Effectiveness of the Sand Engine

An objective evaluation with the Frame of Reference approach

Master thesis
Ben de Weerdt
Delft, 29 October 2015

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Preface

This thesis is the result of my graduation project and concludes the Master of Science programme at the Faculty of Civil Engineering and Geosciences at Delft University of Technology. It is initiated within the consortium of EcoShape (Building with Nature), STW NatureCoast and Van Oord Dredging and Marine contractors BV.

I would like to thank Ir. E.M.M. van Eekelen and Dr.ir. M. van Koningsveld, who took me under contract with Van Oord Dredging and Marine Contractors BV, as a partner within the EcoShape consortium of Building with Nature. You put faith in me as daily supervisors from the start until the end of graduation process. Regular brainstorm and feedback sessions helped me to stay on the right track and finish this report in a relatively short period of time.

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Abstract

The Sand Engine is a pilot project of a 19.5 million m^3 mega-nourishment on the Delfland coast in the Netherlands, constructed between March and June 2011. Since the project was completed in 2011, a comprehensive monitoring plan has been set up in order to be able to follow the development of the Sand Engine effectively. The monitoring is generating high-quality data that will be used, among others, to determine whether the targets in the Environmental Impact Assessment (EIA) for the Sand Engine have been met (Tonnon et al., 2011), and to conduct scientific research looking at how the Sand Engine works and how effective it is (Rijkswaterstaat and EcoShape, 2013). If the Sand Engine proves to be effective, it can be used elsewhere (Rijkswaterstaat and PZH, 2014a). This study focuses on the assessment of this effectiveness, with as main objective to *'make recommendations for improvement of the objective evaluation of effectiveness of the Sand Engine project'*.

The Frame of Reference (FoR) methodology, a management tool developed by Van Koningsveld (2003), is used in this study as a tool for mapping the evaluation of effectiveness. It enables, through a limited number of steps, evaluation of objectives regarding interventions. This approach can be used *descriptively* as well as *prescriptively*, making it useful in addition to *describe* the current evaluation, also to *prescribe* how the situation could be changed.

By means of reviewing literature, websites and carrying out interviews the formal objectives and its (current) evaluation is obtained and consequently made explicit in a basic FoR template. All objectives could be generally divided into the themes coastal safety, nature, recreation, innovation and knowledge development. Elaborated descriptive frameworks demonstrated that none of the formal objectives in the current evaluation meets the criteria for objective assessment of effectiveness.

The following main causes for failure of meeting the criteria for objective assessment can be identified:

- WHERE and WHEN the Sand Engine is being quantified and evaluated in terms of coastal safety seems subjective, because of a lack of clear alongshore boundaries as well as a large variance in timescale of objectives (20 years in the EIA vs. 50 years in the Monitoring and Evaluation Program (MEPr));
- The relation between WHAT the Sand Engine aims for and WHY, in terms of nature and recreation seems illogical, because the initial aim of space for more nature and recreation is evaluated by quantities (e.g. number of recreants) rather than area;
- WHAT is aimed to be achieved in order to generate innovation and knowledge development has not been sufficiently made explicit, because a quantifiable desired state for this objective is lacking.

The FoR methodology was concluded to be a very helpful tool to map the evaluation of effectiveness into a limited number of elements. By including informal objectives and expectations of the Sand Engine, this study has made a first attempt to *prescribe* an objective evaluation procedure of the effectiveness of the Sand Engine. The same division into themes of objectives as for the descriptive frameworks of the current evaluation is regarded, but it appears that many objectives within these themes need revision as well as extra objectives need to be added to enable objective assessment.

The main adjustments made to the current evaluation are:

- Division of the strategic objective for coastal safety into coastal maintenance and coastal reinforcement representing different scales of the coastal system (coastline position, volume of the coastal foundation and residual dune strength);
- Division of the tactical objectives for nature and recreation into objectives relevant for different areas on (and around) the Sand Engine;
- Adding of repeatedly mentioned expectations of the Sand Engine (van Dalfsen and Aarninkhof, 2009; Rijkswaterstaat and PZH, 2014b; EcoShape, 2014) into objectives for innovation; a more cost-effective and environmentally friendlier approach. These approaches have to be compared with the regular nourishment program Kustlijnzorg.

Development of the prescriptive frameworks in which previous adjustments have been made, revealed two main gaps within the current monitoring/research programs, namely:

- In order to effectively maintain the coastline position in case of presence of a Sand Engine, a new 'decision making tool' should be applied. While the current 'local approach' usually results in intervening when the coastline position exceeds (or is foreseen to exceed) the Basic Coast Line (BCL), a new so called 'regional approach' takes into account the trend in coastline position of the adjacent coastline. An average positive trend (accretion) in the two adjacent JARKUS transects on each side of a transect should lead to postponement of an intervention.
- Decreasing the disturbance of (local) benthic communities by concentration of a nourishment in space and time (being a 'tactic' for an environmentally friendlier approach) should be evaluated with hypothesized differences in (initial) ecological footprint and recolonization time between a Sand Engine and regular nourishments.

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List of Acronyms

AHN Actueel Hoogtebestand Nederland

BCL Basic Coast Line

CSI Coastal State Indicator

DHV Royal HaskoningDHV

EIA Environmental Impact Assessment

FoR Frame of Reference

HvH Hoek van Holland

I&M Infrastructure & the Environment

MCL Momentary Coast Line

NAP Normaal Amsterdams Peil

NMNW National Monitoring Network Water

MEPl Monitoring and Evaluation Plan

MEPr Monitoring and Evaluation Program

PZH The Province of Zuid Holland

QSC Quantitative State Concept

RWS Rijkswaterstaat

TCL Testing Coast Line

Chapter 1

Introduction

1.1 Background information

Nourishment policy in the Netherlands

For the past few centuries the coast has been eroding, especially the Delfland Coast. The primary function of the coast is protection of the low-lying hinterland against flooding. The sandy coast however represents important values to other functions as well: ecological values, drinking water supply, recreation, residential and industrial functions. Coastal erosion, dominant along half of the Dutch coast is endangering these functions (Mulder and Tonnon, 2010).

In 1990 it was decided by the ministry of Infrastructure the Environment (I&M) that the position of the coastline had to be maintained. Due to natural influences, limited sediment supply from the rivers and sea level rise, and human interference, trapping the sediment by the construction of dams, the current supply of sediment is not sufficient to maintain the coastline. Therefore continuous nourishments were needed, about 6 million m^3 of sand was added to the coastal system every year. Later, in 2001, a decision was made that not only the coastline should be preserved but also the sand volume in the coastal foundation (down to Normaal Amsterdams Peil (NAP) -20 m). This led to a rise in annually averaged required nourishment volume to 12 million m^3 (Mulder and Tonnon, 2010).

Pilot Sand Engine

In the light of discussions on upscaling nourishment volumes, the need was felt to investigate innovative ways of nourishing larger volumes of sand. The debate on innovative and large−scale nourishments resulted in some exploratory exercises, among others a report exploring the possibilities for and introducing the concept 'Sand Engine' (Rijkswaterstaat, 2005).

The Province of Zuid Holland (PZH) had ambitions to increase 'recreational green' in the coastal zone and to develop this area (Janssen et al., 2014). Research reported a shortage of 6000 ha for recreation in the coastal zone (Abma and Berkers, 2006).
In the beginning of 2008, a platform supporting innovation and led by the Dutch prime minister asked PZH to develop a plan for the Sand Engine. Moreover the ministry of I&M made a budget available for the project (Janssen et al., 2014). The ambition agreement signed in April 2008 among nine stakeholders marked the start of the planning phase. This phase of the Sand Engine constituted a period of developing design alternatives and a period of selecting, optimizing and deciding upon the preferred design. This led in 2010 to the definite Environmental Impact Assessment (EIA) which also formed the basis for acquiring necessary permits (Janssen et al., 2014). In developing the project the initiators (PZH and Rijkswaterstaat (RWS)) collaborated with the Delfland District Water Control Board (in Dutch: Hoogheemraadschap van Delfland)

and the municipalities of The Hague, Westland and Rotterdam. In addition to this, the Stichting EcoShape was a member of the project group and consultant agencies Grontmij and Royal HaskoningDHV (DHV), research institute Deltares and the World Nature Funds were involved as advisors concerning content (Stive and Mulder, 2011).

The pilot implies a mega-nourishment of approximately 19.5 million m^3 on the coast of the Netherlands, between Hoek van Holland (HvH) and Scheveningen (Figure 1.1), constructed between March and June 2011.

Since the project was completed in 2011, a comprehensive monitoring plan has been set up in order to be able to follow the development of the Sand Engine effectively. The monitoring is generating high-quality data that will be used, among others, to determine whether the targets in the EIA for the Sand Engine have been met (Tonnon et al., 2011), and to conduct scientific research looking at how the Sand Engine works and how effective it is (Rijkswaterstaat and EcoShape, 2013).

Only years after the implementation of the pilot, it was mentioned that initial results indicate that the strategy of the Sand Engine is effective in countering coastal erosion, while providing opportunities for nature and recreation (De Vriend and Van Koningsveld, 2012). Rijkswaterstaat (2014a) also mentions that first signs, based on expert judgement, with respect to the objectives, are positive. Several statements about the potentials of the Sand Engine have also been made:

- If the Sand Engine fulfills expectations, no beach nourishments on the Delfland coast between Ter Heijde and Kijkduin will be required for the next 20 years (Rijkswaterstaat and EcoShape, 2013);
- If the Sand Engine proves to be effective, it can be used elsewhere (Rijkswaterstaat and PZH, 2014a);
- The Sand engine is perhaps cheaper than regular nourishments (Rijkswaterstaat and PZH, 2014b).

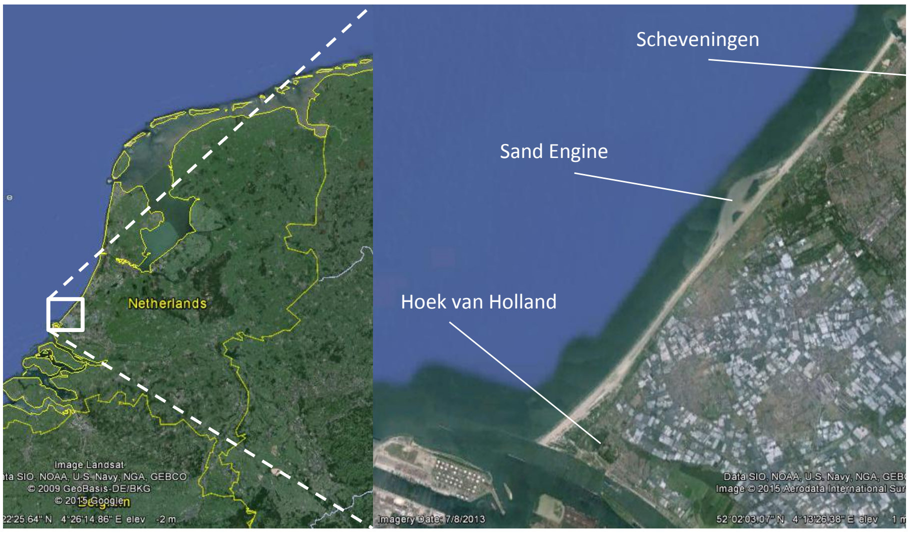


Figure 1.1: Plan view of the Netherlands, indicating the Delfland coast (left) and a plan view of the Delfland coast (right), indicating the location of the Sand Engine (Google Earth)

1.2 Objective

This study will focus on the assessment of effectiveness of the Sand Engine project. Effectiveness is defined as *'a measure of the extent to which the intervention's intended outcomes, i.e. its specific objectives have been achieved'*. The main-objective of this research is to:

> Make recommendations for improvement of the objective evaluation of effectiveness of the Sand Engine project.

1.2.1 Research questions

1. What enables objective evaluation of effectiveness, i.e. what criteria must be met?
2. To what extent does the current evaluation of formal objectives of the Sand Engine meet these criteria?
3. What causes could be identified for failure of meeting the criteria for objective assessment?
4. How could improvement of objective assessment of effectiveness be enabled?
5. What 'gaps' does this improvement disclose in the current monitoring and/or research programmes?

1.3 Method

The Frame of Reference (FoR) methodology, a management tool developed by Van Koningsveld (2003), is used as a tool for mapping the evaluation of effectiveness. It enables, through a limited number of steps, evaluation of objectives regarding interventions. This approach can be used *descriptively* as well as *prescriptively*, making it useful in addition to *describe* the current evaluation, also to *prescribe* how the situation could be changed.

In order to obtain a better understanding of the formal objectives and the current evaluation, besides review of available literature, semi-structured interviews are carried out with stakeholders (see Appendix A). Interviewees are selected depending upon their involvement in the evaluation, ranging from project managers of the initiating parties to researchers within the monitoring and research programs.

1.4 Thesis outline

In Chapter 2 the methodology of the Frame of Reference and its proposed use in this thesis is explained in more detail. This chapter also sets the criteria for objective assessment of effectiveness, as it will be used in the sequent chapters.
Chapter 3 elaborates the application of the current evaluation of formal objectives in a FoR, by analyzing a selection of documents and carrying out interviews. The aim is to check to what extent this current evaluation meets the criteria for objective assessment, as determined in Chapter 2.
Chapter 4 aims to improve the objective assessment of effectiveness by prescribing a framework that takes into account informal objectives and expectations of the Sand Engine. The aim of this chapter is to prescribe improvements of the current evaluation and reveal (possible) gaps within the current monitoring and/or research programmes.
Chapter 5 will feed back on the limitations of the used methodology for this study, followed by conclusions and recommendations regarding the research questions in Chapter 6.

Chapter 2

The Frame of Reference

2.1 Introduction

The FoR approach was developed to help researchers from different fields to use one method generically applicable to embed their results in a practical decision context (Van Koningsveld et al., 2003; Van Koningsveld and Mulder, 2004; Van Koningsveld et al., 2005; Garel et al., 2014). Applying the method increases the probability that specialist research produces results that are applicable in policy development or practical application (Van Koningsveld et al., 2003).

To make the framework more applicable in practice, Van Koningsveld and Mulder (2004) suggest to use a basic FoR template which contains a limited set of elements that appear to be systematically present in succesfully implemented policy. Application of this FoR has shown high potential to better integrate coastal science and coastal policy and management (Van Koningsveld and Mulder, 2004).

This chapter further explains the methodology of the framework and its proposed use in this study.

2.2 Framework elements

The basic FoR template breaks down strategic objectives into one or more operational objectives (see Figure 2.1). The operational objective consequently subdivides the following elements within the operational phase:

- the Quantitative State Concept (QSC)
- the Benchmarking procedure
- the Intervention procedure
- the Evaluation procedure

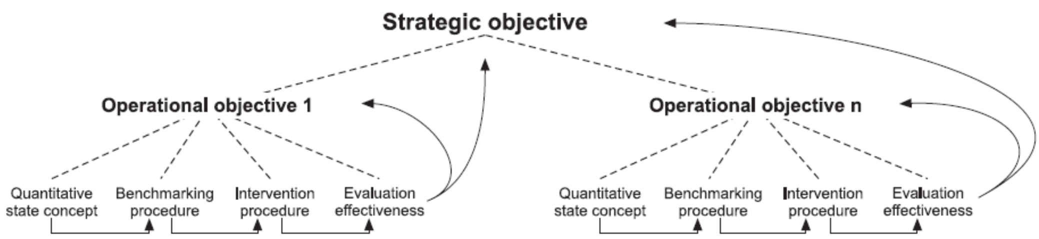


Figure 2.1: The basic frame of reference as a tool for policy development (Mark van Koningsveld)

Strategic objective

The first and uppermost element in the framework is the strategic objective. The strategic background provides the long term vision or ambition of a project, i.e. the (initial) reason *why* an intervention is needed. A single project could have several different strategies, preferably divided in different themes or (management) issues.

Operational objective

The operational objective describes in more detail *what* has to be achieved in order to comply with the strategic objective. As this implies a tactic, this objective could also be called a tactical objective.

Quantitative State Concept

The first element within the operational phase is the QSC, a means of describing *how* to quantify the objective(s). Specific parameters are relevant in this stage as well as the methodology to obtain values for these specific parameters.

Benchmarking procedure

The next element is the benchmarking procedure, in which the desired values of the parameters (usually derived from the operational/tactical objective) are compared with those in the current state. This stage also defines *where* and *when* these parameters are being determined, i.e. the time and spatial scale of the objectives.

Intervention procedure

The intervention procedure describes the action that is considered to enable achievement of the objective, i.e. favourably contributing to the specific parameters in the current state.

Evaluation procedure

The evaluation procedure is the eventual assessment of achievement of objectives. Generally, if the benchmarking procedure reveals the current state satisfies the desired state the operational or tactical objective is achieved. This is however not necessarily the case for the strategic objective, which is sometimes subdivided into more operational objectives and almost inevitably an imperfect translation of the latter.

2.3 Basic questions

CONSCIENCE (2015) suggests the FoR requires an answer to a set of basic questions: *WHY*, *WHAT*, *HOW*, WHERE, WHEN and *HOW*?

In this thesis, all basic questions (except WHO) are answered in specific elements of the framework, as illustrated in Figure 2.2. Although answering the question WHO might be helpful for obtaining more detailed information about an objective, it is not considered necessary for objective evaluation, because 'objective' suggests an evaluation independent of the person, party or discipline carrying out the evaluation.

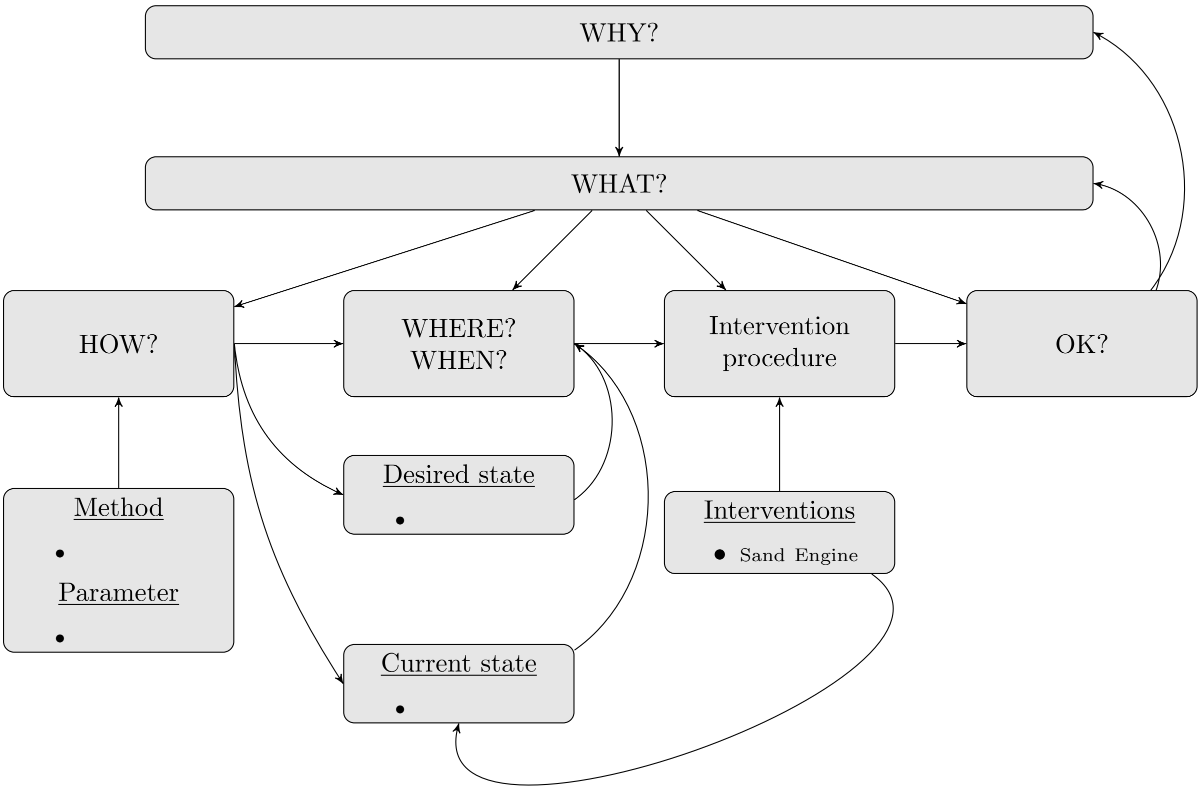


Figure 2.2: Basic FoR template illustrating required basic questions for each framework element

2.4 Criteria for objective assessment

The framework basically consists of blocks and arrows. In order to be able to objectively evaluate effectiveness and thus its specific objectives (see definition of effectiveness in Section 1.2) it is necessary that all 'spots' in the framework could be filled and all 'links' are logical (i.e. the framework is coherent).

