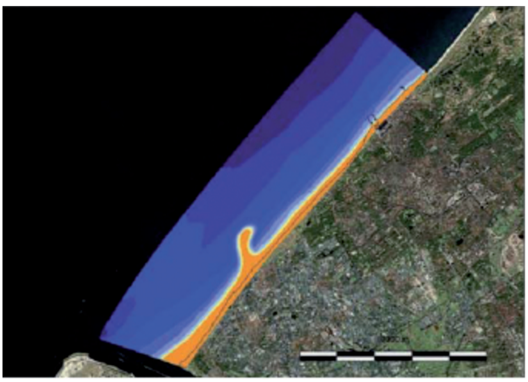


Fig 12a. Alternative "Hook North".

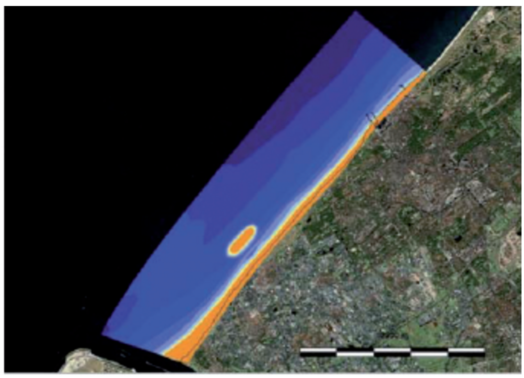


Fig 12b. Alternative "Island".

[8] Ministerie Verkeer en Waterstaat (2010), Project Plan Waterwet – project plan voor de realisatie van de pilot Zandmotor.

- *"Hook North"* and *"Hook South":* hook shaped peninsular-like mega beach nourishments. Two variations were studied: a variation with a northerly orientated hook, focussing more on nature development and an alternative with a southerly orientated hook, focussing more on recreation.

The alternatives were evaluated on the following criteria:

- *Safety:* what are the effects on actual and future state of safety against flooding
- *Coastal morphology:* what are the effects of each alternative on the coastal development and the state of the waterways?
- *Nature:* what are the effects on the development of dune and coastal flora and fauna?
- *Costs and economic effects:* what are the capital and maintenance costs, what are the effects on the local economy?
- *Development of knowledge:* what is the potential of increase of knowledge on the effects of mega suppletions on coastal and nature development?

The finally selected alternative, having the overall best score on the above criteria was the "Hook North" alternative.

SELECTED ALTERNATIVE - "HOOK NORTH"

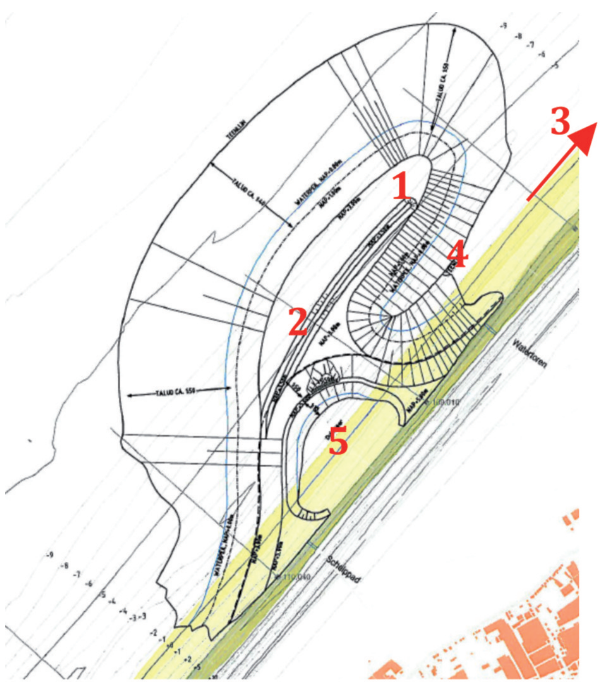


Fig 13. Design Sand Engine.

The alternative "Hook North" is a hook-shaped peninsular positioned adjacent to the "Solleveld" nature reserve. The peninsular extends a distance of approximately 1.5 km seawards. The base of the peninsular –in contact with the existing beach– is approximately 2 km wide.

The peninsular comprises of the following elements:

- *(1) A dynamic head:* the part that extends into the sea: this part is very dynamic and subject to erosion. This part is very suitable for nature (seals, birds) and nature dedicated tourism (water sports).
- *(2) A stable base:* this part will maintain its position during a much longer period, as such, in the years following the execution; there will be adjacent wide beaches.

- *(3) An expanding coastline:* Due to erosion of the dynamic head, the adjacent beaches will result to be wider, promoting dune formation. The wider beaches and more solid dunes will form part of and qualify as “nature 2000” areas.
- *(4) A temporary lagoon:* It is estimated that during 10-15 years there will be a temporary lagoon, serving as resting, feeding and breeding areas for birds and mammals.
- *(5) A dune lake:* The dune lake serves to mitigate a potential rise of the groundwater level at the landward side, in the Solleveld area. Furthermore, the dune lake serves as a resting area for birds.

