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THE SAND ENGINE: A SOLUTION FOR VULNERABLE DELTAS IN THE 21ST CENTURY?

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Abstract

The Netherlands' strategy to combat coastal erosion since 1990 has been through nourishment, initially as beach nourishments but more and more as shoreface nourishments. In the light of sea level rise projections the yearly nourishment magnitudes continue to increase. In view of this an innovative soft engineering intervention, comprising an unprecedented 21 Mm^3 sand nourishment known as the Sand Engine, has recently been implemented in the Netherlands. The Sand Engine nourishment is a pilot project to test the effectiveness and efficiency of a local mega-nourishment as a measure to account for the anticipated increased coastal recession in this century. The proposed concept, a single mega-nourishment, once every 20 years, is expected to be more efficient and effective in the long term than traditional beach and shoreface nourishments, presently being used at the Dutch coast with typically a three to five year interval. While the judgement is still out on this globally unique intervention, if proven successful, it may well become a generic solution for combating sea level rise driven coastal recession on open and vulnerable coasts.

Key words: Nourishment, coastal erosion, sea level rise, storm erosion, shoreface processes, flooding, Sand Engine

1. Introduction

Both climate change induced changes in environmental forcing and human interventions leading to subsidence will pose a significant threat of extensive and/or frequent flooding in deltaic, estuarine and other low-lying coastal regions in the 21st century, and beyond (Nicholls et al., 2007; Nicholls et al., 2011; Gratiot et al., 2008; Houghton et al., 2010; Ranasinghe et al., 2012). A recent Dutch State Committee (also known as the 2nd Delta Committee) delivered far-reaching recommendations on how to keep the Netherlands flood proof over the next century and even longer in the light of possible climate change leading to accelerated sea level rise and increasing river discharges. The recommendations are addressed in this contribution, discussing the shift in the evaluation (and type of) coastal interventions and with emphasis on the Sand Engine pilot project. The Sand Engine mega-nourishment is following the principle of building with nature, aiming to provide safety against flooding in combination with new spatial values. Such an approach could provide useful elements for other low lying areas around the globe.

The Netherlands is a densely populated country with a prosperous, open economy situated largely in coastal lowlands below sea level. This region is strongly urbanized and the centre of the nation's economy. Nearly 9 million people live in this part of the Netherlands, protected by dikes and dunes along the coast, the main rivers and the lakes. The coastal defences along the majority of the Dutch coast have been eroding for the last centuries and have become subject to regular interventions. Moreover, these coastal defences have become and integral part of recreational and ecological values of this region.

Implementing far-reaching interventions in the modern reflective society requires a paradigm shift which is necessary to implement such interventions in the light of possibly accelerated climate change.

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2. Paradigm shift

The paradigm shift in the approach of water and coastal management which is observable during the last decades represents a major challenge for the coming century. Where in the past the challenge was formulated as to “fight” the forces of nature, today’s approach recognises the many issues other than protection against flooding and especially the multiple ecological forces that have to be accommodated and can help the processes of protection. While this issue has received attention in the western world since about two decades, it is increasingly also being recognized by the non-western world, notably the growth countries. This implies that water and coastal management have become interdisciplinary as well as transdisciplinary (Waterman, 2010). Some of the issues and dilemmas involved in this challenge are illustrated by the following examples.

In a critical evaluation of the morphological, ecological and socio-economic effects of the Delta project (following the 1953 flood disaster), Saeijs et al. (2004) advocate working with nature in any future flood protection project in estuarine and coastal environments. A number of their recommendations exemplify this: “ ..(1) If there is still is a choice, leave untouched estuaries and deltas alone. … (2) If there is already a history of human intervention, try to adopt the most flexible approaches to safety and development. …(3) Reversible and local measures within the limits of the natural processes are preferable….”.