For easy recognition of lack of specification and/or illogicality within the framework, so called 'white spots' and 'red links' are introduced, as illustrated in Figure 2.3. A white spot illustrates insufficient specification of an element and a red link an illogical connection between elements.

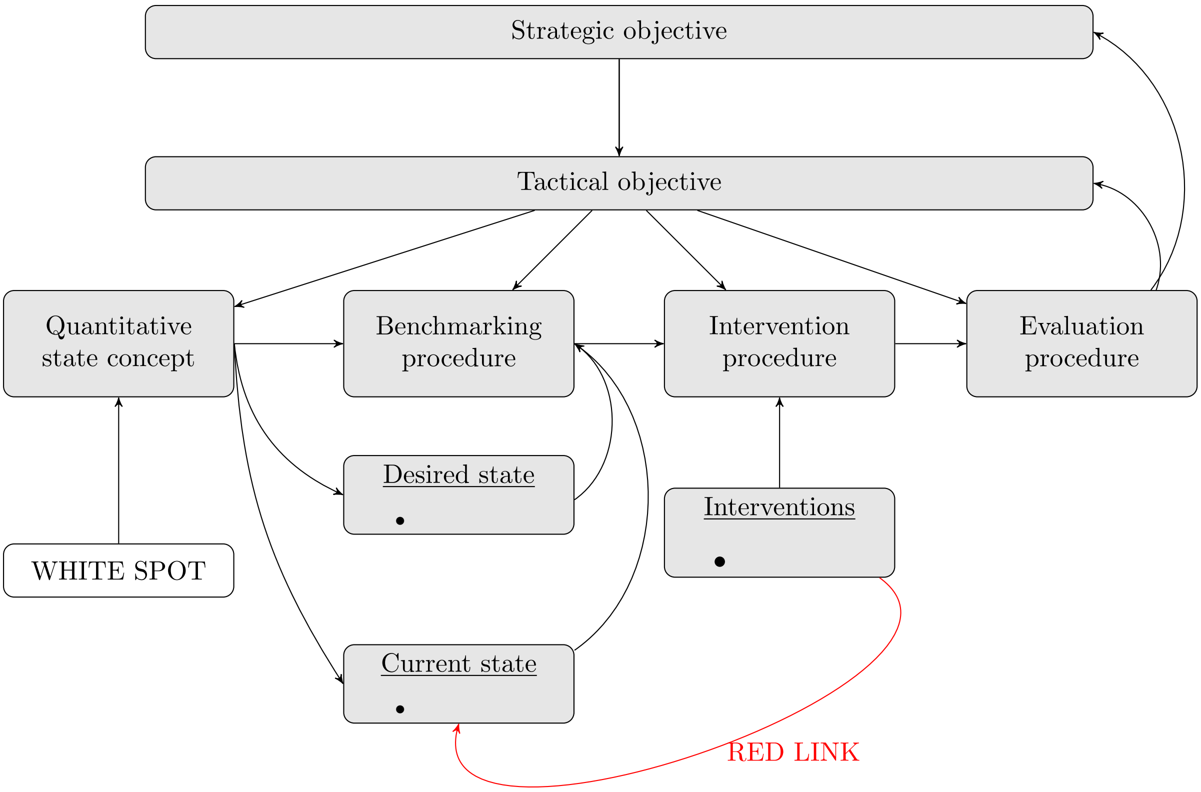


Figure 2.3: Basic FoR template illustrating a 'white spot' (indicating insufficient specification) and a 'red link' (indicating illogicality)

2.5 Conclusion

What enables objective assessment, i.e. what criteria must be met?
It is concluded that objective evaluation is enabled in case of absence of so called 'white spots' (indicating lack of sufficient specification of an element) and 'red links' (indicating illogicality between elements) within a basic FoR template. Presence of either of these can consequently be translated into an insufficient answer to one (or more) of the basic questions *WHY*, *WHAT*, *HOW*, *WHERE* and *WHEN*.

Chapter 3

Descriptive FoR

In this chapter the current evaluation of formal objectives of the Sand Engine is described in a FoR template, as proposed in Chapter 2. The aim is to open up to what extent the current evaluation meets the criteria to enable objective assessment of effectiveness of the Sand Engine. The condition for objective assessment is, as explained in Chapter 2, absence of 'white spots' (indicating insufficient specification) and 'red links' (indicating illogicality) within the FoR template. Presence of these refers to either no answer or an ambiguous answer to the basic questions *WHY*, *WHAT*, *HOW*, *WHERE* and *WHEN*.

The first section describes an analysis of the (formal) objectives of the Sand Engine. By means of reviewing literature, websites and carrying out interviews the formal objectives are obtained. An overview of the documents, websites and interviewees is shown in Table 3.1. Interviews also supported in the making the division between strategic and tactical objectives. At the end of this section a set of formal objectives is proposed that is used in the for the descriptive frameworks.

Secondly, Section 3.2 describes the operational phase (QSC, benchmarking, intervention and evaluation procedures), elaborated in the basic FoR templates, which is also supported by literature and interviews (Table 3.1). Finally, conclusions are drawn regarding the extent to which the criteria for objective assessment are met and the identified causes for failure of meeting the criteria.

Documents	**Date**
Ambition Agreement (Dwarshuis van de Beek et al., 2008)	April 2008
Environmental Impact Assessment (Fiselier, 2010)	Febuary 2010
Monitoring and Evaluation Plan (Fiselier and Ebbens, 2010)	February 2010
Monitoring and Evaluation Program (Tonnon et al., 2011)	March 2011
Working document: Analyses, hypotheses and evaluation (Boon et al., 2014b)	–
Websites	
http://www.zandmotor.nl	–
http://www.rijkswaterstaat.nl	–
http://www.zuid-holland.nl	–
Interviews	
J.P. Fiselier (DHV)	May 2015
C. van Gelder-Maas (Projectmanager 2012-present, RWS)	June2015
K.J. Oome (Projectmanager 2005-2012, PZH)	July 2015
P.K. Tonnon (Deltares)	22 May 2015
A. Boon (Deltares)	15 July 2015

Table 3.1: Documents, websites and interviews used for the descriptive FoR

3.1 Analysis of objectives

This section analyzes the objectives of the Sand Engine that have been explicitly defined in literature. By means of interviews it is aimed to gain understanding of the objectives and its context. Next to that, interviews supported in the suggested division into strategic and tactical objectives.

3.1.1 Ambition Agreement

In April 2008, marked as the end of the initiaton phase, an ambition agreement (Dwarshuis van de Beek et al., 2008) was signed among nine interested stakeholders in which the goals and ambitions of the project were agreed upon.

In the ambition agreement the main- and secondary objective are formulated as:

- **Combining of the long term safety behind the Delfland coast with more space for nature and recreation in this part of the south wing of the 'Randstad'.**
- **Innovation and knowledge development.**

3.1.2 Environmental Impact Assessment

In February 2010 the EIA (Fiselier, 2010) was published, initiated by PZH in collaboration with the same stakeholders that signed the ambition agreement. This document, prepared by DHV, lists three (main-)objectives:

- **Stimulate natural dune growth in the coastal area between HvH and Scheveningen for safety, nature and recreation.**
- **Generate knowledge development and innovation to answer the question to what extent coastal maintenance, increased value for recreation and nature can be realized coherently.**
- **Adding of an appealing recreation and nature area on the Delfland coast.**

It is mentioned by van Gelder-Maas (2015) that it is not a matter of dispute that these three objectives from the EIA are the definite objectives of the Sand Engine, on which the monitoring program is built. Next to that she agrees upon the suggestion that the EIA represents how the objectives from the ambition agreement are aimed to be achieved. In other words, these are the 'tactics' to achieve the ambitions made in 2008.

Tonnon (2015) mentions that, although it was consulted by the EIA-committee, the objectives have not been prioritized, because in this way all stakeholders would be supportive.

3.1.3 Monitoring and Evaluation Plan

Simultaneously with the EIA, the MEPl (Fiselier and Ebbens, 2010) had been published, prepared by DHV. The MEPl aims to answer the question to what extent the objectives, as described in the EIA, are actually being achieved. The MEPl is part of the ambition agreement and forms the basis for the choice of the monitoring package to carry out. On the basis of this MEPl can together with the commitments from the various permits an 'operational monitoring and evaluation plan' be drawn (Fiselier, 2010). This refers to the MEPr.

3.1.4 Monitoring and Evaluation Program

The MEPr (Tonnon et al., 2011), published in March 2011, further elaborates the objectives of the EIA into evaluation issues, hypotheses and information requirements. For every so called sub-objective (coastal safety, nature, recreation and knowledge development) evaluation questions have been formulated. Only the evaluation question for coastal safety is considered in this analysis, namely:

- **Does the Sand Engine provide for a higher safety in the coastal area of HvH and Scheveningen?**

For this evaluation, the following hypotheses have been formulated:

- **The Sand Engine and additional nourishments guarantee the safety in the coastal area between HvH and Scheveningen during 50 years and provide by dune growth for a higher safety in comparison with the regular nourishment program between 1990 and 2010.**
- **As a result of the Sand Engine in total less sand will be needed for maintenance of the BCL in the coastal area between HvH and Scheveningen for a period of 20 years.**
- **With the Sand Engine and additional nourishments the sand balance of the coastal foundation is maintained in the coastal area between HvH and Scheveningen for at least 50 years with a sea level rise of 3 mm/year.**

3.1.5 Working document: Analyses, hypotheses and evaluation

Boon et al. (2014a) are currently working on a further analysis of the hypotheses stated in the MEPr. This document translates some of the hypotheses into examinable null hypotheses. This resulted for coastal safety into the following null hypotheses:

- **The development of the dune volume and the position of the dune foot in the coastal area between HvH and Scheveningen is such that the position of the erosion line develop negatively in the first 50 years after construction of the Sand Engine, in comparison with the period of 1990 until 2010.**
- **The development of the MCL and the nourishment volumes in the coastal area between HvH and Scheveningen is such that the first 20 years after construction more sand is needed for maintenance of the BCL than in the period 1990−2010.**
- **The development of the sand volume of the coastal foundation between HvH and Scheveningen is such that the first 50 years after construction of the Sand Engine the volume of the coastal foundation is not maintained with a sea level rise of 3 mm per year.**

3.1.6 Websites

The objectives, observed from the reviewed websites, are significantly different (especially for coastal safety). For example, according to the website of PZH the Sand Engine aims, among others, for an 'increase of the coastal safety on the long term', while 'natural coastal maintenance' is one of the objectives mentioned on the website of RWS. On the website of the Sand Engine (http://www.zandmotor.nl) also several different sets of objectives can be found (see Appendix B).

Not much clarity can be obtained from these objectives and they are therefore considered rather subjective. Oome (2015) also mentions that not much attention is given to the objectives on the website of the PZH.

3.1.7 Conclusions

While all objectives could be generally subdivided in '*coastal safety*', '*nature*', '*recreation*' and '*innovation and knowledge development*', it is not clear what the actual (formal) objectives of the Sand Engine are. Interviews were necessary to obtain more clarity. Especially review of different websites revealed ambiguity of objectives. One could therefore consider the strategic and tactical objectives as 'white spots' within the framework. However, supported by interviews the objectives of the ambition agreement (Dwarshuis van de Beek et al., 2008) and EIA (Fiselier, 2010) are considered the formal (strategic and tactical) objectives for the current evaluation of effectiveness of the Sand Engine. Only for coastal safety an additional objective (distracted from the MEPr) is included.

In terms of coastal safety could be concluded that no clear answer to the question *WHY* the Sand Engine has been constructed could be directly obtained. In 2008 'long term coastal safety' had been defined as the objective (or actually ambition). In 2011 had been made explicit that coastal safety will be evaluated by questioning whether 'a higher safety' is being achieved.

Providing for a higher coastal safety and long term coastal safety could be interpreted as two different objectives, but long term safety could also be a result of the provision of a higher safety, assuming that on the long term a higher coastal safety is needed due to the rising sea level.

'Long term coastal safety' is considered the strategic objective of the Sand Engine (regarding coastal safety), although a clear definition of 'long term' is lacking, but this is further elaborated in the next section. A higher safety, provided by stimulation of natural dune growth, serves as one tactical objective (although evaluated in two different ways as one will also see in the next section).

S1: Long term coastal safety

- **T1:** (Provide a higher safety by) stimulation of natural dune growth

S2: More space for nature

- **T1:** Stimulate natural dune growth
- **T2:** Adding of an appealing nature area

S3: More space for recreation

- **T1:** Stimulate natural dune growth
- **T2:** Adding of an appealing recreation area

S4: Innovation and knowledge development

- **T1:** Generate knowledge development and innovation to answer the question to what extent coastal maintenance, increased value for recreation and nature can be realized coherently

3.2 Descriptive frameworks

In this section descriptive frameworks are elaborated for every theme of objectives. While previous section focused on the objectives (*WHY* and *WHAT*), this section discusses in more detail the operational phase of the framework (*HOW*, *WHERE* and *WHEN*).

The descriptive framework is elaborated in templates in which 'white spots' (indicating lack of specification) and 'red links' (indicating illogicality and/or incoherence) within the framework can easily be recognized.

3.2.1 Coastal safety

The tactical objective to stimulate natural dune growth (*WHAT*) is likely to be interpreted as an open target in which any natural dune growth seems to suffice to achieve the objective. Fiselier (2015) mentions that this objective is achieved when there is a net dune accretion, which is larger than expected. Also van Gelder-Maas (2015) agrees that when the dune accretion is more than you would expect this objective is achieved.

The morphological effects of the Sand Engine have been calculated using a morphological computer model (Fiselier, 2010; Tonnon et al., 2009). Based on this model, in the EIA, a description is made of these effects for different alternatives, for a period of 20 years. Among these alternatives is the final design of the Sand Engine. Besides that, calculations have been made for a (reference) situation without the Sand Engine, with only maintenance of the BCL and coastal foundation (the regular nourishment program or 'Kustlijnzorg'). Calculations show that with Kustlijnzorg an increase in dune area of 15 to 17 ha would arise. Calculations for the Sand Engine alternative give a growth of 23 to 33 ha. With the regular nourishment program one would thus also expect dune growth but the Sand Engine aims to stimulate this, or in others words, to generate more dune growth than expected in the reference situation.

So, assuming the calculated dune accretion for the reference situation to be the expected dune accretion as mentioned by van Gelder-Maas (2015) and Fiselier (2015), one could take dune accretion (not to confuse with dune growth (dune accretion/year)) as a parameter for the QSC. This parameter is being quantified with Delft3D for the desired state (2011-2031). In the current state, this parameter is being quantified with JARKUS (Tonnon et al., 2011), measured twice a year in the period of 2011-2021. Note that this does not coincide with the period of the desired state. Objectives are explicitly formulated for the coastal area between HvH and Scheveningen, although no exact alongshore boundaries can be found (*WHERE*).

The intervention is the Sand Engine; a 19.5 million m^3 shore face nourishment in the form a peninsula that extends about 1 km into the sea. However, the EIA also mentions that in the period of 2011 to 2031 additional nourishments will be necessary for maintenance of the total coastal area (between HvH and Scheveningen), an extra 3,3 to 5,6 million m^3 sand (net). A descriptive framework for coastal safety, mainly made explicit through analysis of the EIA and interviews, is shown in Figure 3.1.

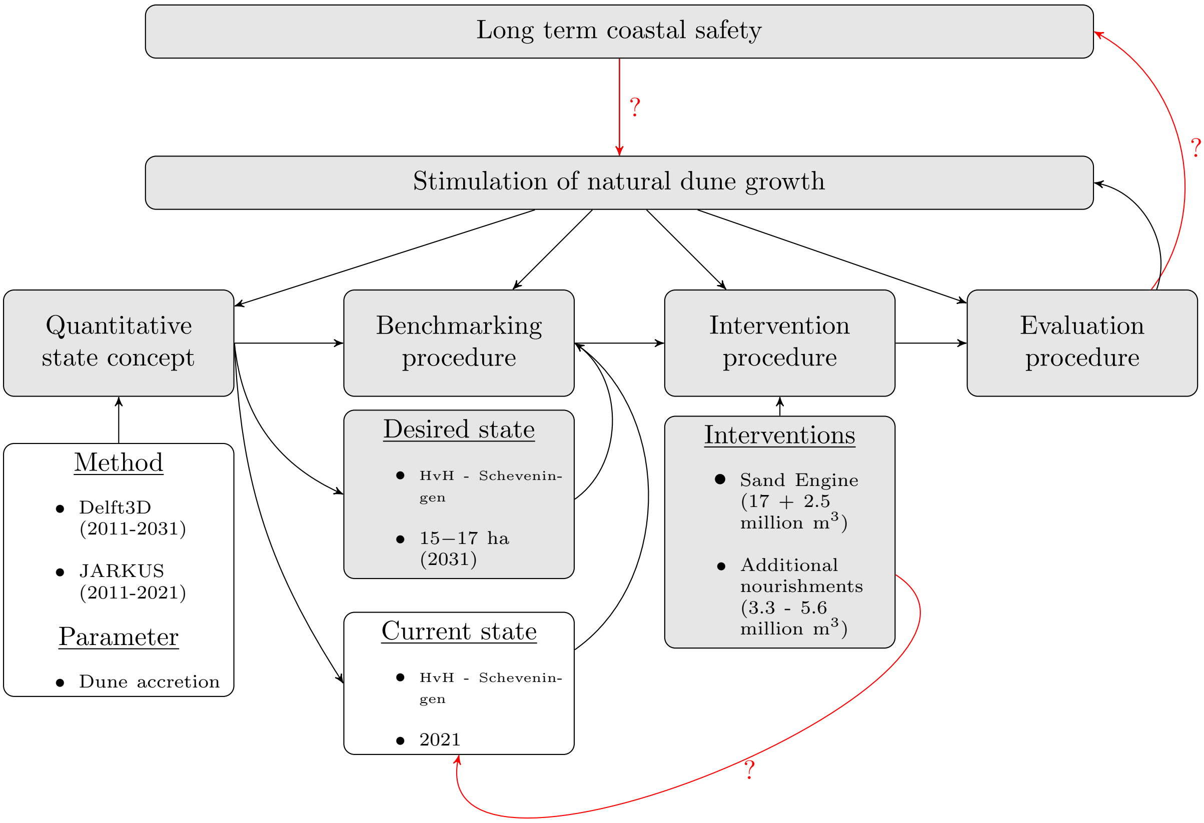


Figure 3.1: Descriptive framework for coastal safety, mainly made explicit through analyzing the EIA and interviews

The descriptive framework in Figure 3.1 focuses solely on the dune accretion in the coastal area between HvH and Scheveningen. Since no 'safety indicators' are used in the QSC one could obviously not evaluate whether 'long term coastal safety' has been achieved.
Next to that, it has been made explicit that dune accretion is monitored with the use of JARKUS, but the exact boundaries of this dune area (*WHERE*) is not defined.
Another aspect causing white spots in the framework is the timescale used (*WHEN*). The desired state has been calculated for 20 years, but the monitoring of dune accretion will only be carried out in the first 10 years. Since the monitoring program only lasts until 2021, it should be made explicit what the expected dune accretion is at that moment in time. Although the QSC already a lacks a method of HOW to evaluate 'long term coastal safety', using a timescale of 10 years it is doubtful whether this could be called a 'long term' timescale.
Notice further that additional nourishments have been included in the intervention procedure. This is an estimation that followed from calculations with Delft3D. Questions arise what happens when for instance more nourishments will be executed. Does that mean the objective has not been achieved? Probably not, especially when the net dune accretion ends up much higher than expected, but a methodology to evaluate these different scenarios have not been made explicit.

If one would make the current evaluation, as described in the MEPr and working document by Boon et al. (2014a), explicit in a FoR, the result is a significantly different descriptive framework. The focus in these documents is directed more towards safety, since the overall evaluation question is whether the Sand Engine results in a higher safety. One of the hypotheses state that by dune growth a higher safety is provided (compared to 1990-2010).
Boon et al. (2014a) describe the dune volume and erosion line as indicators/parameters for evaluation. Subsequently in the MEPr can be found that this is being monitored with Actueel Hoogtebestand Nederland (AHN), Kust LIDAR (2011-2061, every 5 year) and JARKUS (2011-2021, twice a year). *WHERE* this is being monitored is the landward dune foot position until the seaward dune foot position. *HOW* these positions are defined can however not be found directly. Notice also that the timescale (*WHEN*) is different for the JARKUS method and the combination of AHN and Kust LIDAR.
A desired state follows implicitly from the null hypothesis by Boon et al. (2014a), in which it is actually bench marked by checking if during the first 50 years no negative development of the erosion line will occur in the coastal area between HvH and Scheveningen.

