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ASSESSMENT OF THE DESIGN AND BEHAVIOUR OF NOURISHMENTS IN THE NORTH SEA REGION. TOWARDS AN NSR GUIDELINE FOR NOURISHMENTS

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Abstract

A new granted EU Interreg North Sea region (NSR) VB project, Building with Nature (BwN), focuses on the observed behavioural differences of beach and shoreface nourishments with respect to local coastal morpho- and hydrodynamics. The application of BwN in the form of nourishments is already common practice since decades for most partners involved. A comparison of current practices was drafted. It showed that all partners apply beach nourishments, by using multiple parameters in the design in a consistent way. Shoreface nourishments, however, are not commonly applied. Their designs only roughly indicate a volume and location. The project aims to reveal links between presumable driving parameters and observed nourishment behaviour, by co-analysis using a shared methodology. The results will contribute to the effectiveness of BwN Solutions and will be drafted in a NSR guidance on nourishments.

Key words: Nature-Based solutions, Building with Nature, beach, dune and shoreface nourishment behaviour, morphodynamics, bar behaviour, coasts and climate change

1. Introduction

Nature-Based solutions (NBS) also known as Building with Nature (BwN) solutions, are implemented to make coasts more resilient to climate change effects, primarily sea level rise. Common BwN solutions are beach and/or shoreface nourishments. These aim at counteracting erosion, stabilizing coasts, facilitating other functions and ensuring protection to flooding. The application of BwN solutions – first beach nourishments – incidentally started in the 1950's. They are systematically applied since the 1970's (Hanson, et al., 2002). The application of shoreface nourishments started later. One of the first trials using shoreface nourishments, based on good results in applying beach nourishments, originates from Australia in 1985 (Jackson & Tomlinson, 1990). It also was of research interest in Europe (Hamm, et al., 2002). Shoreface nourishments became common practice in the Netherlands since 2001 (Van der Spek & Elias, 2013), based on the results of the European (MAST-programme) NOURTEC project (NOURTEC, 1997).

The strategy of BwN, the application of nourishments in this project, is based on the principle of using natural forces for the prevention of coastal retreat rather than counteracting nature by blocking its processes (Hamm, et al., 2002). In the past, several comparisons were made to analyse observed nourishment behaviour (e.g. Lodder & Sørensen, 2015; Spanhoff & Van de Graaff, 2006), sometimes in relation to coastal management policies, legal frameworks, financial aspects (Hanson, et al., 2002; Van de Graaff, Niemeyer, & Van Overeem, 1991), and to the setup of monitoring and assessment of performance (Hamm, et al., 2002). In addition, several research projects were devoted to the morphodynamic response of beach and/or shoreface nourishments (e.g. Van der Spek & Lodder, 2015; Van der Spek & Elias, 2013; Ojeda, Ruessink, & Guillen, 2008; Grunnet & Ruessink, 2005). Observations of applied BwN solutions reveal behavioural differences in nourishments along the NSR coasts. A preliminary cross country analysis of the design and behaviour of Dutch and Danish shoreface nourishments was made by Lodder & Sørensen

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(2015). They concluded that the observed behaviour of the studied nourishments can partly be explained by the local coastal dynamics and the nourishment design.

The observed behavioural differences of nourishments with respect to local coastal dynamics is one of the main themes in a new EU Interreg project. This Building with Nature project was granted by the European Union Interreg VB North Sea Region (NSR) and lasts from 2016 up to 2020. The project aims at generating key knowledge needed for making the sandy coasts of the NSR more adaptable and resilient to the effects of climate change, primarily sea level rise. This knowledge is gathered through assessment of nourishments executed by the project partners, being the responsible organisations for coastal management in South Sweden, Denmark, Schleswig-Holstein, Lower Saxony, the Netherlands and Flanders.

In this paper we introduce the outline of the project, present current practices in the design and monitoring of nourishments, and give first insights in behaviour of nourishments in relation to the local coastal dynamics. Further, we propose an outline of a shared method for a co-analysis to be performed at all project partners in the forthcoming years.