The recommendations of Saeijs et al. (2004) regarding working with nature are in line with today’s policy (cf. the coastal policy to maintain the coastline with “soft” solutions rather than hard (concrete) barriers). Nevertheless implementing the recommendations appears to be complex. For instance, sea dikes may hamper natural processes, but from an economic viewpoint it is generally not justifiable to remove dikes, let alone from a socio-emotional perspective. The complexity may be further illustrated by comparing the Saeijs et al. (2004) statement with the conclusions of Jonkman *et al.* (2005) drawing lessons for the Dutch from the New Orleans flood disaster of 2005. The latter observe a tendency in Dutch policy to head towards the US model of mitigating the consequences instead of strengthening the flood defences, while prevention of floods is receiving gradually and relatively less attention. Then, arguing that (1) the protection standards are over 40 years old and have not evolved with the increase of economic value of the protected area over time, and that (2) the societal risks associated with flood defences on a national scale are larger than in other domains of the Dutch society (Ten Brinke and Bannink, 2004), these authors concluded that a fundamental debate on the required safety levels of Dutch flood defences is necessary.

However, considering the ecologically based plea of Saeijs et al. (2004) it is obvious that the format of such a fundamental debate is not trivial. Coping with the dilemmas involved, is an example of the major challenge for the near future. It illustrates that “working with nature” not simply implies the use of methods from natural sciences, but involves a range of different disciplines and asks for a transdisciplinary approach. This paradigm shift is very prominent in the Dutch coastal zone management and it is within this context that the Sand Engine concept was developed.

3. The Dutch Context

The Netherlands, where 1/3rd of the land mass is below mean sea level (MSL), is one delta that is faced with potentially massive socio-economic consequences due to relative sea level rise (i.e. eustatic sea level rise (SLR) and other regional and local effects). It is a densely populated country (494 people/km^2) with a 350 km long coastline. At present, nine million residents (out of a total of 16,7 million) live in the coastal areas, vast regions at an elevation below MSL. Roughly 65% of the country’s gross national product — about €400 billion per annum — is generated within this coastal region. The major harbours and airports on or near the North Sea are vital nodes in the international transport network as well as important locations for the goods and services industries.

The damage done by hurricane Katrina in 2005 was a wake-up call to many nations around the world on the potential consequences of coastal flooding. This disaster galvanized the Dutch government to implement a 2nd Delta Committee in 2007 (after the first Delta Committee, which was implemented following the flooding of 1953), primarily to provide advice on the country’s preparation for mitigating flood risk in the near and far future (up to 2200). In 2008, the 2nd Delta Committee delivered twelve recommendations for coping with climate and other environmental changes (Kabat et al., 2009). A firm recommendation of the 2nd Delta Committee regarding coastal defense options was to adopt a soft engineering strategy (i.e. sand nourishment of the coastal system) to mitigate long term coastal recession.

After it became government policy to maintain the Dutch coastline at its 1990 position at all costs, sand nourishments have been in use in the Netherlands to mitigate coastal recession for over two decades (Rijkswaterstaat, 1990; Hanson et al., 2002). Initially these nourishments were implemented as traditional beach and dune nourishments, i.e. sand directly placed on the sub aerial beach and/or the dunes (Fig 1a). However, based on theoretical and field based findings (Stive et al., 1991; Bruun, 1996; Grunnet and Ruessink, 2005; Van Koningsveld et al., 2008) that nourishing the foreshore, just outside or just inside of the outer breaker bar is not only as effective as the traditional beach/dune nourishment approaches, but also cheaper, less intrusive on beach amenity, and much more acceptable to the public, shoreface nourishments have been widely used along the Dutch coast since the late 1990s (Fig 1b). Typically, a shoreface nourishment consists of about 1-2 Mm^3 of sand and has a life time of about 3-5 years (Hamm et al., 2002). The main impact of a shoreface nourishment is to feed the shoreface with sediment, thus modifying surf zone processes to ultimately result in a non-eroding or accretive beach (Grunnet and Ruessink, 2005; van Duin et al., 2004).