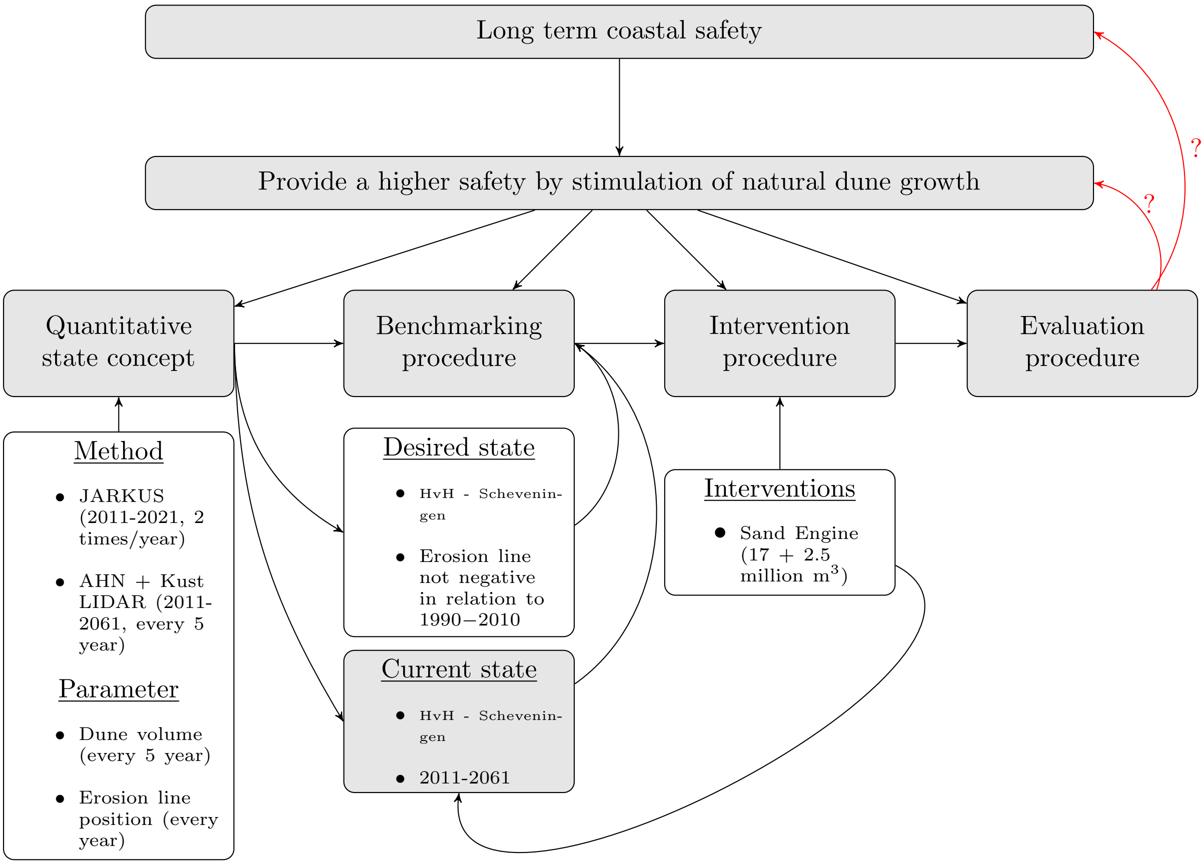


Figure 3.2: Descriptive framework for coastal safety, mainly made explicit through analyzing the MEPr and working document by Boon et al. (2014a)

The desired state actually aims for maintenance of safety rather than a higher safety. One could interpret this as a higher safety because higher safety levels are needed on the 'long term' due to sea level rise.

The hypothesis (Tonnon et al., 2011) states that the Sand Engine *and additional nourishments* will (guarantee coastal safety for 50 years and) provide by dune growth for a higher safety. Additional nourishments have not been defined, but Rijkswaterstaat (2014a) mentions that these are the foreshore nourishments executed on both sides of the Sand Engine. These nourishments are included if one speaks of a nourishment volume of 19.5 million m^3 of the Sand Engine (see Appendix D).

The second descriptive framework for coastal safety is shown in Figure 3.2.

Comparing the two descriptive frameworks one can find several significant differences that make objective evaluation currently difficult, if not impossible.
The first descriptive framework focuses solely on the dune accretion and for a timescale of 10 to 20 years (not clearly defined). In this relatively short period additional nourishments are expected to be needed and an indication of this volume is made explicit.

The second descriptive framework focuses on the safety level of the coastal area (and thus a different QSC), but on a significant different timescale; 50 years. Next to that, if one assumes the additional nourishments only to consist of the foreshore nourishments included in the design of the Sand Engine, for this relatively large period apparently no additional nourishments are expected, as opposed to the calculations for 20 years with Delft3D.

3.2.2 Nature

As mentioned in the previous section, two tactical objectives (*WHAT*) could be defined to achieve more space for nature (*WHY*); stimulation of natural dune growth and adding an appealing nature area.

Stimulate natural dune growth

In the MEPr is mentioned that no separate evaluation question has been formulated for the positive effects of dune formation on the nature values in the existing dunes. New nature values by young dune formation are being evaluated together with the nature values on the area of the Sand Engine and frontside beach area.

This section is being evaluated by the consortium of Witteveen+Bos and it is therefore not made explicit in detail (in these documents) *HOW* these objectives are being quantified and evaluated, although parameters as vegetation, insects and animals are mentioned.

From the description follows that this objective is being evaluated only at newly formed dunes (*WHERE*). Boundaries of the alongshore area are not defined, but it is very unlikely that the total coastal area between HvH and Scheveningen is being monitored for this objective.
Since the monitoring program lasts until 2021, the timescale (WHEN) is regarded as 10 years.

An explicit desired state is lacking, but the development of nature values on the (newly formed) dunes are compared with an artificially constructed dune; Spanjaardsduin, hypothesized that higher nature values will develop.

The descriptive framework for the first tactical objective of nature is shown in Figure 3.3

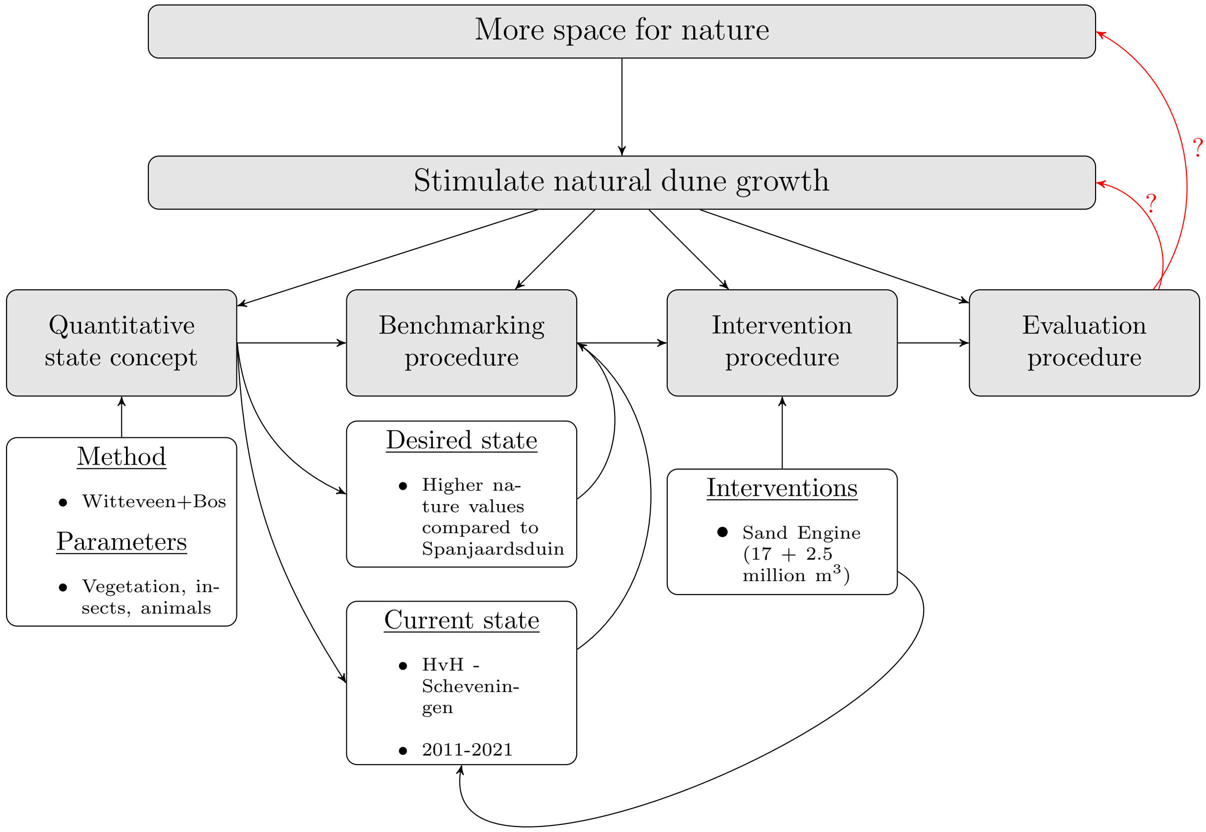


Figure 3.3: Descriptive framework for nature, part 1

Adding of an appealing nature area

Nature values for this objective are quantified within IMARES. Methods (*HOW*) are not described in detail in the MEPr and working document, but parameters are mentioned; a.o. diversity, densities and biomasses.

It is hypothesized that the Sand Engine results in an increase in habitats and that this attracts other and more (types and numbers) organisms than during regular nourishments.
The general evaluation question is 'how the temporary new nature develops in the intertidal area and lagoon of the Sand Engine', which describes *WHERE*. Again, the monitoring program lasts until 2021 (*WHEN*).

The second part of the descriptive framework for nature is shown in Figure 3.4
Although the monitoring of nature seems to be elaborated in much detail, feeding back to the original objectives triggers several questions. Initially, only more space for nature was aimed for, while subsequently the aim is to add an appealing area. This translation seems at first sight illogical.

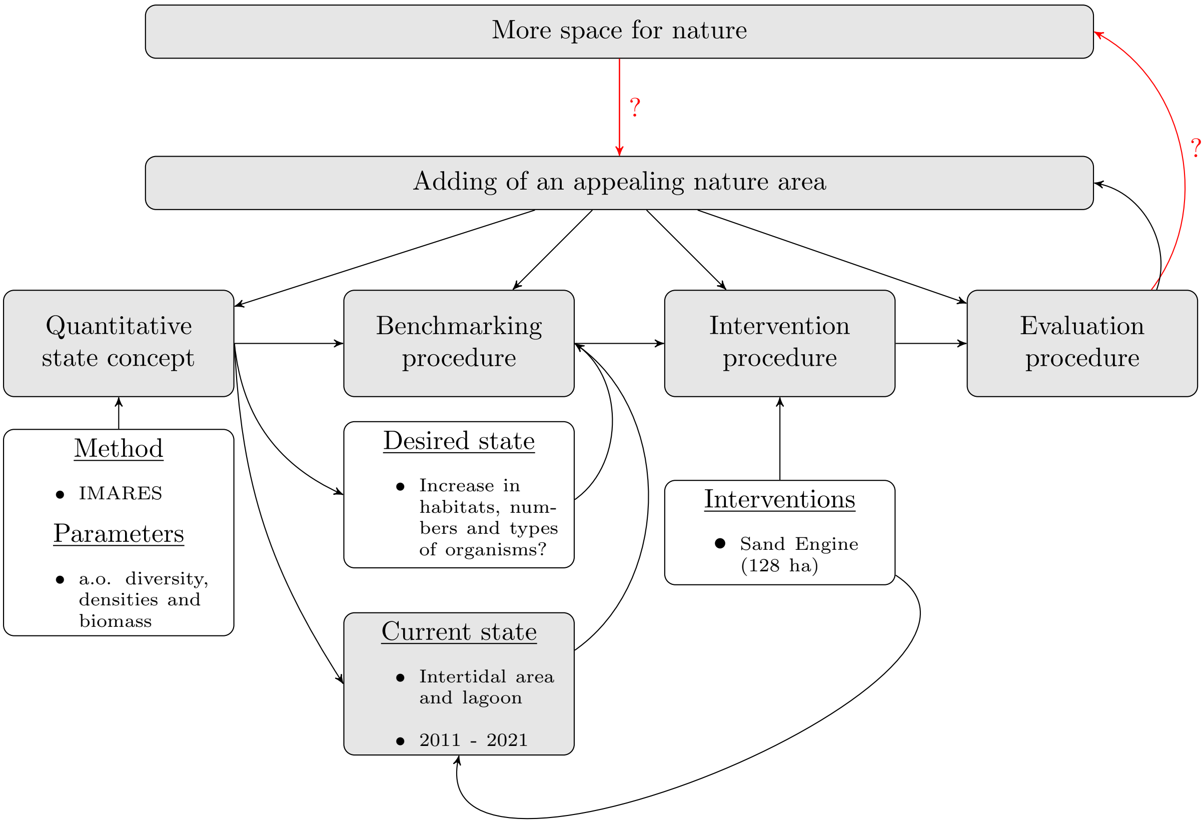


Figure 3.4: Descriptive framework for nature, part 2

3.2.3 Recreation

Similar as for nature, stimulation of natural dune growth and adding of an appealing recreation area (*WHAT*) could be considered tactical objectives to achieve more space for recreation (*WHY*).

Stimulate natural dune growth

Evaluation of this objective for recreation is not elaborated within the MEPr, but within the context of recreational research on behalf of PZH. No detailed information on HOW, WHERE and WHEN this objective is quantified and evaluated could therefore be made explicit.

The first descriptive framework for recreation is shown in Figure 3.5.

Since this objective also serves the function of nature, it should be investigated how these two are interfering between one another.

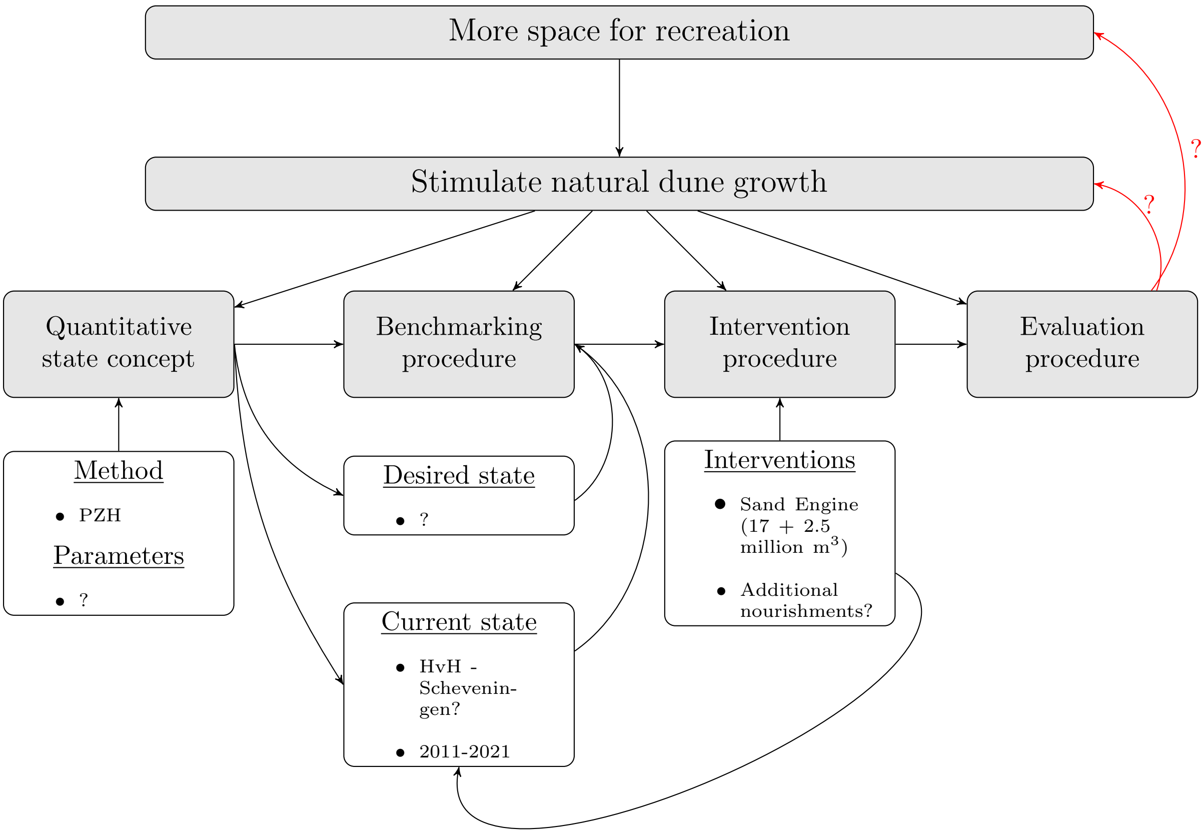


Figure 3.5: Descriptive framework for recreation, part 1

Adding of an appealing recreation area

Evaluation of this objective for recreation is also not elaborated within the MEPr, but within the context of recreational research on behalf of PZH. It is however described that with images from the Argus beach monitoring station, the number of people on the Sand Engine can be counted. The beach user counting remains at the moment a research product.

A desired state and definitions of WHERE and WHEN have not been made explicit. The second descriptive framework for recreation is shown in Figure 3.6.

Just as for nature, the translation of the strategic objective into the tactical objective seems illogical. WHY the Sand Engine has been constructed does therefore not seem to be made clearly explicit. Does the Sand Engine aim to achieve more space for recreation or more recreants?

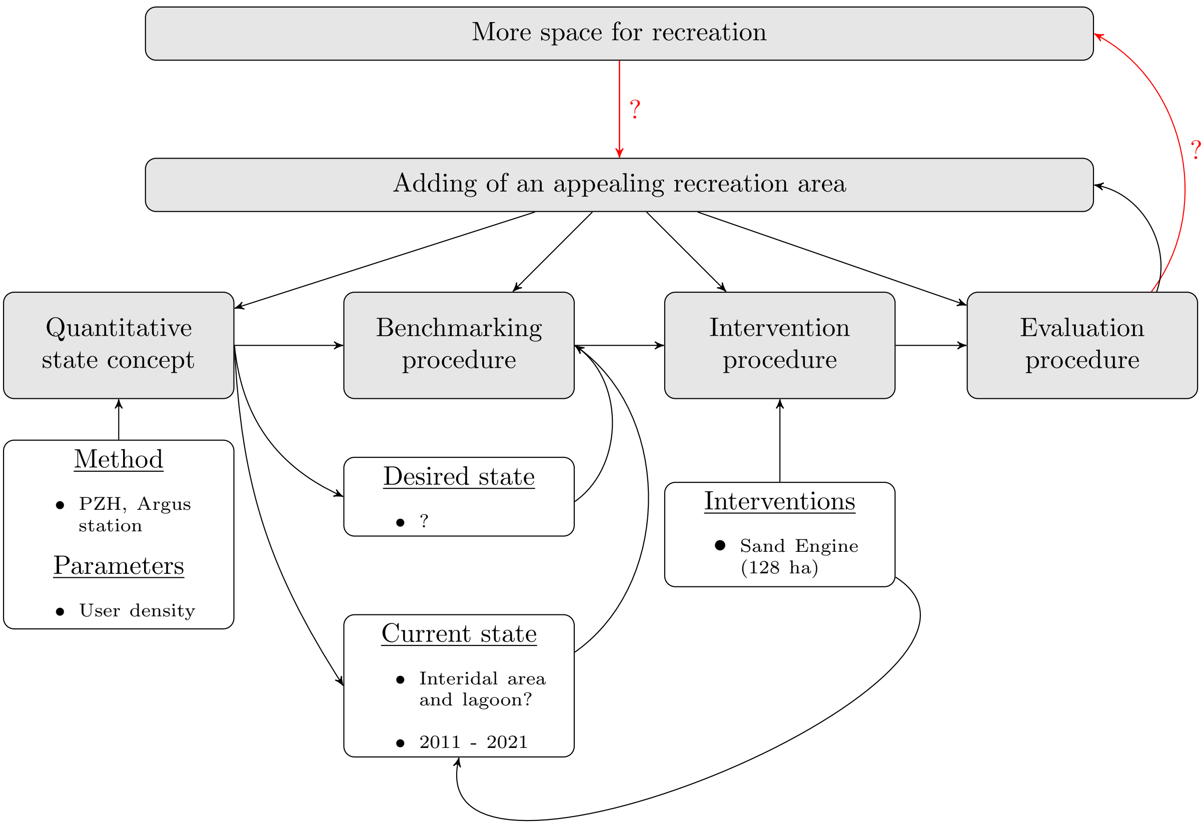


Figure 3.6: Descriptive framework for recreation, part 2

3.2.4 Innovation and knowledge development

The objective to 'generate knowledge development and innovation to answer the question to what extent coastal maintenance, increased value for recreation and nature can be realized coherently' serves in the descriptive framework as the tactical objective (*WHAT*) to achieve the strategy of innovation and knowledge development (*WHY*).