2. Previous results

Lodder & Sørensen (2015) made an attempt to acquire a better understanding of the behaviour of shoreface nourishments applied at different coastal stretches. This work was based on the research of Spanhoff & Van de Graaff (2006). Lodder & Sørensen (2015) analysis focussed on the comparison of three Dutch and three Danish shoreface nourishments. Characteristics and locations of these nourishments are shown in Table **1**.

Table 1. Nourishment characteristics (Updated from: Lodder & Sorensen, 2015).

Country	Location	Year	Position (km-km)	Volume (Mm^3)	Volume per m (m^3/m)	D_{50} Nourished (μm)	Placement depth (m i.r.t. MSL)
NL	Zandvoort 1	2004	62.75 – 67.75	2.2	440	250 – 300	-4
NL	Bloemendaal	2008	61 – 63	1.0	500	250 – 300	-5
NL	Zandvoort 2	2008	67.75 – 70.25	0.5	200	250 – 300	-5
DK	Sdr. Holmsland Tange	2010	11.6 – 21.0	0.54	57	300 – 400	-5
DK	Skodbjerge North	2011	17.2 – 18.0	0.3	400	300 – 400	-5
DK	Skodbjerge South	2011	13.8 – 14.6	0.3	400	300 – 400	-5

The results show that the behaviour of the considered Dutch and Danish shoreface nourishments is quite different. The Dutch shoreface nourishments near Zandvoort and Bloemendaal migrate primarily cross-shore (Figure 1), the Danish shoreface nourishments migrate primarily alongshore, as can be seen in Figure 2 (Lodder & Sørensen, 2015). In addition, the effect of the shoreface nourishment on the through-bar system is divers. Where in the Dutch situation the shoreface nourishments start to stabilise or migrate landward by means of transformation and dissolving of the shoreface nourishments into the bar system (as is in agreement with Van der Spek & Elias, 2013 and Spanhoff & Van de Graaff, 2006), the Danish shoreface nourishment migrates offshore as the natural breaker bar system does (and alongshore).

New observations of behavioural differences on specifically shoreface nourishments were presented by Lodder, Ramaekers, & Hoogland (2015), as shown in Figure 3. This was further investigated by Bruins (2016). In his research he included the migration of 20 shoreface nourishments. Bruins (2016) showed that the migration of shoreface nourishments along the Dutch coast is not uniform. Primairily cross-shore, longshore and non-migrating shoreface nourishments can be observed. Figure **4** shows an example of a shoreface nourishment that remains at its original location.

Based on these results it can be concluded that the Zandvoort shoreface nourishments is not representative for all shoreface nourishments applied along the Dutch coast. The research of Bruins (2016) indicates that shoreface nourishments in the Netherlands have a long term morphological behaviour similar to the original barsystem.