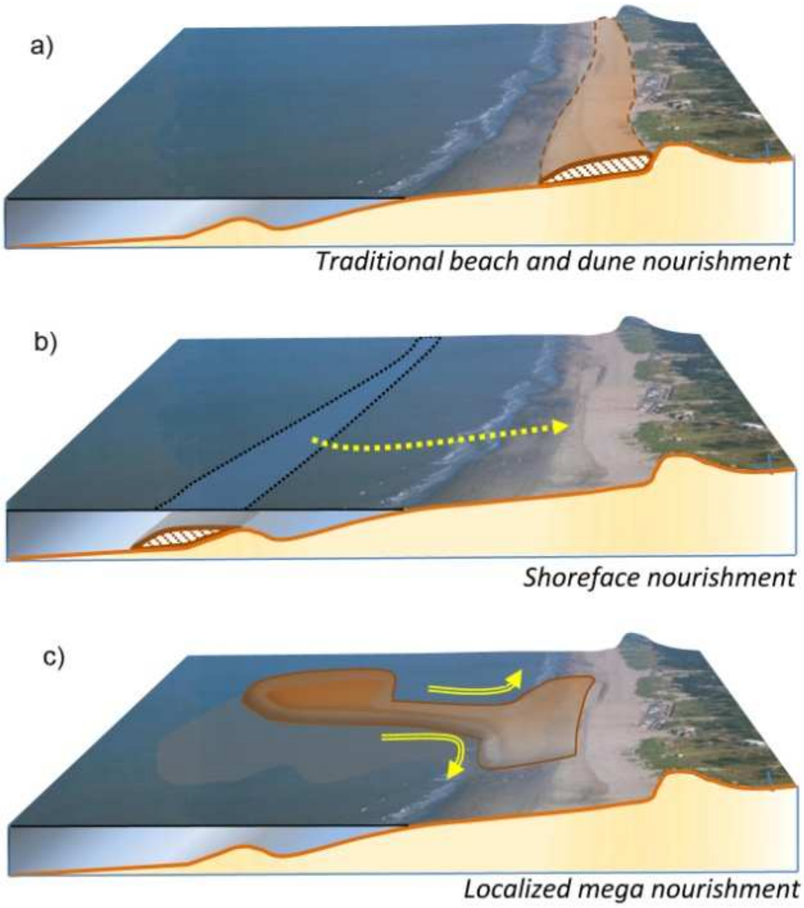

Figure 1. Conceptual diagram of the different nourishment strategies. Traditional beach and dune nourishments, used frequently from the 70's onwards, place sand directly on the beach and dunes (a). Shoreface nourishments, initiated in the 90's, make use of natural marine processes to redistribute the sand that is placed under water in the cross-shore direction and gradually create a wider coastal defense over time (b). Concentrated mega-nourishments, as introduced here, exploit both marine and aeolian processes, to redistribute the sand both in cross and alongshore directions (c) (after Stive et al, 2013).

The aforementioned 2nd Delta Committee report also indicated that to negate the enhanced potential for coastal recession due accelerated SLR in the 21st century, the yearly sand nourishment volume for the Dutch coast should be increased from a presently outdated volume of 12 Mm^3/yr to 80 Mm^3/yr for a high end climate change scenario (Kabat et al., 2009). If this volume of sand were to be provided in the form of traditional shoreface nourishments, to prevent SLR driven coastal recession, these nourishments will need to be implemented along the entire coastline and increased in frequency and size. This will result in a significant widening of the beach along the entire Dutch coastline. A very wide beach is however unattractive to the average beach user, primarily because the water becomes less accessible. It is within this backdrop that the bold, world-first concept of a localized mega-nourishment, or the Sand Engine was conceived (Figure 1c and Figure 2).

Figure 2. Aerial photograph of the Sand Engine after completion (September 2011). Picture courtesy of Rijkswaterstaat/Joop van Houdt.

4. The Sand Engine

The above discussion and context calls for adaptation strategies that are unprecedented; both in form and magnitude. Recognizing this need, policymakers in the Netherlands, in close collaboration with the scientific community, have recently adopted an innovative intervention approach named "The Sand Engine" (*Zand Motor*, www.zandmotor.nl) to address the potentially massive threat of flooding in the low lying coastal zone of the Netherlands from projected Sea Level Rise (SLR). The Sand Engine is a very large sand nourishment of 21 Mm^3: a nourishment magnitude for defence against flooding that is unprecedented anywhere on the globe.