There have been many discussions about the quantification of knowledge and it turns out to be very difficult (van Gelder-Maas, 2015). Although in the MEPr many questions have been made explicit that are aimed to be answered for knowledge development, a 'method' and parameters (*HOW*) to quantify and consequently benchmark this knowledge development has not been clearly made explicit. Another question that arises is *WHEN* is this knowledge aimed to be available?

The descriptive framework for innovation and knowledge development is shown in Figure 3.7.

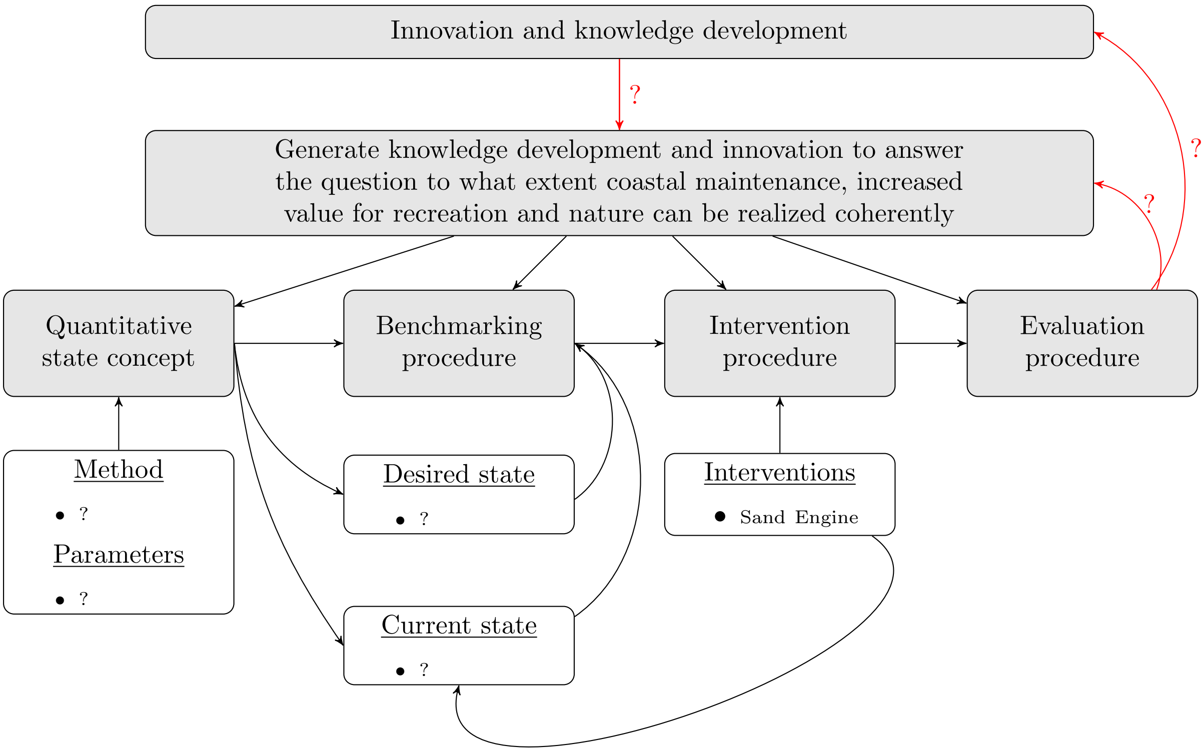


Figure 3.7: Descriptive framework for innovation and knowledge development

The main reason for the insufficient specification of the descriptive framework for innovation and knowledge development is the lack of clear description of *WHAT* is aimed to be achieved. Actually, the tactical objective in the descriptive would better serve as a strategy (WHY).

3.3 Conclusions

This section feeds back to the second and third research question of this study, stated in Section 1.2. In Chapter 2 was concluded that, using the methodology of the Frame of Reference, absence of so called 'white spots' and 'red links' is necessary to enable objective evaluation. These abstract criteria could consequently be translated into a lack of (sufficient) answer to any of the basic questions *WHY*, *WHAT*, *HOW*, *WHERE* and *WHEN*.

To what extent does the current evaluation of formal objectives of the Sand Engine meet the criteria to enable objective evaluation?

The descriptive frameworks in the previous section (Figure 3.7 to Figure 3.1) demonstrate that none of the formal objectives in the current evaluation meets the determined criteria, because many white spots and red links are present in the frameworks. For every theme of objective(s) this is further explained below.

Coastal safety

It does not seem clear-cut *WHY* the Sand Engine has been constructed in terms of coastal safety. It is currently defined as long term coastal safety. This triggers however immediately the question; what is defined as 'long term' (*WHEN*)? Evaluation of objectives differs from a timescale of 10 years up to 50 year. WHAT the Sand Engine aims for, to achieve this 'long term coastal safety', is to stimulate natural dune growth, but an evaluation of this objective seems to result in simply evaluating the dune accretion (*HOW*)(on a timescale of 10 to 20 years), generating loss of sight on the actual objective; coastal safety.

Digging deeper into the evaluation procedure (MEPr) in which (null) hypotheses are used for evaluation, it becomes clear that the stimulation of dune growth aims to provide a higher safety, resulting in evaluation of a safety indicator; the position of the erosion line (*HOW*), between and Scheveningen (*WHERE*), but whether this whole coastal area will be taken into account is doubtful.

While it is calculated that additional nourishments will be necessary between HvH and Scheveningen in the 20 years after construction, Rijkswaterstaat (2014a) states that no additional nourishments (besides the foreshore nourishments included in the Sand Engine) will be necessary in the first 50 years, on the contrary what has been calculated earlier.

Nature

Investigation of the evaluation of the nature aspect of the Sand Engine, revealed that many different parameters are being monitored. The questions that arise within this theme are therefore more directed towards *WHY* and *WHAT*.
The highly abstract objective from the ambition agreement of 'more space for nature' is translated into an objective to 'add an appealing nature area', an illogical translation.

Questions also arise when in search for a desired state. When is something considered an appealing nature area? Within the MEPr comparisons are made with regular nourishments, but does higher nature values compared to regular nourishment mean 'appeal' in general? Formulation of objectives for nature seem to lack sufficient specification to objectively evaluate. Whether the QSC or the 'how to' is sufficient can consequently not be concluded either, regardless the extensive field monitoring program for nature at the moment.

Recreation

Monitoring of recreation falls within the scope of recreational research of PZH and is therefore within this report not made explicit into detail.

Stimulation of natural dune growth seems to serve also more space for recreation, but HOW, WHERE and WHEN could not be defined. Just as for the aspect of nature, initially was aimed for only more space for recreation, while the set of tactical objective requires this area to be 'appealing'. Again, an illogical translation of objectives.

It is mentioned that with the use of the Argus beach monitoring station the use of the Sand Engine could be evaluated. Feeding back to the initial (strategic) objective to create more space for recreation, this would be unnecessary for evaluation.

Innovation and knowledge development

For innovation and knowledge development is not sufficiently made explicit *WHAT* is aimed to be achieved, resulting in a rather 'empty' descriptive framework, lacking specification on *HOW*, *WHERE* and *WHEN*.

What causes could be identified for failure of meeting the criteria for objective assessment?

Regarding the failure of meeting the criteria for objective assessment of effectiveness, the following main causes can be identified:

- WHERE and WHEN the Sand Engine is being quantified and evaluated in terms of coastal safety seems subjective
- The relation between WHAT the Sand Engine aims for and WHY, in terms of nature and recreation seems illogical
- WHAT is aimed to be achieved in order to generate innovation and knowledge development has not been sufficiently made explicit.

Chapter 4

Prescriptive FoR

Chapter 2 described the methodology of the FoR used in this study and associated criteria needed to enable objective assessment of effectiveness (of the Sand Engine).

Chapter 3 applied the methodology of the FoR on the current evaluation of formal objectives. The aim was to check to what extent the current evaluation meets the criteria for objective assessment. It was concluded that to a large extent this evaluation fails to meet the criteria (see Section 3.3).

By analyzing informal objectives and expectations this chapter aims to, with use of own insight, improve the objective assessment of effectiveness. This chapter uses the methodology of the FoR prescriptively (as opposed to the descriptive character in Chapter 3). Changes to the descriptive framework could be made on every level within the FoR (strategic, tactic and operational).

The same division of themes of objectives will be used in this chapter (coastal safety, nature, recreation, nature, innovation and knowledge development). Although a prescriptive framework is elaborated for all themes, some are elaborated in more detail than others. This chapter will illustrate the frameworks in tables rather than templates (used in Chapter 3) to maintain a clear but compact overview.

Eventually, this chapter aims to reveal improvements in objective assessment and possible gaps in the current monitoring and/or research programs of the Sand Engine.

4.1 Coastal safety

It was concluded in Chapter 3 that one of the main reasons why objective assessment of effectiveness could yet not be enabled is because no ambiguous answer could be obtained on the basic questions *WHERE* and *WHEN* (the Sand Engine is being quantified and evaluated).

Looking at the coastal policy in the Netherlands, we can distinguish three different tactical management objectives for Dutch coastal policy (Sutherland, 2010), each being relevant for a different time and spatial scale:

- Safety against flooding during storms (based on rest strength of the dunes)
- Maintain coastline position of 1990, BCL (based on sediment budget in near shore zone)
- Preserve coastal foundation (based on sediment budget including dune area and deeper water)

These three different 'scales' can also be found within the hypotheses in the MEPr, which state that both the coastal safety is guaranteed and the coastal foundation maintained for a period of 50 years. For the coastline position of 1990, the BCL, is only stated that less sand would be needed compared to 1990-2010.

Due to extra examination of the wave forces on the coast, it was concluded in 2003 that several parts of the Dutch coast, so called weak spots (in Dutch 'Zwakke Schakels'), needed to be strengthened in order to guarantee the safety against flooding. In the period 2008-2010 dune and beach nourishments with a total volume of 20.6 million m^3 (see Appendix D) have been executed on the Delfland coast for this purpose.

Next to this, a regular nourishment program (called 'Kustlijnzorg') is being carried out, which aims at maintenance of the coastline position of 1990 (BCL) and maintenance of the volume of the coastal foundation.

One could consider the Delfland coast, at time of construction of the Sand Engine, to be safe against flooding, due to the very recent strengthening activities. Fiselier (2015) also mentions that construction of the Sand Engine was not necessary for guarantee of safety against flooding.

It is suggested to revise the highly abstract strategic objective determined in Chapter 3 (long term coastal safety). On the one hand the Sand Engine contributes to coastal maintenance (coastline position and volume of coastal foundation). On the other hand it contributes to the safety against flooding. However, as mentioned, do we consider the Delfland coast to be safe against flooding at time of construction of the Sand Engine. A more appropriate strategic objective would therefore be 'coastal reinforcement' (due to wider beaches and stimulation of natural dune growth, explained in more detail in Subsection 4.1.2). This division is also mentioned by Rijkswaterstaat and PZH (2014a).

Figure 4.1: Indication of the spatial scale of the main expectation of the Sand Engine (Google Earth)

4.1.1 (Natural) coastal maintenance

As mentioned, Kustlijnzorg, the regular nourishment program for coastal maintenance, implies maintenance of the BCL and volume of the coastal foundation. The Sand Engine is expected to contribute on both of these scales. Due to the expectation of 'natural' redistribution of the sand from the Sand Engine, it is sometimes referred to as 'natural coastal maintenance' (Rijkswaterstaat, 2014c).

Stabilize coastline at position of 2010

Stive et al. (2013) mention that 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 and feed the adjacent coastal sections over an extended length of time (20 years) and space (order of 10 km). Notice that the coastal area between HvH and Scheveningen, which is the spatial scale for most of the objectives determined in Chapter 3, measures ca. 17 km (see Figure 4.1). For the indication of the 10 km scale in this figure, expectations of development of the Sand Engine in the southern and northern direction (Stive et al., 2013) have been taken into account.

The expectation relates to the position of the coastline, which is maintained at the position of 1990, the BCL. This expectation thus actually states that at least the first 20 years after construction of the Sand Engine, for a coastal stretch in the orders of 10 km no maintenance of the BCL is needed.

A part (JARKUS transects 114.1-117.5 (Atsma, 2012)) of the strengthening activities of the 'Zwakke Schakels' on the Delfland coast serves as dune compensation for the construction of Maasvlakte 2. This dune compensation of 35 ha of new dune area between the Van Dixhoorn-driehoek (near HvH and Westland), aims to compensate for the nature values that were lost due to the construction of this project. More or less 5.4 million m^3 had been nourished. The major part is nourished on the beach, of which a wider beach and new dune area is made. The remainder is nourished on the foreshore. After that, a new area of intensive natural dune growth is expected. To stimulate this process periodically sand will be nourished (once in 5 years, for a period of around 20 years) (Deltares, 2007).
Figure 4.2 shows the location of the JARKUS transects 114-119 relative to the Sand Engine. It illustrates that with the uncertainties in expected spatial scale, the Sand Engine might or might not interfere with the dune compensation project.
Attribution to the Sand Engine would become complex when executing nourishments within the time and spatial scale of the Sand Engine. The first nourishment has already been executed within this area (Jarkus transects 114-118) in 2013, consisting of a total volume of 1.5 million m^3 of sand (see Appendix D).

Figure 4.2: Indication of the spatial scale of the main expectation of the Sand Engine and the location of the JARKUS transects 114-119 (Google Earth)

To avoid complex evaluation of the Sand Engine in terms of maintenance of the coastline position, it is suggested to set the alongshore boundaries at JARKUS transect 114 in southern direction and the southern jetty of Buitenhaven (see Figure 4.2) near JARKUS transect 102.3 (see Figure D.1) as the alongshore boundary in northern direction. No nourishments have been executed on this coastal area since 2011 nor are planned within the regular nourishment program. In total this would thus mean stabilization of a coastal stretch of up to almost 12 km.

One could imagine that coastal erosion of the coastline could occur on a different time and spatial scale than accretion by feeding of the Sand Engine, possibly resulting in locally (and temporary) transgression of the BCL. The main expectation by Stive et al. (2013) explicitly mentions to 'stabilize' the coast, possibly for this reason. A different approach for evaluation of the BCL than currently carried out is therefore needed.

To maintain the coastline position, the Momentary Coast Line (MCL) has been developed as a so called Coastal State Indicator (CSI), defining the coastline position as a function of the volume of sand in the near shore zone (see Figure 4.3). In case the MCL exceeds (or is foreseen to exceed) the BCL usually a nourishment is considered.

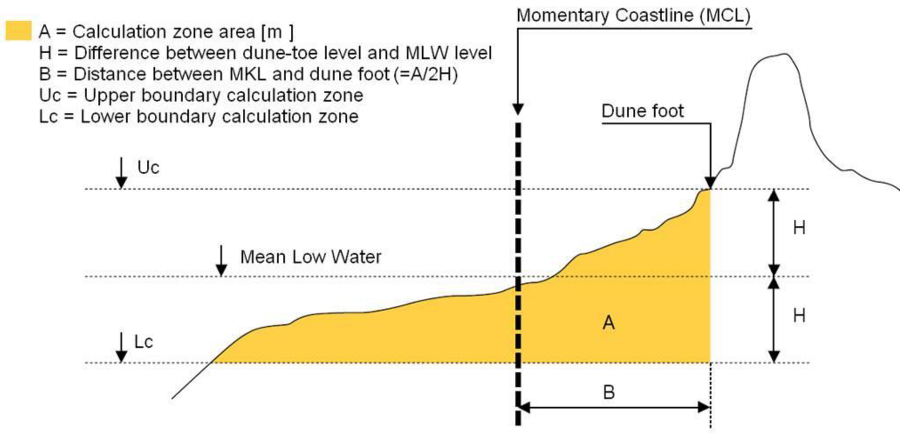


Figure 4.3: Definition sketch of the Momentary Coast Line, which is based on the sediment budget in the near shore zone (Sutherland, 2010)

The calculation of the MCL is based on data from the Dutch annual coastal monitoring programme JARKUS. JARKUS measures coastal depth profiles from the first dunes up to 1 km in a seaward direction, at alongshore intervals of 250m. With respect to the position and trend in momentary coastline the following procedure applies: As a standard reference the BCL, i.e. the position of the coast in 1990, has been defined for each coastal section of 250m wide. The actual state of the coastline is based on the Testing Coast Line (TCL). The position of the TCL is determined in a similar way as the BCL, by linear extrapolating the trend of coastline positions (MCL) of ten previous years (see Figure 4.4). The state of the system is compared with the reference state, i.e. by comparing the TCL position with the BCL position. This comparison provides an indication of the need for intervention (Sutherland, 2010).

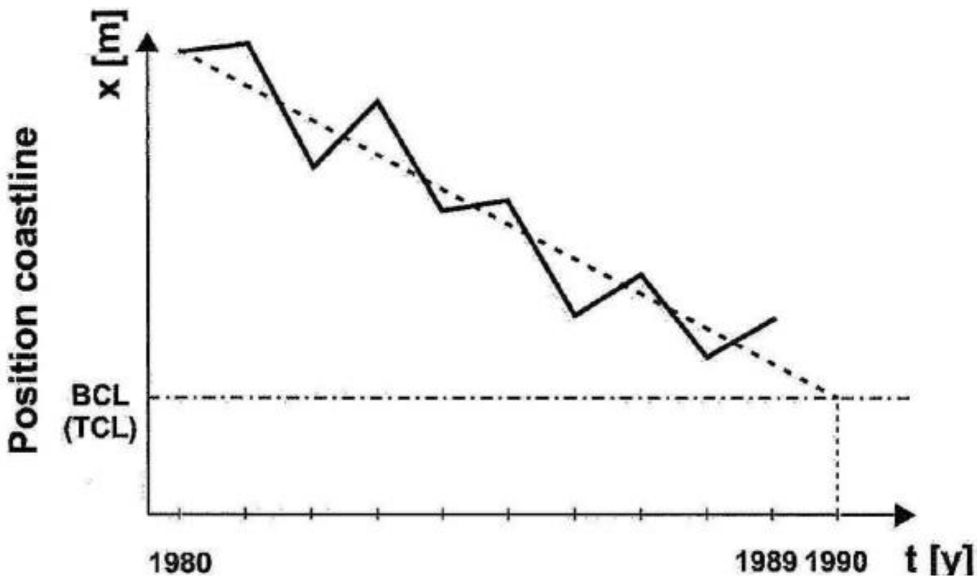


Figure 4.4: Definition of BCL and of TCL by linear extrapolation of a 10 year trend (Sutherland, 2010)

In order to effectively maintain the coastline with the use of a Sand Engine, one should apply a more regional approach rather than the local approach as explained earlier. In Figure 4.5 a schematization is shown of a local erosion event (TCL behind BCL), but on the adjacent coasltine the occurrence of a (large) surplus of sand (TCL in front of BCL).

