Memo

To
EcoShape BwN HK4.1

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Subject
Inclusion of various coastal indicators in the interactive design tool for the Holland Coast

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1 Introduction

This document describes the implementation of various indicators in the interactive tool for the Holland Coast (referred to as ITHK). This tool was developed within the BwN work package HK4.1 (Deltares, 2012). It is noted that the goal of the current document is to describe the implementation of these indicators and not the impact assessment of nourishment strategies. A summary of the aims of the related BwN work packages HK4.1 is given below. It is noted that three rather similar documents are available which describe the inclusion of other somewhat more complex indicators (costs, ecology and dune habitat development) in the ITHK.

Building with nature HK 4.1
The work package HK4.1 aims at “Developing a strategy for the long-term, sustainable development of the Holland Coast through extrapolation of findings from HK-projects and pilots to the scale of the entire Holland Coast”. The strategy will be based on the design philosophy of BwN aimed at maximizing the potentials of the eco-morphodynamic system. The considered coastal management strategies vary between the present management strategy and new strategies that are advised by the Delta commission (2008). The activities are (1) the development of an aggregated morphological model of the Holland Coast enabling the analysis of large scale morphological development, (2) deriving information from geological analogs of sand-engines in order to provide validation material for upscaling of the morphodynamic models, and (3) the development of a habitat - and vegetation model enabling the 'translation' of large scale morphological model forecasts into (ecological) habitat effects and (4) the development of different large scale sand mining - and nourishment scenarios.

2 Explanation of indicators

2.1 General

Indicators have been developed to evaluate the impact of a nourishment strategy on various coastal functions. The considered indicators are simple formulations that relate a physical property (e.g. coastline position, beachwidth or dune position) to a coastal function. It is noted that more complex indicators have been described in three other somewhat similar documents, which describe indicators for costs, ecology and dune habitat development. The indicators in this document relate to:

- Safety (dyke ring and structures outside the primary water defenses)
- Economy (drinking water & fishery)
- Recreation (beach & dunes)
- Residential (groundwater levels & real estate value)
- Dunes (dune dynamics)

2.2 Indicator 1 : Safety

Safety is considered to be one of the primary aims of coastal projects. In order to evaluate this coastal function a differentiation should be made in (1) safety for primary water defenses, (2) safety of structures along the coast that are located outside the dyke rings (e.g. lighthouse or beach house) and (3) buffer capacity of the coast. Figure 1 provides an overview of the location of the safety related coastal indicators.

Figure 1: Example overview of safety related indicators

2.2.1 Safety of the primary water defenses

The safety of the primary water defenses is often considered as a direct aim of a strategy. It is of such an importance that fixed safety levels are imposed by the government. This indicator can therefore be seen as a requirement that should be met. The safety of the primary water defenses is related to measurable quantities like the coastline position and dune width. A minimum position should be maintained. Note that it is assumed that other (potentially relevant) parameters do not change (like extreme wave conditions, sediment size and dune height), which is an assumption that is made to limit the complexity of the analysis. In the current approach the coastline position is used as a proxy for the impact of the buffer capacity on the safety level (e.g. safety level 10 times higher for every 30m of coastline shift). It is assumed that a change of the coastline position of about 30 meter can be used as a proxy for a factor 10 difference in the safety level.

2.2.2 Safety of structures outside the dyke ring

Safety of structures outside a dyke ring is also important for a coastal strategy. A somewhat larger risk of failure may, however, be accepted for these structures than for a dyke ring. The actual value of the structures should be in relation to their safety standards. The actual safety is related to the coastline position. As a first approach, it is suggested to compare the actual coastline position to a safety threshold value that should not be exceeded. It is stressed that this indicator is should only be evaluated for specific locations along of the coast. Similar as for the safety of the primary water defenses, it is assumed that a 30 meter change in coastline position can be considered to have a significant impact on safety.

2.3 Indicator 2 : Economy

Relevant economic functions along the coast are (1) drinking water supply and (2) fishery.