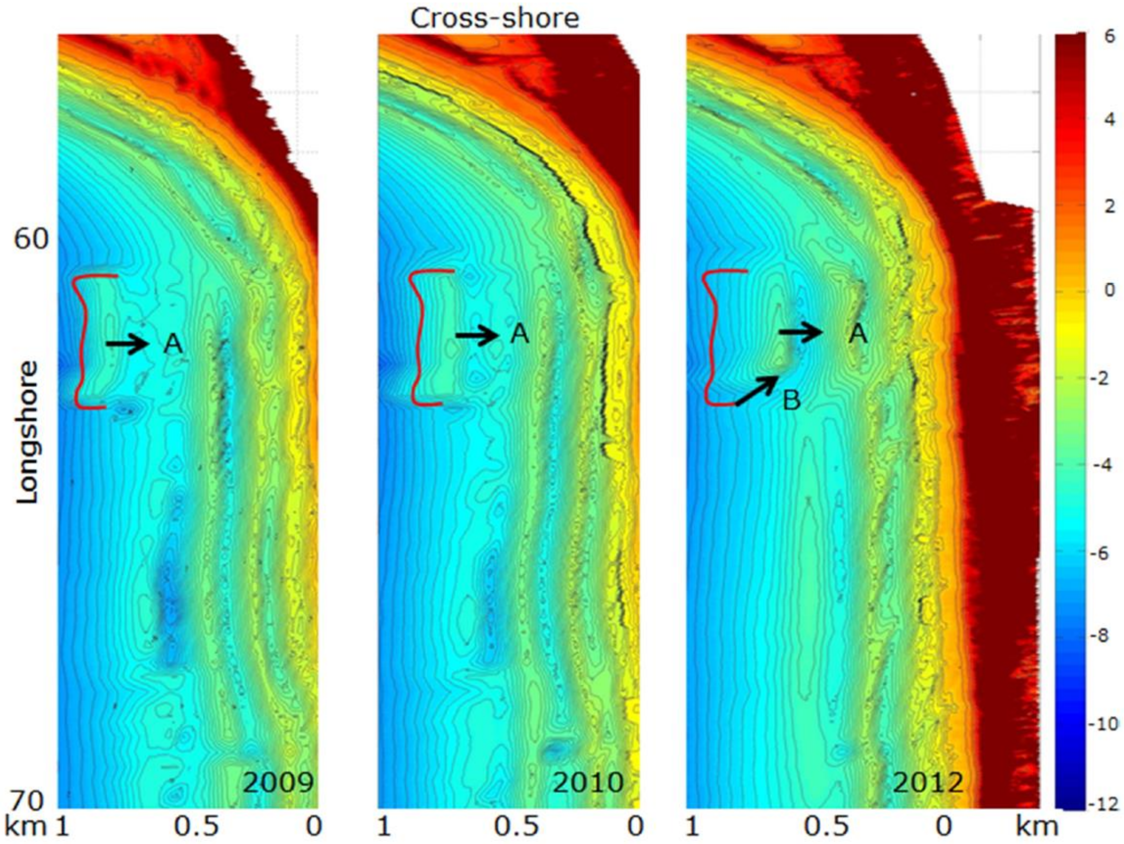

Figure 1. Bathymetry of the Zandvoort-Bloemendaal area. Indicated in red is the Bloemendaal 2008 nourishment location. The nourishment migrated primarily in landward direction (A) and only partly alongshore (B). The y-axis gives the longshore distance, the X-axis gives the cross-shore distance, both in km i.r.t. local coordinate system. The height in m i.r.t. MSL (NAP) (from: Lodder & Sørensen, 2015).