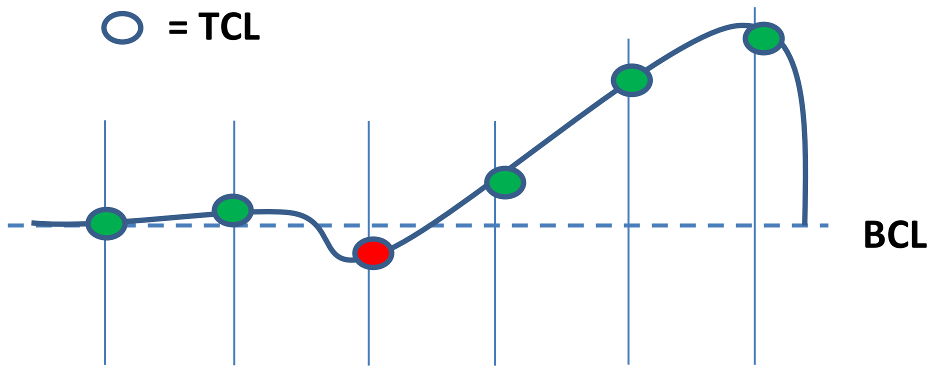


Figure 4.5: Schematization of a local erosion event and a large sediment surplus (Sand Engine) on the adjacent coastline

If one would apply the current evaluation method, so simply looking at local erosion events, an intervention would be necessary. However, with information on a further distance of that erosion event, one might expect this particular coastline in time to be fed by the Sand Engine, possibly resulting in TCL $\geq BCL$.

In order to evaluate this main expectation another evaluation method for maintenance of the coastline position should be applied; a regional approach. van Gelder-Maas (2015) mentions that in 2013-2014 a local erosion event occurred (as sketched in Figure 4.5, but north of the Sand Engine).

Consequently, in consultation with the representative municipality (Kijkduin) it was decided not to intervene due to the expectation that the Sand Engine would feed that coastline in time. 1 to 1.5 years later this expectation seemed true, because the coastline had indeed accredited enough to comply with the BCL.

Figure 4.6 shows the expected (morphological) development of the Sand Engine in the first 20 years after construction. Figure 4.7 shows a (highly) schematized development of the Sand Engine and division into transects.

For the regional approach one should take into account, besides the current (BCL) and foreseen (TCL) coastline position, also the trend in coastline position of the adjacent coastline.

Consider transect *i* in Figure 4.7. If a transgression behind the BCL is observed (or foreseen with the TCL) at this transect, but a positive trend (i.e. accrretion of the coastline) in the last 5 years is observed for transects *i-2* and *i-1*, one should at least postpone an intervention because future accretion of the coastline at transect i is expected. To make it more generally applicable, it is suggested to take both sides of the transects (thus also include transects *i+1* and *i+2* (so one does not need to take into account on which side of the Sand Engine a transect is located).

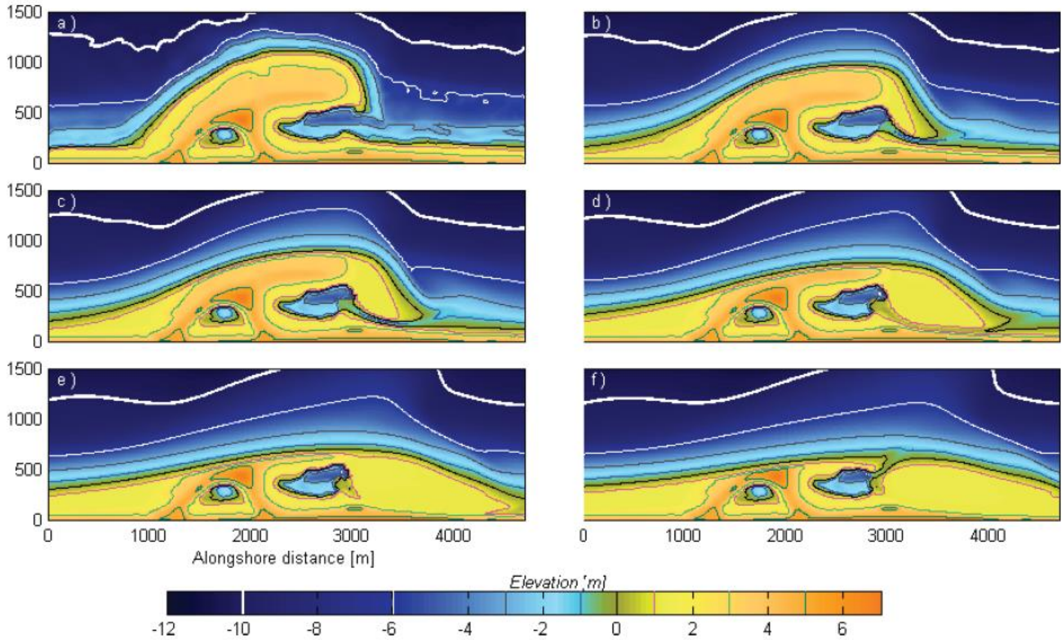


Figure 4.6: Expected morphological development of the Sand Engine. (a) initial model bathmetry; (b-f) the prediction 3, 5, 10, 15 and 20 years after construction (Stive et al., 2013)

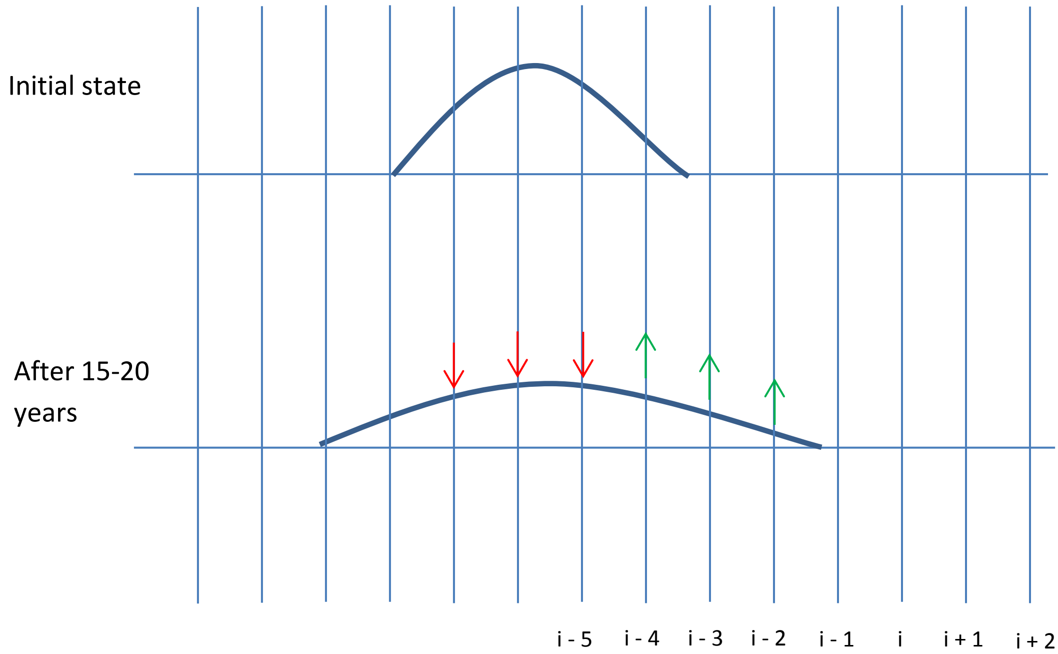


Figure 4.7: Schematization of the expected development of a Sand Engine with division into transects (i+n) and indication of a positive trend (green arrow) and negative trend (red arrow) in coastline position.

Contribute to maintenance of the coastal foundation

Mulder and Tonnon (2010) mention that the Sand Engine is contributing to the maintenance of the coastal foundation for a period of around 20 years. The coastal foundation includes the complete sand area, wet and dry, which is completely of interest as a carrier of functions in the coastal area. The seaward boundary is the continuous −20 m NAP line. On the landward side it includes all dune areas and hard seawalls on top of them (Dillingh et al., 2010).

In order to understand the timescale (20 years) for this expectation one should review the estimated amount of sand needed in the coming decades.

Rijkswaterstaat (2010) mentioned that an average of 400.000 m^3 sand per year is needed for Kustlijnzorg (for the Delfland coast), in which one third is executed as beach nourishments and two third as underwater nourishments. It is expected that the maintenance of the BCL will increase to 500.000 m^3 per year as a consequence of the strengthening of the Zwakke Schakels. This amount would be needed from 2016, 5 years after realization of the Zwakke Schakels and dune compensation of Maasvlakte 2.
The coastal foundation will have to follow the sea level rise. It is expected that the sea level rise will be on average 3mm/year over a period of 20 years. This mean an increase in 300.000 m^3 needed for maintenance per year as a result of the sea level rise. Because it is not certain whether losses of the 'Eurogeul' will have to be compensated for, a bandwidth of the total expected need for maintenance is given. The minimal needed maintenance only consists of maintenance of the BCL of 0.5 million m^3 per year. This will also benefit the coastal foundation but does not suffice the objective to maintain the coastal foundation.

For maintenance of the coastal foundation a volume of 1 to 1.5 million m^3 will be needed. This amount increases with the time and with the rise of the sea level. In consultation with the manager of the coastal foundation an amount of 1.1 million m^3 per year is taken as a work task. The bandwidth for this project is therefore between 0.5 to 1.1 million m^3 per year. This means a total volume of 10 to 22 million m^3 per year (Rijkswaterstaat, 2010). Note that this counts for the total area of the Delfland coast, i.e. the area between JARKUS transects 96-119 (see Figure D.1).

For the EIA calculations have been made for the reference state without a Sand Engine, in which only maintenance of the BCL and coastal foundation are taken into account. It is calculated that in this reference state an expected nourishment volume of 22.2 million m^3 (net) is needed between 2011 and 2031. These calculations take into account a sea level rise of 3 mm/year.

Considering the estimations by RWS the contribution to maintenance of the coastal foundation could thus also be ca. 40 years, due to the large estimated band width.

The procedure for preservation of the sand volume in the coastal foundation is based on compensation of the yearly sand losses in the coastal foundation. Geological information indicates that on a time scale of 50-200 years the coastal foundation may be considered a closed system. Due to this fact sea level rise has a major negative effect on the active sand volume of the coastal system. This sea level rise effect may be calculated as the product of the area of the active coastal system and the observed average sea level rise over the last century (Sutherland, 2010).

The area of the coastal foundation is measured by the JARKUS bathymetry soundings for the offshore part and by airborne Laser Altimetry for the dune part. For the sea level rise use is made of the National Monitoring Network Water as well as of future scenarios regarding accelerated sea level rise (Sutherland, 2010).

The Sand Engine is a nourishment with a total net volume of around 19.5 million m^3, of which all sand is dredged seaward of the continuous −20 m NAP line (see Fiselier (2010)). Assuming the coastal foundation to be a closed system, this would mean an increase of the sand balance of the coastal foundation of 19.5 million m^3. When one determines the area of the active coastal system and the (observed) average sea level rise one can determine for how many years the Sand Engine contributes to maintenance of the coastal foundation:

$$\text{Contributed years} = \frac{\text{Total volume of the Sand Engine}}{\text{Area of active coastal system} \times \text{(average) sea level rise}}$$

Questions arise when determining the area of active coastal system for this formula, especially in alongshore direction. Can we expect the Sand Engine to eventually be equally spread over the coastal foundation of the total coastal area of the Delfland coast? Exact alongshore boundaries of this 'active coastal system' (*WHERE*) to which the Sand Engine contributes should be made explicit in order to calculate the contributed years.

4.1.2 Coastal reinforcement

Preservation of safety against flooding is achieved by maintaining a minimum dune strength (Sutherland, 2010). Mulder and Tonnon (2010) mention that estimations of dune development for the Sand Engine indicate a doubling of the increase rate of the dune area, compared to the reference situation; an increase in dune habitat and contribution to a stronger dune, *enhancing* safety against flooding. Tonnon et al. (2011) state that the dune growth will provide for a higher safety in comparison with the regular nourishment program between 1990 and 2010.

The mega nourishment at Delfland, in combination with wider beaches, will instigate active dune formation in the coming decades. This dune formation is expected to be swift enough to follow sea level rise, so a structural solution is offered that will ensure the safety standards of the sea defence in spite of climatic change (van Dalfsen and Aarninkhof, 2009).

As mentioned earlier, the coast could be regarded safe against flooding before construction of the Sand Engine, due to the recent strengthening activities of the Delfland coast ('Zwakke Schakels'). Wider beaches and an increase in active dune formation could thus be at a first place considered as coastal reinforcement rather than coastal maintenance. Due to (accelerating) sea level rises expectations have been translated into 'swifting enough to follow the sea level rise' and timescales of (more than) 50 years. Furthermore, the spatial scale has not been specified in more detail than the area between HvH and Scheveningen (approx. 17 km). If the main expectation is that the Sand Engine will stabilize the coastline for a coastal stretch in the order of 10 km, wider beaches and an increase in active dune formation could not be expected outside this area.
In order to evaluate the effectiveness of the Sand Engine alone, objectives and/or expectations should be translated into time and spatial scales in which one could monitor and evaluate the effects of the Sand Engine as autonomous as possible. A spatial scale of 17 km (HvH - Scheveningen) and a timescale of 50 years seems therefore not appropriate.
If indeed the Delfland coast is expected to be safe against flooding for a period of 50 years, what should the state, and of which part, of the coast be after 10 or 20 years?

In order to evaluate the dune strength, the erosion line and the presence of the residual dune volume behind this line are being tested every year in a procedure using a dune erosion model with hydrodynamic design conditions (Sutherland, 2010). Several computer models are used to calculate the erosion line, such as DUROS+ and XBeach.

The prescriptive framework for coastal safety is summarized in Table 4.1.

Management issue:	Coastal safety		
Strategic objective:	Coastal maintenance		Coastal reinforcement
Tactical objective:	Stabilize the coastline at position of 2010	Contribute to maintenance of the coastal foundation	Provide a higher safety against flooding by wider beaches and stimulation of natural dune growth
QSC			
Method:	*Regional approach* JARKUS (yearly, every 250 m) 2011-2021: half yearly, every 125 m	JARKUS (yearly, every 250 m) Laser Altimetry	DUROS+/XBeach
Parameters:	MCL TCL	Nourishment volume Area of active coastal system (Average) sea level rise	Hydrodynamic conditions Erosion line Residual dune volume
Benchmarking			
Desired state:	BCL over O(10) km coastal stretch in 2031	*Alongshore boundaries?* 2011−2031	*WHERE?* *WHEN?*
Current state:	Transects 102-114 2011-2031	HvH-Scheveningen 2011-..	HvH-Scheveningen 2011-...
Interventions:	Sand Engine	Sand Engine	Sand Engine *Additional nourishments?*
Evaluation:	if MCL$\leq BCL$, *but* positive trend in two adjacent transects; postpone intervention	Can be assumed that sand volume divides over total area of Delfland coast?	Sufficient to follow sea level rise?
Sources:	Stive et al. (2013) Sutherland (2010)	Mulder and Tonnon (2010) Sutherland (2010)	Fiselier and Ebbens (2010) Sutherland (2010)

Table 4.1: Prescriptive framework for coastal safety

4.2 Nature

It was concluded in Chapter 3 that for nature questions mainly arise within the relation between *WHAT* the Sand Engine aims for and *WHY*, or in other words the real objectives. Obviously, this influences consequently whether *HOW*, *WHERE* and *WHEN* is sufficiently specified.

The scale of the nourishment is expected to be environmentally friendlier, but this expectation will be treated within the aspect of innovation, which considers the comparison with the regular nourishment program.

In this section the objectives to achieve 'more space for nature' are further elaborated.

4.2.1 Provide new areas for (development of) nature

Looking at the stated hypotheses in the MEPr one can divide different areas for nature (space) the Sand Engine is expected to provide: new dune, lagoon and beach area. Each of these areas has a function for nature and its development.

Provide by natural dune growth for a new dune habitat

The development of wider and more robust dunes (which is a result of natural dune growth (Fiselier and Ebbens, 2010)), will provide a new dune habitat (with higher nature values).

The evaluation of this expectation/objective is evaluated within the consortium of Witteveen+Bos. By monitoring (a.o.) the vegetation density it can be checked whether indeed new area for nature is being developed.

Provide by the presence of a sheltered lagoon for a nursery area with high food availability

The presence of a sheltered lagoon is expected to function as a nursery area, which is expected to develop in time. van der Moolen (2015) mentions that this function of the lagoon can be measured by the density of juvenile fish and benthos (parameters in the QSC). The lagoon is moreover expected to generate an increase in waders and seabirds (another parameter).

Since, the objective is actually the development of nature no desired values have been defined for these parameters, but an increase of these parameters (from 2011 onwards) seems desired.

Provide by a larger intertidal area for a feeding and resting area for marine mammals

The sand hook is also expected to function as a feeding and resting area for marine mammals. The sand hook is in terms of area an increase in beach area and therefore the third tactical objective is chosen as 'provide by a larger intertidal area for a feeding and resting area for marine mammals'.

Whether the new (increased) intertidal area will function as a feeding and resting area for marine mammals can be indicated by the number of (spotted) marine mammals. Numbers of sea lions can for instance be monitored with use of the Argus mast.

For this objective also applies that no clear desired values have been given, but a larger presence compared to the surrounding area is hypothesized (Tonnon et al., 2011).

The prescriptive framework for nature is shown in Table 4.2.

Management issue:	Nature		
Strategic objective:	Provide new areas for (development of) nature		
Tactical objective:	Provide by natural dune growth for a new dune habitat	Provide by the presence of a sheltered lagoon for a nursery area with high food availability	Provide by a larger beach area for a feeding and resting area for marine mammals
QSC			
Method:	Witteveen+Bos	IMARES	IMARES
Parameters:	Vegetation density	Juvenile fish density Benthos density No. of seabirds and waders	No. of marine mammals
Benchmarking			
Desired state:	Increase in vegetation density	Increase in densities and numbers from 2011 onwards	Larger presence on Sand Engine than surrounding areas
Current state:	*HvH-Scheveningen 2011-2031*	Lagoon area 2011-2021	Sand Engine 2011-2021
Interventions:	Sand Engine	Sand Engine	Sand Engine
Evaluation:			
Sources	Tonnon et al. (2011) van der Moolen (2015)	Tonnon et al. (2011) van der Moolen (2015)	Tonnon et al. (2011)

Table 4.2: Prescriptive framework for nature

4.3 Recreation

In Chapter 3 was concluded that the relation between the initial (strategic) objective (*WHY*) and tactical objective (WHAT) was not logical. It remained unclear whether 'simply' more space for recreation has to be achieved or (more) attractiveness of the area. The strategic objective is revised to 'provide new areas (attractive) for recreation'. Just as for nature, three different areas can be divided for recreation, each with a different function for recreation.

4.3.1 Provide new areas (attractive) for recreation

Provide for more accessible dune area

Fiselier and Ebbens (2010) mentions that wider and more robust dunes (which is achieved by natural dune growth) can be partly made accessible for recreation. Also, by Dwarshuis van de Beek et al. (2008) is mentioned that the extra dune area should be accessible for recreation as much as possible. The tactical objective is therefore chosen to be 'provide for more accessible dune area'.

Whether new dune area is made accessible for recreation can be reviewed with the manager of the dunes, DUNEA. Since the objective to stimulate (natural) dune growth was set for the coastal area between HvH and Scheveningen, also for this objective no exact spatial scale is defined. One could expect this to be (much) smaller than the complete coastal area between HvH and Scheveningen.

Provide by the presence of a sheltered lagoon for an attractive area for kite surfers

Rijkswaterstaat (2014c) mentions that the Sand Engine is a popular spot for kite surfers. Because of the presence of a dune lake and a lagoon, the Sand Engine has become a 'heaven' for kite surfers (van Gelder-Maas, 2015).
This provision of the Sand Engine was not found to be expected before realization of the Sand Engine, but is now nevertheless added as a tactical objective for the strategy to provide new areas (attractive) for recreation.

Whether this area is attractive for the kite surfers could be monitored with the number of kite surfers that appear on the Sand Engine and their satisfaction. This falls within the recreational research on behalf of PZH. The number of kite surfing lessons could be obtained with requests from several kite surfing schools that operate at the Sand Engine. Furthermore, with a survey one could determine the overall satisfaction of the different kite surfers.

Provide by a larger beach area for an attractive area for beach hikers and horse riders

Fiselier and Ebbens (2010) mentions that with the design of the Sand Engine new extensive forms of recreation, among others strolling and walking during the beach season, becomes possible. NPOWetenschap (2014) mentions that this area is also attractive for horse riding.

Just as for the objective concerning kite surfers, this objective could be indicated with number of recreants as well. Also, executing a survey to review their overall satisfaction helps to determine whether the area is attractive for this type of recreation.

An indication of the number of recreants for this type might be possible with the use of the Argus mast, although distinguishing these recreants might be difficult.

The prescriptive framework for recreation is shown in Table 4.3.