Drinking water supply

The drinking water companies use the dunes as an infiltration area for river water. The infiltrated water is then pumped up from the ground water and used as drinking water. The availability of fresh water depends on the volume of the dunes as well as on the amount of water that is infiltrated. Increasing the width of the dunes can result in a larger volume of water (not salt) that can be used. Increasing the width of the dunes may therefore bring an economic benefit for such companies. It is, however, expected that this relation is very weak as the amount of available water depends more strongly on the quantity of infiltrated water than on the dune volume. Furthermore, legal aspects make it difficult to make use of the increased volume of dune water. A positive change in dune area for drinking water is therefore not valued very differently from the current situation. However, a negative change of the dune area would have influence on the actual drinking water production. A change of 50 meter is considered as a significant change.

Fishery

Fishery may either benefit or induce a penalty from measures along the coast. As the impact on the fish population will be very difficult to determine. Therefore only a relation with the suitable habitat area for species is included. The available space in water depth regions (that are suitable for a certain species) is used as a measurable quantity for this indicator. It is noted that fishery uses the same physical parameter (average foreshore width) as the indicator for the impact on juvenile fish, which is described in the document on ecological coastal indicators.

The impact on fishery is considered an indirect impact of a nourishment strategy, which is related to the change of the foreshore area as a result of a prograding or retreating coast. The actual foreshore area is considered a proxy for the available space for juvenile fish along the coast (so called nursery function for juvenile fish). For example, a reduction in the foreshore area as a result of continuous nourishments along the coast may have a negative impact on the nursery function of the coast which on its turn may reduce the fish population at sea.

In order to evaluate this indicator it was assumed that the area at each depth contour reduces equally to the reduction of the foreshore area in time. The available foreshore area along the Dutch coast up to the NAP-20m contour was estimated in a very simple way by using an average width of the foreshore for the whole of the Holland coast of about 10 km (referred to as shorewidth). The relative reduction in the available foreshore width (ψ) is then evaluated over time for each of the grid cells along the coast with formula 1. An impact of 20% of the foreshore width is considered a significant impact at which the effects may get noticeable.

$$\psi(x,t) = \frac{B_{ref}(x) - \Delta B(x,t)}{B_{ref}(x)} \qquad (1)$$

With:

B_{ref}	*Reference width of the foreshore [m] (default = 10 km)*
ΔB	*Coastline change [m]*
ψ	*Relative change of foreshore area*
x	*Alongshore distance [m]*

2.4 Indicator 3 : Residential

The coastal strategy has an impact on (1) ground water levels in residential areas and (2) the value of real-estate.

Ground water levels at residential areas

Ground water levels at residential areas behind the dunes can be impacted by the seaward extension of the dune front. This impact is related mainly to the width of the dunes (wider dunes relate to a higher phreatic level) and the type of coastal nourishment (e.g. a dune lake at the existing dune face may reduce the impact). It is noted that the influence on the ground water at residential areas is only relevant for specific locations. For these locations a maximum width of the dunes can be specified for which ground water levels at the residential areas are okay. Another would be to mitigate the damage due to the rising water levels. This would, however, require more insight in the actual impact of specific measures on ground water levels. Furthermore, such an approach would reduce the public acceptance of a coastal strategy. A threshold value of 30 meter of dune position change is used as a significant impact, while a large negative impact can be seen for a seaward dune position change of 60 meter.

Real-estate

The value of real-estate generally is related to the availability of nature and the safety level at the considered site. As the actual safety level was already included in the ‘safety outside the dyke ring’, only the impact of nature development on real-estate value remains. This indicator can therefore be related to dune width (initial and current). It is, however, noted that potential co-financing of projects as a result of positive effects on real estate value is expected to be limited. This is due to current regulations that do not allow new developments in nature areas or close to primary sea defenses. A seaward or landward change of 50 meter is assumed to have some effect on real estate value. It is, however, noted that real estate value is influenced by many more parameters than the suggested one (like economic conditions), which may be more important than this physical parameter.

2.5 Indicator 4 : Recreation

The recreation on the (1) beaches and in the (2) dunes may be affected by a coastal strategy.

Recreational attractiveness of beaches

It is assumed that most beaches get more attractive for recreation if they are wider. So, a relation between beach width and beach recreation could be adopted. This holds especially for the area that is still dry at high water. However, for very wide beaches the effect is expected to be negligible. Furthermore, it is noted that substitution between beaches may play a role (i.e. visitors are attracted from other beaches), which means that there is only a local benefit. The relation between beach width and attractiveness for recreation is also expected to be weaker than for aspects related to infrastructure (like the availability of parking lots close to the beach). A positive or negative beach width change of 50 meter was assumed to be a significant change for this indicator.