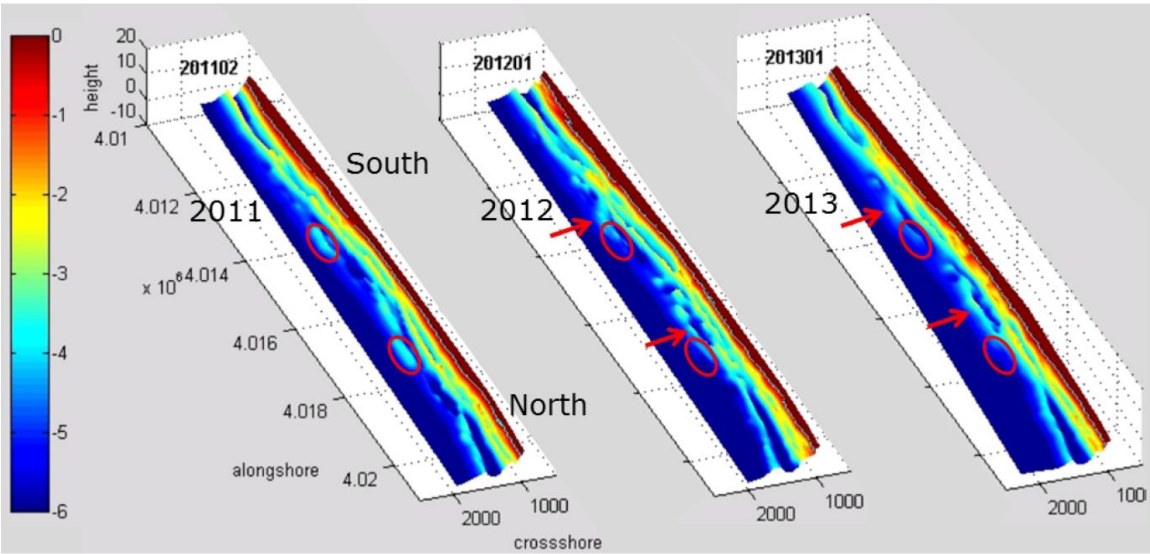

Figure 2. Bathymetry of the Skodbjerge area. Indicated with the red circles both the 2011 Skodbjerge nourishments. The red arrows indicate the position of the nourishment after one and two years. The nourishments migrated primarily alongshore. Note that south is up in this figure. The Y-axis gives the longshore distance in km, the X-axis gives the cross-shore distance in m i.r.t. local coordinate system. The height is in m i.r.t. MSL (Lodder & Sørensen, 2015).

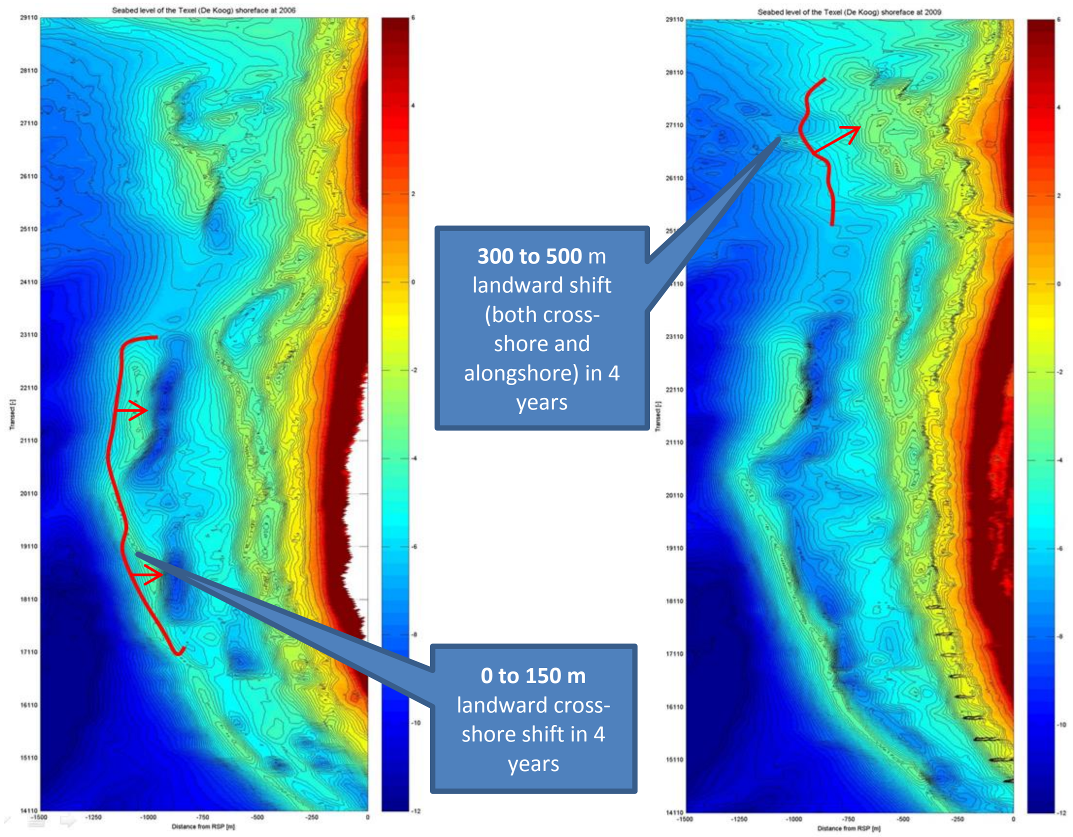

Figure 3. Divers observed morphological behaviour shoreface nourishments at the island of Texel. The red line indicates the initial position of the shoreface nourishment. Left is sea bottom level in 2006, right is sea bottom level in 2009. On the Y-axis, coastal transects are shown. On the X-axis the distance from RSP (reference line 'Rijksstrandpalenlijn' in Dutch) is shown. The colours present the seabed level from +6m MSL to -12m MSL). Adjusted from: Lodder, Ramaekers, & Hoogland, NCK Days 2015 (2015).