Management issue:	Recreation		
Strategic objective:	Provide new areas (attractive) for recreation		
Tactical objective:	Provide for more accessible dune area	Provide by the presence of a sheltered lake and lagoon for an attractive area for kite surfers	Provide by a larger beach area for an attractive area for beach hikers
QSC:			
Method:	DUNEA	PZH Counting, satisfaction survey	PZH Counting, satisfaction survey
Parameters:	Accessible dune area	Number of recreants	Number of recreants
Benchmarking			
Desired state:	More accessible dune area compared to 2011	Appearance of (satisfied) kite surfers	Appearance of (satisfied) beach hikers/horse riders
Current state:	*HvH-Scheveningen* 2011-2031	Lagoon area 2011-2031	Sand Engine area 2011-2031
Interventions:	Sand Engine	Sand Engine	Sand Engine
Evaluation:			
Sources	Fiselier and Ebbens (2010)	van Gelder-Maas (2015)	Fiselier and Ebbens (2010)

Table 4.3: Prescriptive framework for recreation

4.4 Innovation

In Chapter 3 no clear objectives have been defined for innovation. Janssen et al. (2014) mention that the innovation relates in particular to the scale of the nourishment and the multifunctional approach. They also mention that the ministerial budget for the Sand Engine was not taken from the coastline maintenance budget. Rather an 'innovation' fund was made available for the Sand Engine. With the fact that 83,3% of the project was paid by the ministry (I&M), the objective innovation could be regarded as relatively important and should at least be taken into account for evaluation.

In order to evaluate the aspect of innovation, some definitions of innovation have been looked up:

'*Innovation can be viewed as the application of* <u>*better solutions*</u> *that meet new requirements, inarticulated needs, or existing market needs.*' (Maranville, 1992)

'Innovation is accomplished through <u>*more effective*</u> *products,* <u>*processes*</u>*, services, technologies, or ideas that are readily available to markets, governments and society.'* (Frankelius, 2009)

The Sand Engine investigates the concept of mega−nourishments as an environmentally friendly method for coastal maintenance (van Dalfsen and Aarninkhof, 2009), which one could regard as a 'better solution'. Next to that, the Sand Engine is expected to be cheaper than regular nourishments (Rijkswaterstaat and PZH, 2014b), or in other words more cost-effective.

For the Sand Engine, three different approaches (or strategies) can be distinguished; more cost-effective, environmentally friendlier and multifunctional. By providing for new areas (attractive) for recreation, the approach is multifunctional in relation to the regular nourishment program. The prescriptive framework for recreation can be found in Table 4.3.

The more cost-effective and environmentally friendlier approach are further elaborated below. The prescriptive framework for innovation is summarized in Table 4.6.

4.4.1 More cost-effective approach

Potentially, the choice of a large volume of sand will be cost-effective because of economy of scale and because a mega supply can be timed to a dip in market prices (van Dalfsen and Aarninkhof, 2009), or in others words is executable during favorable market conditions.

Economy of scale

When one compares this nourishment of the Sand Engine (of 19.5 million m^3) with four smaller nourishments (with the same total volume), equipment necessary for the execution only has to be mobilized once. Thus, only looking at the costs for mobilization, a Sand Engine should result in a lower price.

However, making one early investment will generally be more expensive than in the case the investments will be spread over time and thus be partly done at a later moment. Whether this is significant or neglectable depends on the height of the interest rate of up following years.

Secondly, in the regular nourishment program sand is placed for maintenance at a specific moment and at a specific location. Except from sand loss during the dredging activities, the total amount of sand benefits the coastal maintenance. A Sand Engine is expected to redistribute the sand along the coast. The pace of this redistribution depends on the wind, waves and currents, which have been predicted with numerical models. One could assume that the efficiency of the volume of sand in terms of contribution to coastal maintenance (when and where it is needed) will for a

Sand Engine not be as high as for the regular nourishments.

Proof of this can also be found in the EIA in which it is calculated that with the reference case (thus with regular nourishments) 22.6 million m^3 will be needed to guarantee maintenance of the coastline. For the alternative with the Sand Engine (19.5 million m^3 was then used) another 3.3 to 5.6 million m^3 is calculated to be necessary. This would thus mean that in total more volume of sand is expected to be necessary to guarantee maintenance of the coastline.

So, if using economy of scale for a more cost-effective approach, the cheaper sand price as a result of less mobilization costs, will have to weigh up against the (expected) negative impact of the interest rate and the redistribution efficiency of the sand volume on the cost-effectiveness.

Executable during favorable market conditions

Fiselier (2015) mentions that the market conditions were ideal at time of construction of the Sand Engine. Many dredging equipment was in close vicinity of the current location of the Sand Engine due to the Maasvlakte 2 project and strengthening of the weak spots (in Dutch 'Zwakke schakels'), which would have had an impact on the prices of sand. It is also mentioned by van Dalfsen and Aarninkhof (2009) that a mega nourishment can be timed to a dip in market prices. If a Sand Engine is not required immediately to guarantee (short term) safety, timing of construction is flexible and could therefore be planned whenever sand prices are low (due to for instance availability of dredging equipment in close vicinity).

Parameters

From the previous can be concluded that the parameters needed to evaluate the objective of cost-effectiveness (in terms of coastal maintenance) are the interest rate, nourishment volumes and the nourishment prices.

Interest rate

Interest rates are the rate of growth of money per unit of time. It is used to determine the present and future value of money and of annuities. The present value (PV) can be calculated with the future value (FV), the interest rate (i) and the number of years from present (n), with the following formula:

$$PV = \frac{FV}{(1+i)^n}$$

Next to that, one has to take into account the *real* interest rate, which means the interest rate that is adjusted for inflation (the interest rate without adjustment for inflation is called the nominal interest rate). Further on in this chapter, only the real interest rate will be used.

The real interest rate was last measured in 2012 (WorldBank, 2012). The real interest rates from 2002-2012 are shown in Table 4.4.

Year	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002
Interest rate (%)	0.4	1.9	0.6	1.5	2.2	2.7	1.4	1.1	1.7	0.8	0.3

Table 4.4: Real interest rates in the Netherlands from 2002-2012 (http://data.worldbank.org)

A variation of about 2% can be found in a period of 10 years, but there has also been a change of 1.5% in only 1 year. Before 2002 interests rates in the Netherlands have been even 10%, so for a timescale of decades the interest rate will be very uncertain.

Nourishment volume
The second variable is the volume of the nourishments executed in the period 2011-2031. When comparing nourishment volumes one should check whether it is necessary to adjust for the net/gross volume. The 21.5 million m^3 of the Sand Engine is the gross volume. The net volume is 19.5 million m^3 (including additional foreshore nourishments). In the rest of the chapter only net volumes will be used (unless other stated otherwise).

Nourishment price
For the determination of the cost-effectiveness of the Sand Engine, changing price levels also have to be taken into account. The price per m^3 for the Sand Engine was around €2.6 (net) (=50/19.5). The average price per m^3 of nourishment sand for the 2012-2015 nourishment program is around €2.5 per m^3 for foreshore nourishments and around €5.0 per m^3 for beach nourishments (Lodder, 2015a). The chosen sand price for the Sand Engine excludes overhead costs such as the monitoring program, informing the public etc. (almost 20 million euro). For the regular nourishments no reductions have been made for the chosen sand prices, because it is assumed these are relatively small, as opposed to those of the project Sand Engine.

For the regular nourishment program in het Netherlands the average ratio of shore face and beach nourishments is 70/30. Considering previously mentioned prices, this would result in an average nourishment price of €3.3 per m^3 (Lodder, 2015a).

Lodder (2015b) also mentions that the strengthening activities of the Delfland coast (previous to the construction of the Sand Engine, see Section 4.1) are however expected to influence the ratio of shoreface and beach nourishments such that we would rather expect a ratio of more or less 50/50 for the Delfland coast in this period. This would then result in a slightly higher average nourishment price of around €3.75 per m^3 for the period of 2012-2015.

For comparison, in the period 2007-2011 the prices were €4.5 (foreshore) and €8.5 (beach). The prices between 2012 and 2015 are thus still relatively low which might be still due to the fact of the close vicinity of equipment from different dredging contractors. An overview of the nourishment prices between 2007 and 2015 is shown in Table 4.5.

Period	**Sand price (€/m^3)**
2007−2011	4.5/8.5 (fore shore/beach)
2011	2.6 (Sand Engine)
2012-2015	2.5/5 (fore shore/beach)

Table 4.5: Nourishment prices in the period 2007-2015

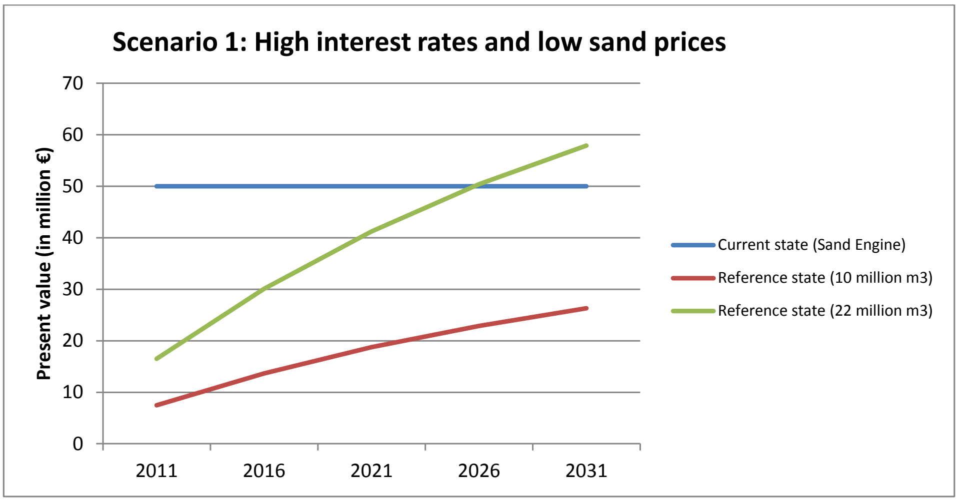
Scenarios

Figure 4.8 and Figure 4.9 illustrate the benchmarking procedure for different possible scenarios. For all parameters determined in the previous section (interest rate, nourishment volume and price), the 'extreme' values (e.g. minimum and maximum) are used.

The scenarios consider the period of 2011-2031 (shown on the horizontal axes) in which in the current state with a Sand Engine, neither additional nourishments have been nor will be executed within the first 20 years. So for the spatial scale the Delfland coastal area south of JARKUS ray 114 and north of 102 (southern jetty of Buitenhaven, see Figure 4.1) is not considered. The band width of expected nourishment need for 2011-2031 on the Delfland coast, as described in Section 4.1 is used; 10-22 million m^3. Note that this band width actually covers the whole coastal area of the Delfland coast (e.g JARKUS ray 96-118 (approx.)), thus including the area north of the southern jetty of Buitenhaven (Scheveningen).

The present value (as of 2011) has been calculated (shown on the vertical axes). A constant interest rate (0.5% or 4%) has been used for the whole 20 year period. The already available (constant) sand prices for the period of 2011-2016 have been taken into account. For the period 2016-2031 a constant low (3.75 €/m^3) or a high (7 €/m^3) price has been used. The nourishment volume of either 10 or 22 million m^3 has been spread over the period of 20 years in nourishments every 5 year (the first nourishment in 2011 and the last nourishment in 2031). The present value is calculated with the following formula:

$$\text{Present value} = \frac{\text{Sand price} \times \text{Volume}}{(1+i)^n}$$



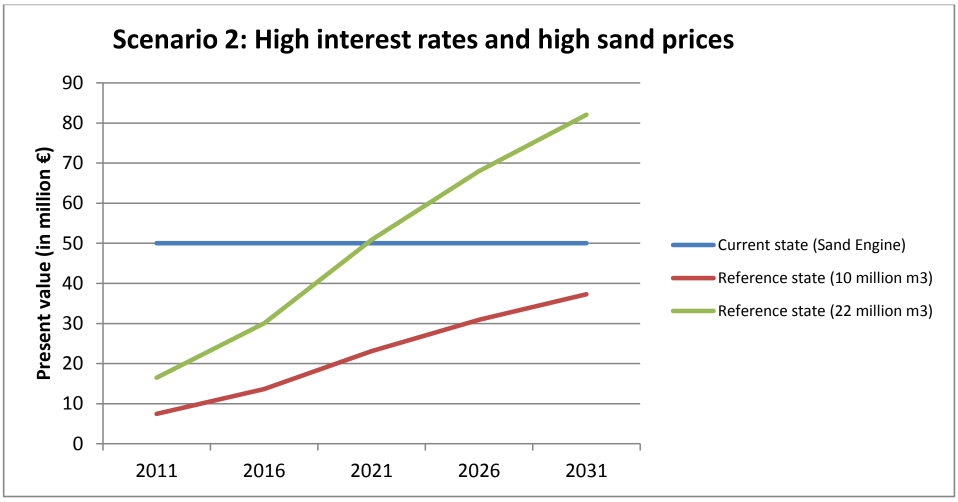
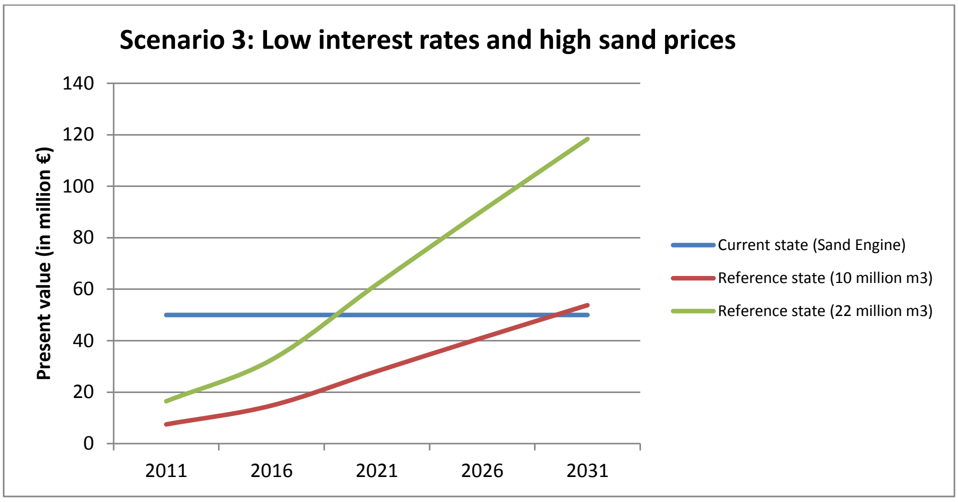


Figure 4.8: Scenarios of present value (as of 2011) with a constant high interest rate (4%) and changing sand prices (€3.75 - €7 per m^3)



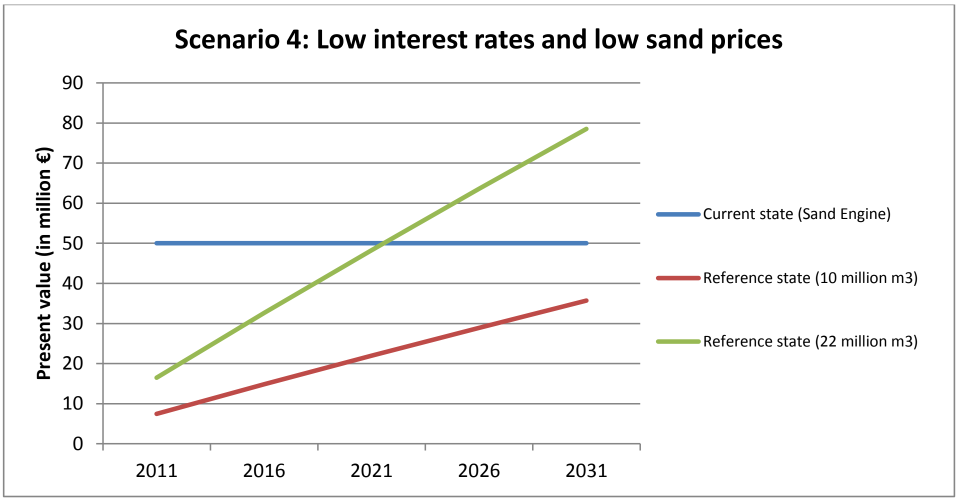


Figure 4.9: Scenarios of present value (as of 2011) with a constant low interest rate (0.5%) and changing sand prices (€3.75 - €7 per m^3)

Figure 4.8 and Figure 4.9 illustrate that if the nourishment need for the considered coastal area is 22 million m^3 in 20 years, the Sand Engine turns out to be a more cost-effective approach than the regular nourishment program, regardless of the interest rate or sand price and already within 15 years (and in scenario 2-4 even within 10 years).

In case of the minimum nourishment need (10 million m^3), the Sand Engine turns out to be only cost-effective in a scenario of low interest rates and high sand prices (scenario 3). However, in case of this minimum nourishment need, a surplus of 9.5 million m^3 still exists in the coastal system, contributing to coastal maintenance after 20 years. If considering a longer period, only scenario 1 (the 'worst case scenario') will result in the Sand Engine being less cost-effective.

Note that this calculation of cost-effectiveness only considers coastal maintenance. In order to obtain an overall cost-effectiveness one should monetize extra benefits of the Sand Engine in relation to Kustlijnzorg as the recreational function, coastal reinforcement and environmental friendliness.

4.4.2 Environmentally friendlier approach

EcoShape (2014) mentions that a traditional design of a sandy nourishment has the primary objective of shoreline maintenance using a medium volume of sand (2-5 million m^3). The lifespan of the nourishment is typically in the order of 5 years. This means that every 5 years the nourishment has to be redone, resulting in a frequent disturbance of the ecosystem.
In the Delfland Sand Engine experiment, a *concentrated* nourishment of 19.5 million m^3 of sand was introduced. The sand is gradually redistributed by natural processes over the shoreface, beach and dunes. By making use of natural processes to redistribute the sand, this innovative approach aims to limit the disturbance of local ecosystems (EcoShape, 2014).

Fiselier and Ebbens (2010) mentions that the scale of the nourishment is expected to be environmentally friendlier, because the one time deposit is expected to be less disruptive to the ecology, and an increase in nature values are expected due to a decrease in number of nourishments.

Decrease disturbance of benthic community by concentrating nourishment in space and time

A tactical objective for an environmentally friendlier approach could be formulated as 'decrease disturbance of benthic community by concentrating nourishment in space and time'. In order to evaluate the disturbance one could distinguish two main parameters. On the one hand, the ecological footprint, describes the relative impact on the local ecosystem or benthic community.On the other hand, the recolonization time is the time that a local ecosystem/benthic community has to recover before it is disturbed again.

Ecological footprint
Generally, the ecological footprint is defined as a measure of human demand on the Earth's ecosystems, the amount of natural capital used each year. The footprint of a region can be contrasted with the natural resources it generates (Ewing et al., 2010). In the approach in this section however, it describes the (relative) impact on the local ecosystems, e.g. the benthic community.

Comparing the ecological footprint of the Sand Engine with regular nourishments triggers questions. For example, one could express the ecological footprint in disturbed area. For the Sand Engine, this would roughly mean an ecological footprint of 128 ha (the initial surface area of the Sand Engine (Rijkswaterstaat and PZH, 2014a)).

Figure 4.10 schematizes a regular beach, foreshore and a Sand Engine nourishment. This figure illustrates that in case of a Sand Engine the disturbance *on top* of the seabottom is much larger. It could therefore be hypothesized that per square meter of sea bottom the ecological footprint of a Sand Engine is larger than of a regular nourishment (Figure 4.11).