The main advantages of the Sand Engine concept are: (a) a nourishment will only be required approximately every 20 years as opposed to the 2-5 year cycle of present day beach and shoreface nourishments; (b) the nourishment will slowly diffuse and advance the shoreline over a ~ 10km stretch of the coastline in a more natural fashion; (c) the large initial local perturbation will result in a short to medium term increase of locally available space for recreation and the environment, and (d) the ecological stress, while considerable at the initial nourishment location, does not disturb adjacent areas, thereby containing it to a small (~ 2.5 km^2) area. The responsible decision makers found this solution attractive and approved the mega-nourishment of 21.5 Mm^3 at Ter Heijde coast in the province of South Holland (Figure 3) and, as it seems now, the Dutch public is generally in favor of this intervention.

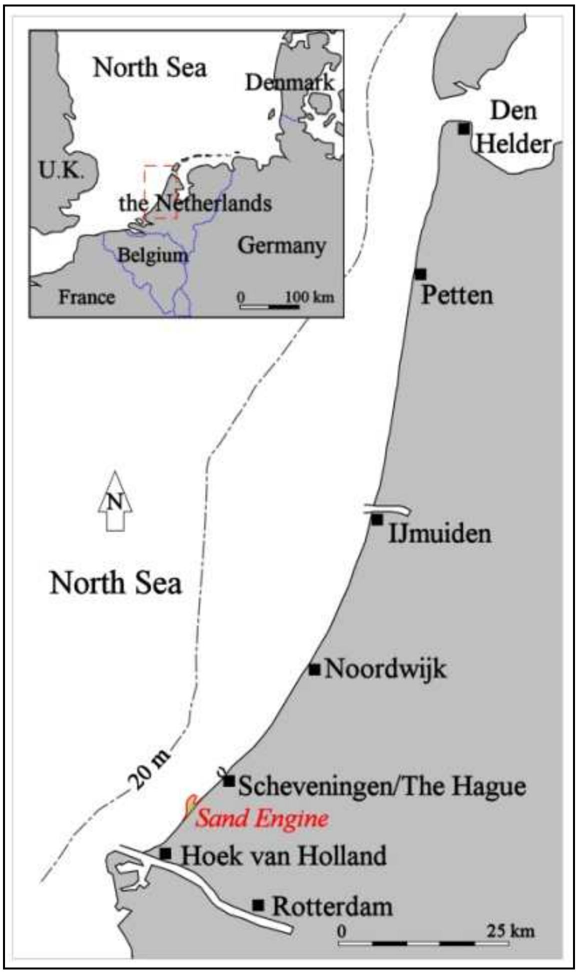

Figure 3. Location map of the Sand Engine project on the south coast of the Netherlands.

The initial nourishment spans the coastal system over a 2.4 km stretch, and extends up to 1 km offshore following a specific shape (Figure 2). The main expectation is that the Sand Engine will perturb the coastal system such that the coastline will, as a minimum, be stabilized at its present position over an extended length of time (20 years) and space (10 km). An anticipated secondary benefit is the creation of environmentally and recreationally attractive space in this strongly urbanized coastal stretch.

5. Projections and first observations

The state-of-the-art coastal morphodynamic numerical model Delft3D (Lesser et al., 2004) was used to obtain preliminary projections of the temporal and spatial evolution of the Sand Engine over its 20 yr planning horizon. In this preliminary model application, a slightly schematized initial bathymetry, which closely followed the prototype, was adopted.