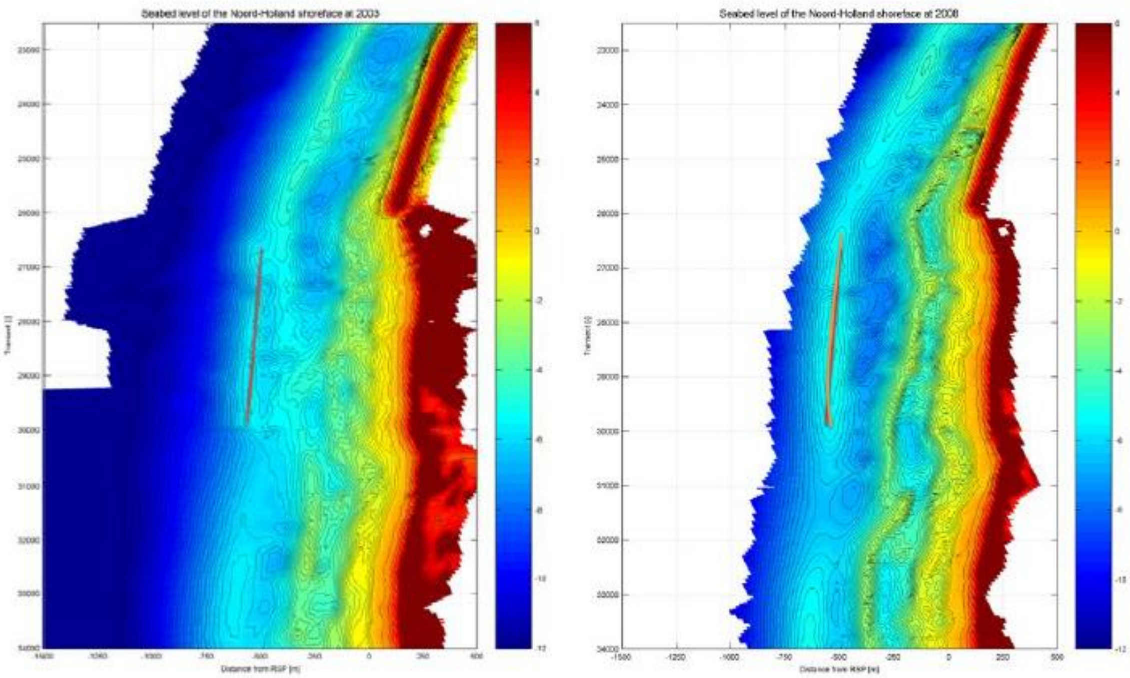

Figure 4. Migration of shoreface nourishment in Camperduin (2003, province of Noord Holland, the Netherlands) up to 2008. The red line represents the execution position (left) and the orange line the final position (right). On the Y-axis, coastal transects are shown. On the X-axis the distance from RSP is shown. The colours present the seabed level from + 6m MSL to -12m MSL).

3. General outline Interreg North Sea Region VB Building with Nature

The Interreg North Sea Region (NSR) VB BwN project aims at making coasts and catchments more adaptable and resilient to the effects of climate change, specifically sea level rise. The project is granted by the European Union Interreg VB NSR and lasts from 2016 up to 2020. The project exchanges transnational knowledge and develops a sound evidence base for BwN solutions in coastal and catchment (flood)risk management. The project consists of six work packages focussing on coastal laboratories, catchment laboratories, business case development, upscaling through policy learning, communication, and project management. The project will enable further uptake of BwN solutions in national/regional policies for climate change resilience of coasts and catchments. The need of this Building with Nature project arose from the observed behavioural differences in Dutch and Danish nourishments. It was one of the main reasons to start this project on the co-analysis of coastal laboratories.