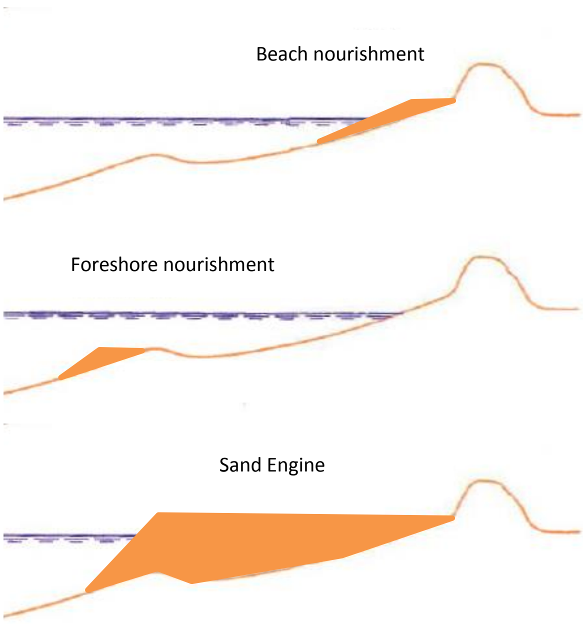


Figure 4.10: Schematization of a regular beach, foreshore and Sand Engine nourishment

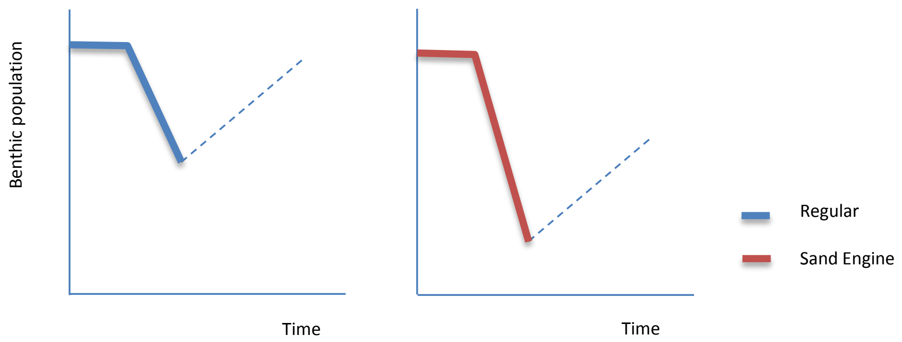


Figure 4.11: Hypothesized difference of the ecological footprint between the Sand Engine and a regular nourishment in terms of survival rate of the benthic community

One could also look at the alongshore length of the disturbance. The formulation of 'concentration in space' suggests that we could expect this to be relatively small. Figure 4.12 illustrates the alongshore length of the nourishments of the Sand Engine (note that the cross shore width is not on scale). The Sand Engine disturbs an alongshore area of 6.2 km. Looking at historical nourishment data (Appendix D) we can see that in that same coastal area (between JARKUS 102 and 119) between 1990 and 2010 an only slightly larger alongshore coastal area was disturbed; more or less 8 km. The tactic of 'concentration in space' is therefore a doubtful formulation.

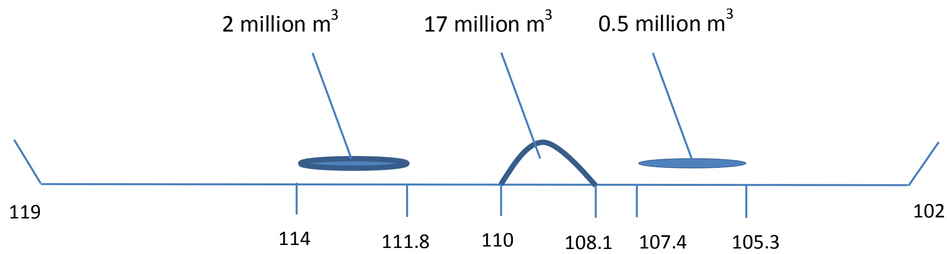


Figure 4.12: Schematization of Delfland coast (until southern jetty of Buitenhaven) in terms of JARKUS transects with locations of Sand Engine nourishments (cross shore width not on scale)

Lastly, one could also express the ecological footprint in nourishment volume. Figure 4.13 gives an overview of the nourished volumes between the JARKUS transects 102 and 119 on the Delfland coast. Volumes nourished for the 'Zwakke Schakels' are not included within this graph, because those nourishment did not have the purpose of coastal maintenance. This graph illustrates that at a relatively far alongshore distance from the Sand Engine (JARKUS 117-119) the nourishment need has been relatively high. Following the main expectation by Stive et al. (2013) contribution of the Sand Engine to coastal maintenance at this part of the coast is not expected. Only excluding this coastal area (thus JARKUS 117-119) reveals a larger ecological footprint by volume of the Sand Engine (19.5 million m^3) compared to the regular nourishment program between 1990 and 2010 (more or less 12 million m^3).

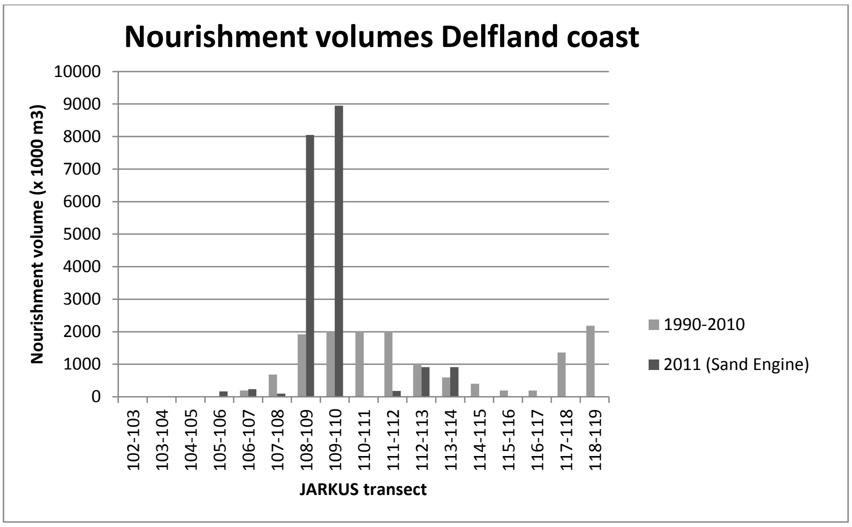


Figure 4.13: Nourished volumes between 1990 and 2010 for coastal maintenance and the Sand Engine in 2011, between JARKUS transects 102-119

Recolonization time

Concentration in time refers to the expected positive effect of a Sand Engine on the recolonization time of the benthic community. EcoShape (2014) mentions the typical lifespan of a nourishment to be 5 years. Analyzing the nourishment data (Appendix D), it is found that for the Delfland coastal area actually the frequency of nourishments varied between 1 to 4 years.

Simply looking at the frequency of the nourishments and assuming a lifespan of the Sand Engine, the Sand Engine has a recolonization time of 20 years versus 1-4 years for a regular nourishment. Questions arise however, if the recolonization time of regular nourishment can be compared with a Sand Engine in such a schematized way.

As followed from descriptions about the ecological footprint, the impact of a Sand Engine is expected to be (much) larger. This might result in such a small survival rate of the benthic population that one should speak of progressive recovery of the community, while for a regular nourishment with a small impact one might speak of homogenous recovery due to a relatively large survival rate. Difference between these two types of recovery are illustrated in Figure 4.14.

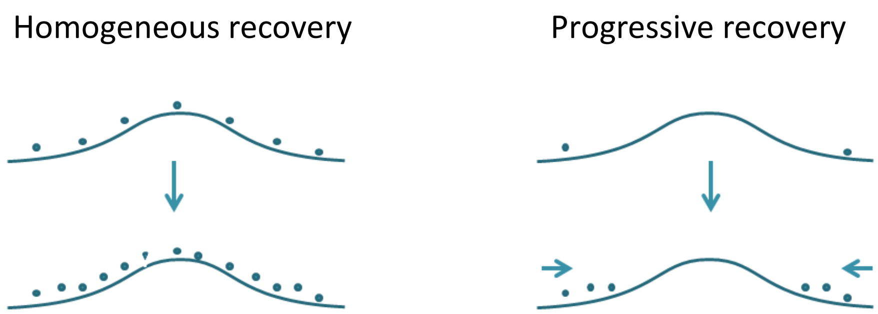


Figure 4.14: Difference between homogeneous and progressive recovery

To evaluate the overall environmental friendliness of the approach, one should also take into account the new areas that the Sand Engine provides for nature (see Table 4.2). The prescriptive framework for innovation is shown in Table 4.6.

Management issue:	Innovation		
Strategic objective:	More cost−effective approach		Environmentally friendlier approach
Tactical objective:	Economy of scales	Executable during favorable market conditions	Decrease disturbance of benthic community by concentrating nourishment in space and time
QSC			
Method:	Present value	Present value	*HOW?*
Parameters:	Sand volume (m^3) Sand price (€/m^3) Interest rate (%)	Sand price (€/m^3)	Ecological footprint Recolonization time
Benchmarking			
Desired state:	Cheaper compared to Kustlijnzorg	Cheaper compared to Kustlijnzorg	Smaller net disturbance compared to Kustlijnzorg
Current state:	JARKUS 102−114 2011−2031	JARKUS 102−114 2011−2031	JARKUS 102−114 2011−...
Interventions:	Sand Engine	Sand Engine	Sand Engine
Evaluation:			
Sources	van Dalfsen and Aarninkhof (2009)	Lodder (2015a,b)	EcoShape (2014)

Table 4.6: Prescriptive framework for innovation

4.5 Knowledge development

The strategic and tactical objectives determined in the descriptive framework (Chapter 3) for (innovation and) knowledge development were considered difficult to evaluate (due to a very open objective) and illogical translation of a strategy into a tactic.

Knowledge development could be regarded as obtaining insight in the different processes relating to the Sand Engine. NatureCoast (2015) mentions as its objective to ‘obtain insight in the morphological, hydrological, geochemical, ecological and social processes involved in a Sand Engine, which could serve as an appropriate and easier assessable strategic objective for knowledge development.
To gain insight in those processes, at first monitoring of relevant indicators is necessary. Therefore an (intensive) field monitoring program is carried out (MEPr), which is regarded as one tactical objective. This produces data, which on itself, does not generate knowledge development yet. This is subsequently gained by scientific research by postdocs, PhD and MSc students.

As indicators for the monitoring program, one could chose to include all the indicators that are being monitored, but this would make the framework unnecessarily detailed and is therefore simplified to morphological, hydrological, geochemical and ecological data.

Scientific research could be indicated by (number of) publications, but herein a desired state is not defined and/or difficult to define. Since a defined desired state is lacking, a benchmarking procedure is not possible. Evaluation could however be done during meetings with researchers to evaluate whether current indicators that are being monitored are sufficient.

Evaluation of scientific research could subsequently be done in meetings with end users, which are organized regularly by NatureCoast.

Management issue:	Knowledge development	
Strategic objective:	Obtain insight in the morphological hydrological, geochemical, ecological and social processes involved in a Sand Engine	
Tactical objective:	Intensive field monitoring program	Scientific research by postdocs, PhD and MSc students
QSC		
Method/parameters	Morphological, hydrological, geochemical and ecological data	Publications
Benchmarking		
Desired state:	?	?
Current state:	NEMO (Argus, Jetski, Quad Multicopter, Rigs and Drifters)	NatureCoast (3 postdocs and 12 PhD students) TU Delft (.. MSc students)
Intervention:	Sand Engine	Monitoring program
Evaluation:	Meetings with researchers	Meetings with end−users
Sources	TUDelft (2015)	NatureCoast (2015)

Table 4.7: Prescriptive framework for knowledge development

4.6 Summary

This chapter summarizes the explanation of each prescriptive framework in this chapter. For the prescriptive frameworks is referred to Table 4.1 - Table 4.3 and Table 4.6 - Table 4.7.

4.6.1 Coastal safety

Objectives and expectations regarding coastal safety can be subdivided in coastal maintenance and coastal reinforcement. Uncertainties in the (morphological) development of the Sand Engine have resulted in a lack of explicitation in *WHERE* and *WHEN* this is quantified and consequently evaluated (see also Chapter 3).

Expectations regarding maintenance of the coastline have made boundaries in time and spatial scale however explicit. Though this has not yet resulted in a clearly defined method (*HOW*) to evaluate the maintenance of the coastline position in case of the presence of Sand Engine. The current evaluation of the coastline position is focused on a local approach. In case the TCL exceeds the BCL, generally an intervention is executed. In case a Sand Engine is present on the coastline, a regional approach should be applied, which takes into account the trend in coastline position on the adjacent coastline to a (JARKUS) transect.

Expectations state also a contribution of the Sand Engine to the maintenance of the coastal foundation for at least 20 years. Methods to calculate the volume of the coastal foundation exist, but it is however doubtful whether one could assume the volume of the Sand Engine to eventually be equally spread over the total coastal area between HvH and Scheveningen. At least expectations for alongshore boundaries (*WHERE*) of this contribution to the volume of the coastal foundation should be made explicit for a timescale in which attribution of the Sand Engine is feasible (10-20 years).

Several expectations state that the Sand Engine provide a higher coastal safety, sometimes expected to be enough to follow the sea level rise. Any exact spatial and time scale (*WHERE* and *WHEN*) is however lacking. Just as for the coastal foundation, also for this objective expectations for smaller timescales (10-20 years) should be made explicit.

4.6.2 Nature

In Chapter 3 was concluded that the relation between WHAT the Sand Engine aims for and WHY, in terms of nature is not logical. The prescriptive framework approaches the evaluation of nature by dividing objectives for three different areas: dune, lagoon and beach area.

This report has not investigated the methods for evaluation in detail. The prescriptive framework however reveals that objectives (or expectations) are formulated as 'open', e.g. any development of nature seems to already suffice for effectiveness. One could conclude therefore that still needs to be made explicit 'how much' development is expected or desired, but this does not seem very meaningful.

As for coastal reinforcement, also applies for the dune growth for a new dune habitat, no spatial scale has been defined (WHERE). This should still be made explicit.

4.6.3 Recreation

As for nature, for recreation was also concluded in Chapter 3 that the relation between *WHAT* the Sand Engine aims for and *WHY* is not logical. The prescriptive framework for recreation also distinghuish three different areas: dune, lagoon and beach area.

The lagoon and the beach area have already proven to provide attractive area for recreants; kitesurfers, beach hikers and horse riders are present. No exact threshold values have however been defined to benchmark' the recreation on these areas. It is suggested to make explicit how much dune area and where is to be expected.

The dune area is expected to become more accessible for recreation, depending on the management of the dunes, DUNEA. As for the other objectives, a real benchmarking procedure is not in place, suggesting that any square meter of extra dune area accessible for recreation will prove effectiveness.

4.6.4 Innovation

Innovation, an important aspect of the Sand Engine (since over 80% was paid by an 'innovation fund'), had barely been made explicit within the descriptive framework (Chapter 3). Innovation refers generally to comparison with the regular nourishment program; Kustlijnzorg.

Expectations state (a.o.) the Sand Engine to be (potentially) more cost−effective and environmentally friendlier than the regular nourishment program.
Evaluation of cost-effectiveness has not yet been made explicit. A proposed method in this report is to calculate the present value by using the interest rate, nourishment volume and nourishment price as parameters. Figure 4.8 and Figure 4.9 give indications of possible scenarios of cost-effectiveness for an assumed lifetime of the Sand Engine of 20 years, using certain band widths for each of the mentioned parameters.

Uncertainties in values for interest rates and expected nourishment need result in large variation between scenarios. Overall, if the nourishment need for the coastal area is the maximum expected volume of 22 million m^3 in 20 years (note that this covers the total coastal area of the Delfland coast), the Sand Engine (without additional nourishments) turns out to be cost-effective in all scenarios, already within 15 years. One should keep in mind that extra benefits have not been taken into account for this evaluation. The recreational value and contribution to a higher safety (coastal reinforcement) other than coastal maintenance should be monetized to give an overall cost-effectiveness.

The second aspect of innovation, an environmentally friendlier approach states that the disturbance of the benthic community is limited compared to Kustlijnzorg, due to concentration of the nourishment in space and time.

It was found that one could actually not speak of concentration in space, because with its additional foreshore nourishments the Sand Engine covers a relatively large (alongshore) coastal area.

It is suggested to evaluate this strategy with two main parameters: the ecological footprint and the recolonization time. *HOW* to exactly determine and benchmark these parameters has not been clearly made explicit. As one might notice, nature is already being evaluated in other objectives. The difference is however that these aim to 'create' space/area for nature instead of limiting disturbance.

First comparisons of ecological footprint illustrate that the ecological footprint of a Sand Engine should not be simply compared with regular nourishments by size. The large volume of a Sand Engine is hypothesized to have a larger impact per square meter sea bottom than a small regular nourishments. This should consequently be verified.

Secondly, previous hypothesis also influences the recolonization time, which is expected to be larger due to a returning frequency of only 20 years instead of 1-4 years. Recolonization time is however hypothesized to not be that easily compared with regular nourishments. Whether a benthic community recovers homogeneously of the coastal area around the Sand Engine or progressively (see Figure 4.14) requires further research.

Chapter 5

Discussion

This study proposes the Frame of Reference approach as a method to objectively evaluate the effectiveness of an intervention on the Delfland coast: the Sand Engine project. The framework, successfully applied in coastal erosion management (CONSCIENCE, 2015), breaks down strategic objectives into one or more tactical objectives, which are consequently subdivided into four elements: the quantitative state concept, the benchmarking, intervention and evaluation procedures.

One of the difficulties with the use of the FoR was to distinguish different level of objectives (i.e. strategic and tactical). Especially the strategic objective can often be easily formulated in different levels of abstractness. For instance, as determined in Chapter 3, one could chose 'long term coastal safety' as a strategy. In Chapter 4 strategies of coastal maintenance and coastal reinforcement have been used, but either of these could actually still serve a higher (more abstract) objective of 'long term coastal safety'. Due to many different ways of formulating objectives, it is difficult to remain objective within this determination of objectives.

This study analyzes the current evaluation of the Sand Engine besides by literature by means of interviews with stakeholders. It needs to be mentioned that the majority of the interviews have been carried out during the very beginning of this study. Relatively a lot of information gained within these interviews was very useful in understanding the concept of the Sand Engine and its involvement with many different stakeholders. The frameworks have been generally developed after this process rather than parallel to the interviews, because just as the concept of the Sand Engine, the methodology of the FoR was also relatively 'new' and required study in order to understand the functioning of this framework. A parallel approach would generate more feedback on the developed framworks during the process, resulting in more objectivity. Secondly, the number of interviews carried out for this project was limited. It became clear that during the time span from initiation until this moment many different persons have been involved in the project Sand Engine and tasks have been frequently handed over.

The calculation of cost-effectiveness in this report uses values for nourishment prices that have been obtained from a presentation showing key figures for sand prices. These prices did not contain much explanation, making the validity of these calculations doubtful. It was aimed to verify these prices before publication of this report with the cost manager at Van Oord Dredging and Marine Contractors BV. Unfortunately, due to time restrictions, this was eventually not feasible.

Chapter 6

Conclusions and recommendations

6.1 Conclusions

The Sand Engine is a pilot project of a 19.5 million m^3 mega-nourishment on the Delfland coast in the Netherlands, constructed between March and June 2011. Since the project was completed in 2011, a comprehensive monitoring plan has been set up in order to be able to follow the development of the Sand Engine effectively. The monitoring is generating high-quality data that will be used, among others, to determine whether the targets in the EIA for the Sand Engine have been met (Tonnon et al., 2011), and to conduct scientific research looking at how the Sand Engine works and how effective it is (Rijkswaterstaat and EcoShape, 2013).

If the Sand Engine proves effective, it can be used elsewhere (Rijkswaterstaat and PZH, 2014a). This study focuses on the assessment of this effectiveness , with as main objective to *'make recommendations for improvement of the objective evaluation of effectiveness of the Sand Engine project'*.

This section elaborates all conclusions that could be drawn regarding each research question. In the next section, from the conclusions overall recommendations will be made.

What enables objective evaluation of effectiveness, i.e. what criteria must be met?
The Frame of Reference methodology, a management tool developed by Van Koningsveld (2003), is used in this study as a tool for mapping the evaluation of effectiveness. It enables, through a limited number of steps, evaluation of objectives regarding interventions. This approach can be used *descriptively* as well as *prescriptively*, making it useful in addition to *describe* the current evaluation, also to *prescribe* how the situation could be changed.

It is concluded that objective evaluation is enabled in case of absence of so called 'white spots' (indicating lack of sufficient specification of an element) and 'red links' (indicating illogicality between elements) within a basic FoR template. Presence of either of these can consequently be translated into an insufficient answer to one (or more) of the basic questions *WHY*, *WHAT*, *HOW*, *WHERE* and *WHEN*.

To what extent does the current evaluation of formal objectives of the Sand Engine meet these criteria?
By means of reviewing literature, websites and carrying out interviews the formal objectives and its (current) evaluation is obtained and consequently made explicit in a basic FoR template. All objectives could be generally divided into the themes coastal safety, nature, recreation, innovation and knowledge development.

Elaborated descriptive frameworks (Figure 3.1 to Figure 3.7) demonstrated that none of the formal objectives in the current evaluation meets the determined criteria, because many white spots and red links are present in the the frameworks. In particular for coastal safety, little ambiguity could be obtained about the current evaluation, even resulting in two significantly different descriptive frameworks for this theme of objectives.