The initial and model predicted morphology after 3, 5, 10, 15 and 20 years is shown in Figure 4. The results show that the nourishment will gradually diminish in its width (i.e. cross-shore direction) and extend alongshore by 8 km over a period of 20 yrs as desired (Figure 4a-f), thus feeding the adjacent coast. The approximate beach area gained over the 8 km modified coastline is approximately 200 ha. In the model, the Sand Engine, has an initial maximum cross-shore extent (maximum width) of 0.95 km and an alongshore extent (length) of 2.4 km. Within 3 years, the nourishment length increases by 1.1 km (0.7 and 0.4 km extensions to the south and north respectively) while its maximum width decreases by 0.2 km (Figure 4b). The tip of the initially alongshore parallel spit-like feature recurves shoreward, and develops into a transverse sand bar that is separated from the shoreline by a narrow channel (about 50 m wide), forming an artificial lagoon with a surface area of 17 ha (Figure 4b). From 3 – 10 yrs, the Sand Engine slowly diffuses such that its maximum width decreases from 0.8 km to 0.6 km while its length increases from 3.5 km to 5.3 km (extensions of 1.6 km (south) and 1.2 km (north), relative to the initial configuration (Figure 4c-d). The lagoon area decreases to 14 ha while the ocean connecting shore parallel channel continues to prevail during this time. After 15 yrs (Figure 4e), the Sand Engine is 7 km long (extensions of 2.5 km (south) and 2.1 km (north)) with a maximum width of 0.5 km, while the shore parallel channel disappears, such that the lagoon becomes a lake. Between 15-20 yrs, the predictions show a new, more hydraulically efficient channel that develops on the northern side of the main part of the remaining nourishment such that the lake reconnects with the ocean. When the 20 yr planning horizon is reached (Figure 4f), the maximum width of the nourishment is 0.45 km and its length is 8 km (extensions of 3 km south and 2.5 km north), while the artificial lagoon area decreases to 8 ha, but remains open to the ocean via its north shore channel.

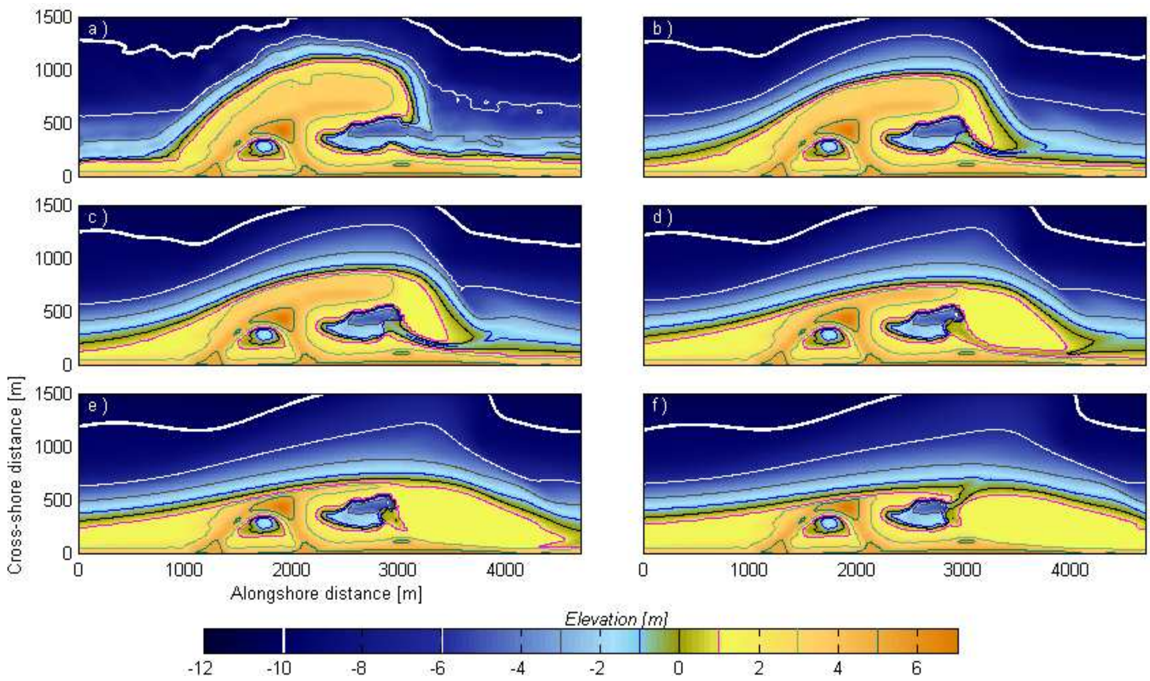

Figure 4. Long term model predictions of the morphological development of the Sand Engine. Panel a shows the initial model bathymetry, panels b–f show the prediction 3, 5, 10, 15 and 20 years after construction. Blue colors indicate sub-aqueous zones, yellow to brown colors show the sub-aerial beach and green colors indicate the intertidal area between high and low water. Depth values of the contour levels are indicated in the color bar (after Stive et al, 2013).