3.1. Resilient coastal laboratories study sites

Ten coastal laboratories along the NSR are selected. Here, regularly nourishments are performed, see Figure 5. These (potentially) sandy managed coasts make use of (pilot) BwN solutions. Most attention will be paid to beach and shoreface nourishments to counteract coastal erosion.

Figure 5. Coastal Laboratories. A: Ystad (Sweden), B: Danish West coast (Denmark), C: Sylt (State of Schleswig Holstein, Germany), D: Langeoog (State of Lower Saxony, Germany), E: Norderney (State of Lower Saxony, Germany), F: Ameland Inlet (The Netherlands), G: Bergen-Egmond (The Netherlands), H: Zandvoort (The Netherlands), I: Domburg (The Netherlands), J: Oostende-Mariakerke (Flanders, Belgium)

3.2. Research steps

The first step in this research is to share and analyse current practices of the project partners, as in Hanson, et al. (2002). This brief overview partly explains the different legal and financial frameworks, decisions made for a specific coastal defence strategy, choice for nourishment type, size, design, monitoring and evaluation. The inventory forms a baseline for nourishments in relation to the observed coastal dynamics.

The year 2017 will be used to define a shared common approach to analyse nourishment behaviour in relation to qualitatively and quantitatively observed behaviour, changes in coastal state indicators and presumable driving parameters. In 2018, the project partners will apply this shared methodology to their laboratories. In 2019, a co-analysis will be performed of all laboratories. The activities aim at relating the observed behaviour and performance of nourishments to the local morphodynamics and hydrodynamics. The co-analysis focusses on the performance of nourishments of each project partner and attempts to reveal links between presumable driving parameters and the observed behaviour.

The results of the co-analyses will contribute to the evidence base on the performance of BwN solutions in the North Sea Region. From these results, several business cases will be explored and developed. In addition, the outcomes will be used to support practitioners and policy makers to implement BwN schemes in national and regional policies. As a result, an NSR guideline document on the implementation of BwN projects with a focus on nourishments will be drafted.

4. First results

The project started by comparing current practices of all project partners (Factsheets: "From flood prevention strategy to current practice nourishments'', to be published on http://www.northsearegion.eu/building-with-nature/). This comparison shows that there are essential similarities and differences in the current approach to the design and monitoring of nourishments per project partner. In Table 1 an overview of the comparison of current practices of the project partners is given. All partners have experience in applying beach nourishments. Shoreface nourishments are not commonly applied yet. Further, all projects partners do have a flood risk reduction goal in their coastal management policy. The underlying policy goals, however, deviate. Also the choice to include NBS / BwN solutions differs. Full compensation of erosional losses is not common. In addition, the choice of which nourishment type is to be applied is divers and partly depends on the observed coastal behaviour.

Table 1. Snapshot overview comparison current practices. P(f) indicates the flood risk reduction standard expressed as an annual probability of an extreme event that a flood defence should be able to withstand. * Budget restricted.

Project partner	Flood risk reduction goal	Policy goals (criteria)	Compensate erosion goal	NBS/BwN in policy	Nourishment type (Beach / shoreface)
1. DCA (Denmark, central North Sea coast)	Yes	$P(f){:}\frac{1}{100}$, exceptional $P(f){:}\frac{1}{1000}$ (Hold the line)	Yes*	Yes	Both
2. LKN.SH (Germany)	Yes	(Hold the line)	Partly	Yes	Both
3. NLWKN (Germany)	Yes	Protect other functions (Hold the line and dune safety)	No	Yes	Beach
4. RWS (Netherlands)	Yes	1) $P(f){:}\frac{1}{300}$ $up\ to$ $P(f){:}\frac{1}{100.000}$ 2) Protect coastal functions (Hold the line)	Yes	Yes	Both
5. MDK (Belgium)	Yes	1) $P(f){:}\frac{1}{1000}$ 2) No fatal casualties allowed (Hold the line)	No	Yes	Beach and experimental shoreface
6. LST (Sweden)	No	Shoreline protection (Building prohibited within range coastal zone)	No*	No	Beach and experimental shoreface

Table **2** presents an overview of design parameters that are used for beach and shoreface nourishment per project partner. The nourishment volume is quite consistently determinded by multipying the erosional trend by the proposed life span of the nourishment.