The morphological modelling of this alternative was executed by *Deltares*. A so-called process based depth average hydrological model (2DH) was constructed, using Delft3D numerical modelling package in combination with a SWAN wave modelling package[9]. The goal of the modelling was to predict the evolution of the sand engine over time. A graphical representation of the modelling results at 0, 5, 10 and 20 years after completions is provided in fig 14.

Fig 14a. 0 years.

Fig 14b. 5 years.

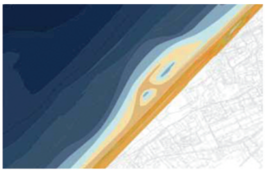


Fig 14c. 10 years.

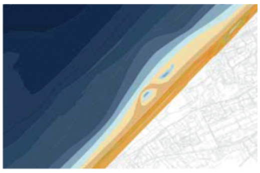


Fig 14d. 20 years.

EXECUTION

The execution of the pilot project “Sand Engine” was undertaken by a joint venture formed by Van Oord Dredging & Marine Contractors and Boskalis. The execution started in March 2011 and was completed in November 2011. In total 21.5 Mm3 of sands (D_{50} 250µ-300µ) were extracted from a sand -borrow area located at approx. 10 km from the discharge location, below the -20m isobaths (below the coastal fundament).

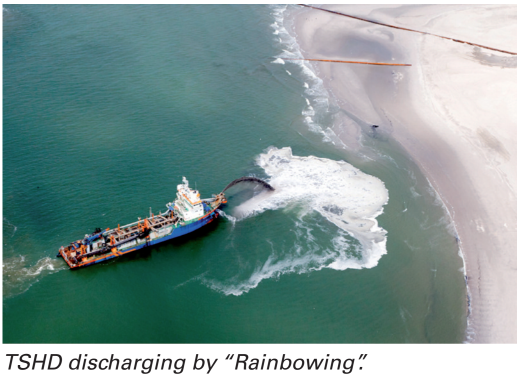
During the execution 4 Trailing Suction Hopper Dredgers were deployed, varying in size from 4,750 m3 to 18,300 m3 hopper capacity. Discharge of dredged sands was done in three discharge modes: 1) pumping through a pre-installed pipeline system (submerged pipeline + landline), 2) dumping throught the vessels bottom doors and 3) pumping through the vessels discharge nozzle (rainbowing).

---

[9] Deltares (2009). Achtergronddocument Morfologische berekeningen MER Zandmotor.


1st April 2011.


7th June 2011.


TSHD discharging by "Rainbowing".


5th September 2011.

DELFLAND SAND ENGINE - MONITORING & EVALUATION

Part of the project comprises the monitoring and evaluation of the project, post construction. The primary targets of the project are defined in the environmental impact assessment, being:

- To stimulate natural dune formation in the area "Hoek van Holland – Scheveningen" for safety, nature and recreation
- To generate knowledge and innovation in order to be able to define to what extend coastal maintenance can be achieved in co-existence with added value for nature and recreation
- To add an attractive nature reserve and recreation area to the Delfland Coast.

To evaluate the success of the project, the success on each of the above targets has to be defined over the project life span. To this extend a monitoring and evaluation plan (MEP) was developed. The MEP comprises the following monitoring and evaluation elements[10]:

---

[10] DHV (2010). Monitoring- en evaluatieplan Zandmotor.

- *Climate, waves and currents:* to understand the ecological and morphological functioning of the sand engine, it is important to have insight in the influence of climate, waves and currents on the morphological processes. Climatological influences are frequently measured by the Royal Meteorological Institute and only require interpretation. Wave conditions are proposed to be evaluated using a waverider buoy. Currents are proposed to be measured using the "Argus pole"

- *Morphology:* to evaluate dune formation and morphological developments yearly topographical and bathymetrical measurements will be undertaken.

- *Abiotics: groundwater level and salt intrusion / saltspray:* frequent measurements will be undertaken to establish the development of the groundwater level as well as composure of groundwater. Saltspray will not be directly measured. Indirect, saltspray will be measured by monitoring the roughness of the vegetation.

- *Biotics: vegetation and fauna:* monitoring of vegetation and flora in the beach and foreshore areas, the dune areas and the intertidal areas.

- *Recreation:* post construction there will be recurring assessments to determine the quantity, quality and diversity of recreation. Frequent measurements are proposed by analysing Argus pole video footage, surveys, enquiries and interviews.

- *Policy and governance:* the evaluation of success comprises the assessment of the organisation and cooperation between stakeholders. It is proposed to assess this post construction by means of surveys, enquiries and interviews.