Ever since the completion of the project in summer 2011, the topographic and bathymetric evolution of the Sand Engine is monitored on a monthly basis via a purpose built Jetski mounted with an RTK-GPS and an Echo sounder (accuracy ~ 10 cm; van Son et al, 2010). Furthermore, regular aerial photographs are collected to visualize the development. During the first year of its existence, which included the stormy winter of 2011-2012, the shape of the Sand Engine has changed considerably (Figure 5). The maximum width decreased from 0.96 km to 0.84 km while its length increased from 2.4 km to 3.6 km (~ 0.6 km extensions to the south and north). The northern tip of the initial spit-like feature has recurved shoreward and formed a transverse sand bar which is separated from the shoreline by a ~100 m wide approximately shore parallel channel, forming an artificial lagoon with a surface area of ~ 20 ha.

Above observations of the large scale behavior of nourishment are consistent with the model predicted morphology after 1 year, thus providing a reasonable level of confidence in the longer term model projections shown in Figure 4.

6. Discussion on public safety

While in general the political and public perception of the Sand Engine over the last one and a half year is positive, there have been some incidents around public safety. Since regular visitors of the Holland coast and the Beach Lifeguard units had become familiar with a straight nearly uniform beach, they are now confronted with a very dynamic and transient beach and lagoon system. Specifically the large difference in the morphology at high water versus low water (see Figure 5) leads to two safety issues. First, as the lagoon starts to fill when the water level rises the inward flood flow velocities in the channel(s) are rather high, comparable to a strong rip current. This has surprised some beach goers and the Lifeguards. Second, some parts that can be reached by foot during low water become isolated at high water (see Figure 5). This has surprised some beach visitors. Due to an increased effort of both lifeguards and beach police, most incidents concerning these issues have been avoided. Nevertheless, it remains important to inform both the Lifeguards and the general public on these safety issues.

Figure 5. Southward looking aerial photograph of the Sand Engine at high water *(left)* and at low water *(right)* (spring 2013). Pictures courtesy of Rijkswaterstaat/Joop van Houdt.

7. Conclusions

The projected climate change and the increased socio-economic pressure on the coastal zone require a paradigm shift in the implementation of coastal interventions, such that these interventions are to become larger and evaluated multidisciplinary. The paradigm shift in the approach of water and coastal management represents a major challenge for the coming century. Where in the past the challenge was formulated as to “fight” the forces of nature, today’s approach recognises the many issues other than protection against flooding and especially the multiple ecological forces that have to be accommodated and can help the processes of protection

In that light, a boldly innovative soft engineering intervention, comprising an unprecedented 21 Mm^3

sand nourishment known as the Sand Engine, has been recently implemented in the Netherlands. The Sand Engine is a pilot project to test the efficacy of local mega-nourishments as a counter measure for the anticipated enhanced coastal recession due to accelerated sea level rise in the 21st century. This single mega-nourishment is expected to be more efficient and economical in the long term than traditional shoreface nourishments that are presently being used to negate coastal recession. Preliminary numerical model results, which qualitatively agree with the 1st year of observed morphological evolution of the Sand Engine, indicate that this nourishment will result in the widening of the beach along an 8 km stretch of the coastline, and a beach area gain of 200 ha over a 20 yr period. While the jury is still out on this globally unique intervention, if proven successful, it may well become a global generic solution for combating sea level rise driven coastal recession on open coasts.

Acknowledgements

Marcel Stive, Matthieu de Schipper, Rosh Ranasinghe, Jaap van Thiel de Vries, Martijn Henriquez and Sierd de Vries are partly supported by the ERC-Advanced Grant 291206 – NEMO. Arjan Luijendijk is partly supported by the STW supported NatureCoast project. Field data was collected with the support of EFRO and Building with Nature. The Building with Nature program is funded from several sources, including the Subsidieregeling Innovatieketen Water (SIW, Staatscourant nrs 953 and 17009) sponsored by the Dutch Ministry of Transport, Public Works and Water Management and partner contributions of the participants to the Foundation EcoShape. The program receives co-funding from the European Fund for Regional Development EFRO and the Municipality of Dordrecht.

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