All project partners locate their nourishments directly in front of the erosion hotspot. Optimisation with regards to the longshore placement of shoreface nourishments might be possible, given the observed longshore migration of nourishments (Bruins, 2016 and Lodder & Sørensen, 2015). Beach nourishments are mostly applied at + 3 to + 5 m MSL and following a slope of 1/20 – 1/35, or a locally a steeper natural slope. The volume per running meter of coast is generally in the order of 150 – 250 m^3/m. Shoreface nourishments are commonly applied offshore of the outer breaker bar or in connection with beach nourishments. Not all project partners apply shoreface nourishments. In addition, not many general design parameters are used when a shoreface nourishment is applied.

Table 2. Overview of design characteristics beach and shoreface nourishments.

Project partner	Nourishment location w.r.t. erosion spot	General design beach nourishment	General design shoreface nourishment	Determination of total volume (Mm^3)
1. DCA (Denmark, central North Sea coast)	Erosion hotspot	± 150-200 m^3/m. Starting above + 4m MSL. Follows initial slope of location	seaward of outer breaker bar, volume of breaker bar	Erosion Trend * Lifespan
2. LKN.SH (Germany)	Erosion hotspot or damage driven	± 150 m^3/m. Start at +5 m MSL Slope: 1/10, 400 μm	seaward of outer breaker bar. ± 300-400 m^3/m	Erosion Trend * Lifespan. ± 1 - 1,5 Mm3
3. NLWKN (Germany)	Erosion hotspot & dune safety	± 300-400 m^3/m. Starting above + 3.7m MSL. Berm slope 1/100, beach slope 1/30	None	Reference height and slope, ± 0,4-0,6 Mm^3
4. RWS (Netherlands)	Erosion hotspot	± 150-250 m^3/m. Starting, + 3-3.5m MSL. Slope 1/20 - 1/30, 200-250 μm	At -5m MSL. Seaward of outer breaker bar. ± 300 - 400 m^3/m	Erosion Trend * Lifespan. ± 0.2 - 7 Mm3 (excl. Sand motor)
4. MDK (Belgium)	Erosion hotspot	Berm + 4,67m MSL (storm level). Berm on seawall. Slope: 1/25 - 1/35	Only 1, connecting to the beach nourishment.	Erosion Trend * Lifespan
5. LST (Sweden)	Erosion hotspot	No general design on beach nourishments	No experience	Erosion Trend * Lifespan

The comparison of current practices reveals that all project partners use quite detailed design parameters for beach nourishments. In designing shoreface nourishments, less detailed design parameters are available/used. Several reasons could be the cause of this observed difference.

Firstly, the need for a detailed design. Beach nourishments are applied along coastal stretches that are quite often, especially in summer, heavily in use by recreational and other coastal functions. Taking into account the value of all these functions in the design of a beach nourishment is therefore important and could result in additional design parameters. On the other hand, shoreface nourishments are applied offshore in a highly dynamic and less intensively used environment. This highly dynamic morphological environment is reason for a less detailed design. The nourishments are rapidly reshaped by the hydro- and morphodynamic processes as shown in Figure **6**, making detailed designs less relevant. Secondly, the morphological behaviour of beach nourishments is much better understood. More experience with this type of nourishment is available, resulting in more defined and detailed design.