In several cases, information obtained from interviews was necessary to obtain good insight into the current evaluation. Getting a clear overview of the current evaluation of the Sand Engine is a time intensive assignment for a person not directly involved. The FoR methodology has shown to be a very helpful tool to map the evaluation into a limited number of elements and making lack of specification easily recognizable.

What causes could be identified for failure of meeting the criteria for objective assessment?
As previously explained, lack of specification of an element within the FoR could be translated into lack of a sufficient answer to one or more of the basic questions *WHY*, *WHAT*, *HOW*, *WHERE* and *WHEN*. Regarding this translation, the following main causes for failure of meeting the criteria for objective assessment can be identified:

- WHERE and WHEN the Sand Engine is being quantified and evaluated in terms of coastal safety seems subjective, because of a lack of clear alongshore boundaries as well as a large variance in timescale of objectives (20 years in the EIA vs. 50 years in the MEPr)
- The relation between WHAT the Sand Engine aims for and WHY, in terms of nature and recreation seems illogical, because the initial aim of space for more nature and recreation is evaluated by quantities (e.g. number of recreants) rather than area
- WHAT is aimed to be achieved in order to generate innovation and knowledge development has not been sufficiently made explicit, because a quantifiable desired state for this objective is lacking.

How could improvement of objective assessment be enabled?
The FoR methodology was concluded to be a very helpful tool to map the evaluation of effectiveness into a limited number of elements. By including informal objectives and expectations of the Sand Engine, this study has made a first attempt to *prescribe* an objective evaluation procedure of the effectiveness of the Sand Engine. The same division into themes of objectives as for the descriptive frameworks of the current evaluation is regarded, but it appears that many objectives within these themes need revision as well as extra objectives need to be added to enable objective assessment.

The final prescriptive frameworks elaborated in this study can be found in Table 4.1 - Table 4.3 and Table 4.6 - Table 4.7. The main adjustments made to the current evaluation are:

- Division of the strategic objective for coastal safety into coastal maintenance and coastal reinforcement representing different scales of the coastal system (coastline position, volume of the coastal foundation and residual dune strength).
- Division of the tactical objectives for nature and recreation into objectives relevant for different areas on (and around) the Sand Engine.
- Adding of repeatedly mentioned expectations of the Sand Engine (van Dalfsen and Aarninkhof, 2009; Rijkswaterstaat and PZH, 2014b; EcoShape, 2014) into objectives for innovation; a more cost-effective and environmentally friendlier approach. These approaches have to be compared with the regular nourishment program Kustlijnzorg.

What 'gaps' does this improvement disclose in the current monitoring and/or research programs?
Development of the prescriptive frameworks in which previous adjustments have been made, revealed two main gaps within the current monitoring/research programmes, namely:

- In order to effectively maintain the coastline position in case of presence of a Sand Engine, a new 'decision making tool' should be applied. While the current 'local approach' usually results in intervening when the coastline position exceeds (or is foreseen to exceed) the BCL, a new so called 'regional approach' takes into account the trend in coastline position of the adjacent coastline. An average positive trend (accretion) in the two adjacent JARKUS transects on each side of a transect should lead to postponement of an intervention.

- Decreasing the disturbance of (local) benthic communities by concentration of a nourishment in space and time (being a 'tactic' for an environmentally friendlier approach) should be evaluated with hypothesized differences in (initial) ecological footprint and recolonization time between a Sand Engine and regular nourishments.

6.2 Recommendations

This study has shed light on the shortcomings of the current evaluation of effectiveness of the Sand Engine. In order to enable objective evaluation, an almost complete revision of formal objectives would be necessary. Modification of these objectives is however not recommended, because this is expected to only cause more confusion and ambiguity about the objectives of the Sand Engine than there already is.

Although this study suggests significant changes to the objectives, the general subdivision in themes has remained the same: coastal safety, nature, recreation, innovation and knowledge development. A subdivision in coastal safety, nature and recreation is already existing in the current monitoring and evaluation program (MEPr). A clear elaboration of the objectives for innovation is however lacking, although considered an important aspect of the Sand Engine.

The current evaluation shows that only 50 years after construction of the Sand Engine conclusions can be drawn about the effectiveness regarding coastal safety. It is recommended to evaluate the coastal safety in (a) smaller timescale(s) and more exact spatial scale(s) in order to attribute effects to the Sand Engine. It is expected that with the use of numerical morphological models expectations here for could be made explicit. Although one could consequently still use the current methodology of hypotheses, it is recommended to use a tool as the FoR, because it gives a clear overview of what still lacks specification and whether the evaluation towards the objectives is logical.

As long as a desired state for the aspects of nature and recreation won't be specified more exactly (it is currently only specified as 'more' compared to the initial state or surrounding area), evaluation with the prescriptive frameworks as developed in this study won't differ (much) from the current evaluation in the MEPr. If one chooses however to use the developed frameworks for the evaluation of any of the other themes, it is recommended to use one and the same methodology for the complete evaluation for consistency. Moreover, one has to keep in mind that these frameworks have been developed by an engineer. It is recommended to consult ecologists with the framework for nature and discuss the usefulness of the frameworks relative to the evaluation methodology of hypotheses.

Regarding innovation, it is recommended to take into account evaluation of the more cost-effective and environmentally friendlier approach of the Sand Engine. Although cost-effectiveness of a Sand Engine has been stated repeatedly, clear substantiation of this can not be found. It is recommended to use the evaluation method as suggested in this study (i.e. calculate the present value using parameters interest rate, nourishment volume and price), but to gain more precise information about the exact values of these parameters, since used resources in this study were limited. Next to that, if cost-effectiveness appears to be doubtful one should keep in mind the extra advantages of the Sand Engine (compared to regular nourishments) and if possible monetize these benefits.

The environmentally friendlier approach should not be confused with the objective to create 'more space for nature', which seems to occur in the current evaluation. The expectation that the Sand Engine decreases the disturbance of (local) benthic communities relative to regular nourishments should be evaluated separately from the evaluation of 'nature values' on the Sand Engine and its surrounding area. Further investigation within the research programs on the differences in initial disturbance and recolonization of a Sand Engine compared to regular nourishments is recommended in order to (objectively) evaluate the effectiveness of this approach.
Next to that, validation of the in this study suggested regional approach for effective maintenance of the coastline position in case of presence of a Sand Engine is recommended, in order to further improve and reveal possible limitations of this approach.

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Appendix A

Interviews

For this thesis several interviews have been carried out with the aim to obtain a better understanding and context of the objectives of the Sand Engine.

The structure that is used for the the interviews is semi-structured, in which more or less open-ended questions are brought to the interview situation. The aim is to get the interviewee to expand upon their answer, give more details and add additional perspectives. Sometimes also own interpretations are brought into the conversation with the aim to verify.
Before the interview a list of questions have been set up, divided in several themes (generally the different objectives). This paper is consequently used as a guide for the interview. All interviews have been recorded with permission of the interviewees. The interviews have all been conducted in Dutch, as a result of which citations in this report have been translated into English.
The interviewees are listed in Table A.1.

Organization	**Position respondent**	**Name**	**Interview date**
Deltares	(Co-)author MEPr	P.K. Tonnon	22 May 2015
Royal Haskoning DHV	(Co-)author EIA	J.P. Fiselier	26 May 2015
Rijkswaterstaat	Projectmanager Sand Engine	C. van Gelder-Maas	17 June 2015
Rijkswaterstaat	Communication consultant	C. de Wilde	17 June 2015
Rijkswaterstaat / Deltares	Researcher	J.P.M. Mulder	2 July 2015
Province of Zuid Holland	Projectmanager Sand Engine	K.J. Oome	3 July 2015
Deltares	Researcher	A. Boon	15 July 2015
Rijkswaterstaat	Adviser	Q.J. Lodder	17 August 2015

Table A.1: Interviews

Appendix B

Objectives of the Sand Engine

This appendix gives an overview of all the different objectives (Table B.1 − Table B.3) and sub−objectives (Table B.4) of the Sand Engine.

Coastal safety	**Source**
Natural coastal maintenance	Rijkswaterstaat (2013a)
Increase of coastal safety on the long term	ProvinceZuidHolland (2014)
Long term safety behind the Delfland coast	Dwarshuis van de Beek et al. (2008)
Stimulate natural dune growth in the coastal area between Hoek van Holland and Scheveningen for safety	Fiselier (2010); Fiselier and Ebbens (2010) Tonnon et al. (2011)
The enhancement of coastal protection in the long term	Rijkswaterstaat (2013b)

Table B.1: List of objectives of the Sand Engine regarding coastal safety

Nature and recreation	**Source**
Development of nature and recreation	Rijkswaterstaat (2013a)
Create space for nature and recreation	ProvinceZuidHolland (2014)
More space for nature and recreation	Dwarshuis van de Beek et al. (2008)
Adding of an appealing nature and recreation area on the Delfland coast	Fiselier (2010); Fiselier and Ebbens (2010) Tonnon et al. (2011)
Natural and recreational development by widening beaches and dunes	Rijkswaterstaat (2013b)
Stimulate natural dune growth in the coastal area between Hoek van Holland and Scheveningen for nature and recreation	Fiselier (2010); Fiselier and Ebbens (2010) Tonnon et al. (2011)
Limit the disturbance of local ecosystems while also providing new areas for nature and more types of recreation	EcoShape (2014)

Table B.2: List of objectives of the Sand Engine regarding nature and recreation

Innovation and knowledge development	**Source**
Innovation in coastal maintenance	Rijkswaterstaat (2013a)
Innovation and knowledge development in relation to coastal defence	ProvinceZuidHolland (2014)
Generate knowledge development and innovation to answer the question to what extent coastal maintenance, increased value for recreation and nature can be realized coherently	Fiselier (2010); Fiselier and Ebbens (2010) (Tonnon et al., 2011)
Innovation and knowledge development	Dwarshuis van de Beek et al. (2008)
Knowledge development and innovation in the field of coastal management and reinforcement	Rijkswaterstaat (2013b)

Table B.3: List of objectives of the Sand Engine regarding innovation and knowledge development

Coastal safety	**Source**
Achieve sufficient volume of dunes between Hoek van Holland and Scheveningen for protection during dune erosion	Fiselier and Ebbens (2010) Tonnon et al. (2011)
Maintain the Basic Coast Line (BCL) between Hoek van Holland and Scheveningen	Fiselier and Ebbens (2010) Tonnon et al. (2011)
The coastal foundation in the coastal area between Hoek van Holland and Scheveningen grows with the sea level rise	Fiselier and Ebbens (2010) Tonnon et al. (2011)
Nature and recreation	
Adding a recreation area for at least 20 years with new recreational possibilities	Fiselier and Ebbens (2010) Tonnon et al. (2011)
Development of nature values for foreshore, beach, intertidal area and dunes	Fiselier and Ebbens (2010) Tonnon et al. (2011)
Innovation and knowledge development	
Obtain insight in the functioning and success factors of the Sand Engine on technological, ecological, organizational and social level, so that in the future the chances of success for meganourishments for any location on the Dutch coast can be predicted better	Fiselier and Ebbens (2010) Tonnon et al. (2011)

Table B.4: List of sub−objectives of the Sand Engine

Appendix C

Expectations of the Sand Engine

This appendix gives an overview of all the different expectations of the Sand Engine (Table C.1 – Table C.5).

Coastal safety	Source
The Sand Engine will, in combination with the strengthening activities for the Delfland coast, provide for a sufficient volume of dunes against erosion for a period longer than 50 years.	Fiselier and Ebbens (2010).
The Sand Engine and additional nourishments maintain the sand balance of the coastal foundation in the coastal area between Hoek van Holland (HvH) and Scheveningen for at least 50 years with a sea level rise of 3 mm per year.	Rijkswaterstaat (2014a).
The Sand Engine and additional nourishments guarantee the safety in the coastal area between Hoek van Holland and Scheveningen during 50 years and provide for dune growth for a higher safety in comparison with the regular nourishment program between 1990 and 2010.	Rijkswaterstaat (2014a).
The Sand Engine and additional nourishments guarantee the safety in the coastal area between HvH and Scheveningen during 50 years and provide by dune growth for a higher safety in comparison with the regular nourishment program between 1990 and 2010.	Tonnon et al. (2011).
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).	Stive et al. (2013)
The mega nourishment at Delfland, in combination with wider beaches, will instigate active dune formation in the coming decades. This dune formation is expected to be swift enough to follow sea level rise, so a structural solution is offered that will ensure the safety standards of the sea defence in spite of climatic change.	van Dalfsen and Aarninkhof (2009)

Table C.1: List of expectations of the Sand Engine regarding coastal safety

Nature	Source
By a decrease in the number of nourishments for maintaining the BCL as well as the necessary volume an increase in nature values of the beach, intertidal area and foreshore are expected.	Fiselier and Ebbens (2010).
The one-time deposit of a large amount of sand is less disruptive to the ecology (especially for macrobenthos) than periodic replenishments.	Fiselier and Ebbens (2010).
The development of wider and more robust dunes will provide for a high value new dune habitat with higher nature values in comparison with artificially constructed dunes.	Fiselier and Ebbens (2010).
As a result of the presence of sheltered (lagoon) and exposed regions (seaside), the hook will characterize itself by a diversity in sediment composition.	Rijkswaterstaat (2014a).
The construction of the Sand Engine will lead to a higher natural value in the intertidal area and the shallow coastal zone due to new and variation in habitats.	Rijkswaterstaat (2014a).
The strong gradients (epoxed beach and sheltered lagoon) as a result of the construction of the Sand Motor will translate into a different and more diverse benthic community.	Rijkswaterstaat (2014a).
The relatively sheltered location of the lagoon and high food availability, will increase the nursery function of the area.	Rijkswaterstaat (2014a).
The lagoon will lead to an increase in waders and seabirds in the area.	Rijkswaterstaat (2014a).
The sand hook will create a feeding and resting area for marine mammals.	Rijkswaterstaat (2014a).
An anticipated secondary benefit is the creation of environmentally attractive space in this strongly urbanized coastal stretch.	Stive et al. (2013).
By making use of natural processes to redistribute the sand, this innovative approach aims to limit the disturbance of local ecosystems, while also providing new areas for nature.	EcoShape (2014)

Table C.2: List of expectations of the Sand Engine regarding nature

Recreation	Source
The dynamics of the Sand Engine will manifest itself in a changing pattern of recreational use	Rijkswaterstaat (2014a).
Through the design of the Sand Engine, new extensive forms of recreation become possible (among others strolling and walking during the beach season)	Fiselier (2010).
The Sand Engine provides, by the accretion of dunes, for more space for extensive recreation	Fiselier and Ebbens (2010).
The new area invites to extensive recreational use	Rijkswaterstaat (2014a)
The extra dune area and beach that which arises along the coast will visibly contribute to the expansion of the existing coastline and results in extra dune area and beach that is accessible for recreation as much as possible	Dwarshuis van de Beek et al. (2008)
An anticipated secondary benefit is the creation of recreationally attractive space in this strongly ubranized coastal stretch	Stive et al. (2013).

Table C.3: List of expectations of the Sand Engine regarding recreation

Innovation	Source
The strategy of introducing concentrated nourishments is seen as a climate−robust and environment−friendly means of countering coastal erosion.	EcoShape (2014)
Potentially, the choice for a large volume of sand will be cost−effective because of economy of scale and because a mega supply can be timed to a dip in market prices.	van Dalfsen and Aarninkhof (2009)
In the 20 years after the construction of the Sand Engine, less sand will be needed for maintaining the Basic Coast Line (BCL).	Rijkswaterstaat (2014a)
With the Sand Engine, in comparison with the regular nourishment program, in total less sand will be needed for maintenance of the BCL in the coastal area between HvH and Scheveningen for a period of 20 years.	Tonnon et al. (2011).

Table C.4: List of expectations of the Sand Engine regarding innovation

Knowledge development	Source
The Sand Engine provides (physical) knowledge that explains the occurred morphological changes from the steering processes and makes more efficient coastal management possible.	Rijkswaterstaat (2014a).
The Sand Engine provides (ecological) knowledge for determining to which extent a Sand Engine has an added value for nature compared to the regular nourishment.	Rijkswaterstaat (2014a).
The Sand Engine pilot project aims at gaining a better understanding of the morphological development of a mega nourishment, the growth of beach and dunesdue to landward transport of sediment, (temporary) nature development as a result of the interaction between morphology and ecology, and the identification and utilisation of ecological potential in the design.	van Dalfsen and Aarninkhof (2009)

Table C.5: List of expectations of the Sand Engine regarding knowledge development

Appendix D

Nourishment data Delfland Coast

This appendix gives an overview of nourishment executed on the Delfland coast since 1988. Figure D.1 illustrates division of the Delfland coast into JARKUS transects.

Year	**Volume** (×1.000)	**Type of nourishment**	**JARKUS transect**	**Purpose?**
1988	200	Beach	118−118.5	
1989	100	Beach	118−118.75	
1990	183	Beach	117.75−118.75	
1991	223	Beach	117.75−118.75	
1992	560	Beach	117.75−118.75	
1993	200	Beach	114−118.75	
1994	200	Beach	117.75−118.75	
1995	200	Beach	117.75−118.75	
1996	200	Beach	117.75−118.75	
1997	200	Beach	117.75−118.75	
1999	200	Beach	117.75−118.5	
2000	200	Beach	117.5−118.5	
2003	200	Beach	117.5−118.5	
2004	200	Beach	117.5−118.5	
2007	750	Beach	117.25−118.75	
2007	750	Foreshore	113−118	
2008	4.500	Beach−dune	115.35−117.5	‘Zwakke Schakels’
2013	1.500	Fore shore	114−118	

Table D.1: List of nourishments near HvH and the Hague between 1988 and 2015

Year	**Volume** (×1.000)	**Type of nourishment**	**JARKUS transect**	**Purpose?**
1993	1.150	Beach	106.2−112.2	
1995	300	Beach	112.2−114.5	
1997	1.050	Foreshore	107.5−112.5	
1997	850	Beach	113.2−114.9	
2001	800	Beach	107.4−112.5	
2001	3600	Foreshore	108−112	
2003	1250	Beach	107.7−113.2	
2004	1150	Beach	107.7−113.2	
2005	900	Foreshore	108.6−113	
2008	3.000	Beach−dune	112.8−115.1	'Zwakke Schakels'
2009	3.000	Beach−dune	105.3−106.8	'Zwakke Schakels'
2009	5.000	Beach−dune	107.1−112.6	'Zwakke Schakels'
2010	2.500	Beach−dune	102.0−105.1	'Zwakke Schakels'
2011	17.000	Beach	108.1−110.0	Sand Engine
2011	2.000	Foreshore	111.8−114	Sand Engine
2011	500	Foreshore	105.3−107.4	Sand Engine

Table D.2: List of nourishments near Kijkduin and Ter Heijde between 1988 and 2015

Year	**Volume** (×1.000)	**Type of nourishment**	**JARKUS transect**	**Purpose?**
1991	1.000	Beach	97.8−101.4	
1996	800	Beach	97−101	
1999	1.500	Foreshore	97.7−100.5	
2004	100	Beach	99.25−99.65	Safety
2004	700	Beach	99.7−101.1	Safety
2009	1.400	Beach	99−101.5	'Zwakke Schakels'
2010	1.000	Beach	99−101.5	'Zwakke Schakels'

Table D.3: List of nourishments near Scheveningen between 1988 and 2015

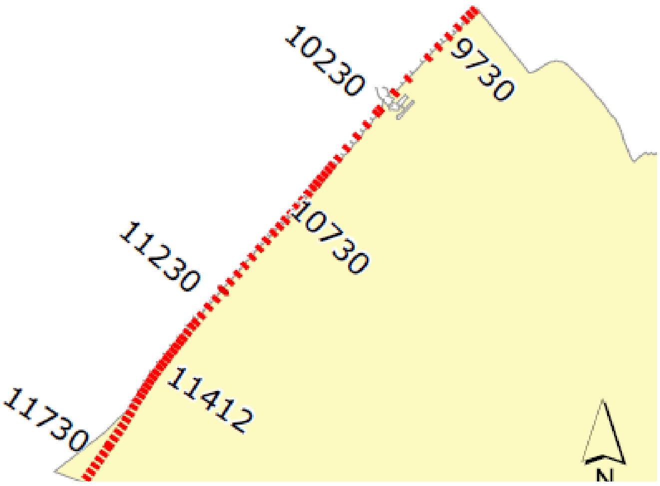

Figure D.1: Coastal area of the Delfland coast with JARKUS transects (Hoogheemraadschap Delfland)