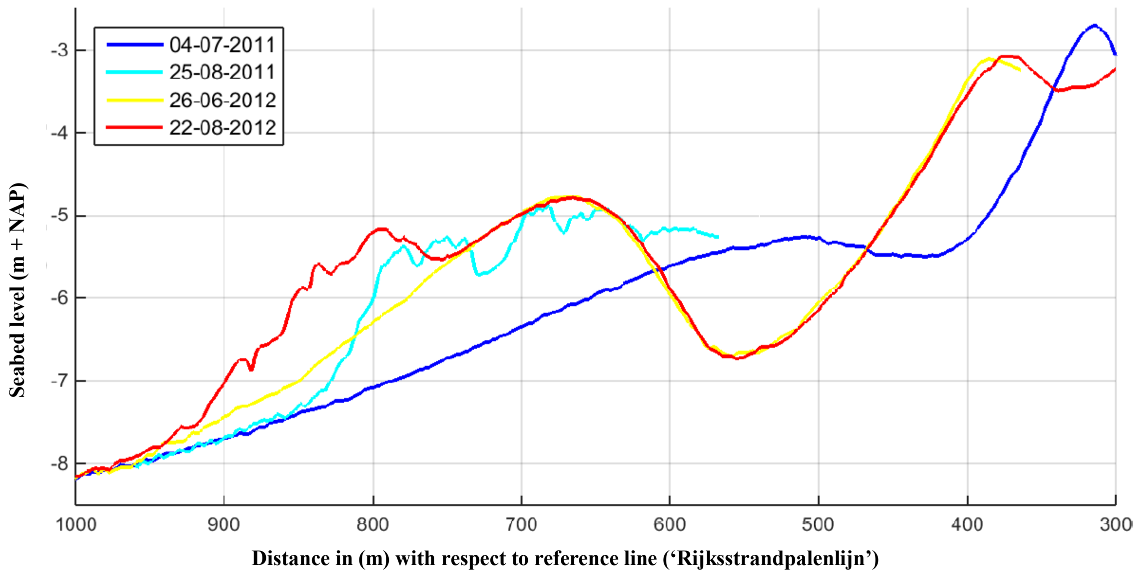

Figure 6. Example of quick reshape shoreface nourishment into breaker. Cross-shore profile (transect 4925, Noord Holland) of Southern shoreface nourishment Heemskerk. The nourishment was constructed in two phases, 2011 and 2012). After the first phase (finished in August 2011), the nourishment quickly reshaped into a smooth bar (yellow measurement in June 2012). Source: Deltares (2017).

This Interreg project focuses on the differences in design approaches of beach and shoreface nourishments of the project partners and the knowledge gaps on the behaviour and effectiveness of both beach and shoreface nourishments. The project aims to enrich the NSR evidence base on these kind of nourishments as widely implemented BwN solutions. The first step towards this evidence base is the co-analysis of multiple nourishments along the North Sea Region.

5. Outline for co-analysis of NSR nourishments.

The proposed co-analysis for the ten coastal laboratories along the North Sea Region (see Figure 5) consisting of beach and shoreface nourishments concerns multiple steps. The most important are:

1. Analysis of the morphological development of individual nourishments in relation to the local coastal morpho- and hydrodynamics, taking into account the coastal state indicators and nourishment design practices.
2. Definition and determination of the effectiveness of nourishments in relation to coastal characteristics like autonomous erosion rates.
3. Draft NSR guidelines on nourishments.

As a first step, the morphological behaviour of each nourishment will be studied using a pre-defined method. This method will be detailed further in 2017. Main elements will be:

- Qualitative description of general morpho- and hydrodynamic characteristics of the area including a description of existing coastal infrastructure and earlier nourishments.
- Qualitative description of the morphological development of the nourishments.
- Quantitative description of morphological development using coastal state indicators, as low water mark, high water mark, dune foot position, beach width, expected dune erosion during design storm, etc.
- Quantitative description of design parameters.

The gathered information will be used to identify distinctive driving parameters and/or coastal characteristics of the observed behaviour of nourishments by using statistics and modelling.

The second and third step will be to define and determine the effectiveness of the nourishments and to draft guiding principles on nourishments in the NSR region. These guiding principles will be used to make an NSR guidance document on nourishments. The document, combined with the insights on the driving parameters of the morphological behaviour of nourishments, will help to predict the behaviour and assess the implementation of future nourishments. The insights from this project can relatively easy be implemented in the management of the NSR sandy coast by the responsible authorities, since they are partner in the project.

Acknowledgements

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