Recreational attractiveness of dune areas

Dunes are considered nature areas in the Netherlands. The attractiveness for recreation in the dunes is expected to be related to the dune area. It is, however, noted that the attractiveness of the dunes is only affected significantly if there is a large increase in dune volume. So, the impact of the coastal strategy on recreation may result in some co-financing, but quite a significant increase in dune area should be made then (at least locally). A positive or negative dune position change of 50 meter was assumed to be a significant change for this indicator.

2.6 Indicator 5 : Dunes (Dune dynamics)

The ecology of the dunes varies along the Dutch coast. Different types of dune habitats can for example be distinguished for the North-Holland coast and the Delflandse coast. The dune habitat type depends on the dynamics of the dunes as well as on a number other parameters (e.g. height of dunes, sediment). In general, a more dynamic dune front can be considered beneficial for the ecology of the dunes. Furthermore, the management of the dunes is of importance for the actual habitat. A wider dune front will therefore allow a less strict management of the dunes. As a first approach, it is therefore suggested to link the dune habitat quality to the dynamics of the dune front and the width of the dunes. The relation between these parameters and the dune habitat quality can be differentiated spatially along the coast (depending on local dune system). A dune position change (positive or negative) of 0.5 m/yr is used as a threshold value for significant dune dynamics.

3 Changes to the code

3.1 General

This section describes some aspects related to the implementation of the considered coastal indicators (see Section 2) in the Interactive tool for the Holland Coast (ITHK). Consecutively, it is described how the assessment of dune position changes is performed (Section 3.2), what the typical procedure is for each of the post-processing routines of the indicators (Section 3.3), what the typical output information is like (Section 4.2) and where these changes were made in the model code (Section 3.4).

3.2 Dune dynamics model

Some of the indicators described in Section 2 require information on the dune position in time (i.e. drinking water, groundwater, real estate, dune recreation and dune dynamics). In order to evaluate these parameters a simple eolian transport model was used to predict the changes to the dune foot position. The eolian transport model is included in a post-processing routine (‘ITHK_postprocessdunegrowth.m’) that computes the amount of dune growth (volume per year per meter length of the beach) on the basis of the beach width (B). The formulation contains a maximum growth rate (Cmax) and a critical beach width (Bthr) for which the growth is zero. A relaxation factor (Bhalf) is used to set the beach width at which the maximum growth rate (Cmax) is reached.

$$V_{dunegrowth} = \max\left(C_{\max} \cdot \left(1 - e^{-(B-B_{thr})/B_{half}} \right), 0 \right) \quad (1)$$

With:

Vdunegr	*Rate of dune volume change [m^3/m/yr]*
Cmax	*Coefficient with maximum rate of dune volume change [m^3/m/yr]*
B	*Beach width [m]*
Bthr	*Threshold beach width at which dune growth starts [m]*
Bhalf	*Relaxation time, defining the dune growth between zero and maximum transport [m]*

Typical values that are used are 80 m for Bthr, 80 m^3/m/yr for Cmax and 150 m for Bhalf. This gives a dune growth rate of at most 40 m^3/m/yr for the existing beaches along the Holland and Wadden coast. The dune growth is not allowed to be smaller than 0. Erosion of the coast is included by assuming that a minimum beach width (Bthr) should be present. The dune position will retreat if the beach width is smaller than the minimum beach width (Bthr). The actual beach width will then be equal to the minimum beach width.

3.3 Procedure

Some background information on the procedure for each of the post-processing routines of the indicators is described in this section. All indicators are evaluated in a separate matlab routines, of which the naming starts with 'ITHK_ind_' followed by the name of the considered indicator. These routines are called consecutively from the overall post-processing routine 'ITHK_postprocessing.m'.

All coastal indicators follow more or less similar steps. First the settings are loaded from the settings field of a global variable called 'S', which contains information that is specified in the 'ITHK_settings.xml' file. Aspects like actual position and scaling of the indicator plots should be adjusted in this file. For some indicators that are only to be evaluated for a part of the coast, a file is loaded containing the considered areas. The effect on the indicator is then evaluated and results are converted to KML plots. A schematic overview of the procedure is provided in Figure 1.

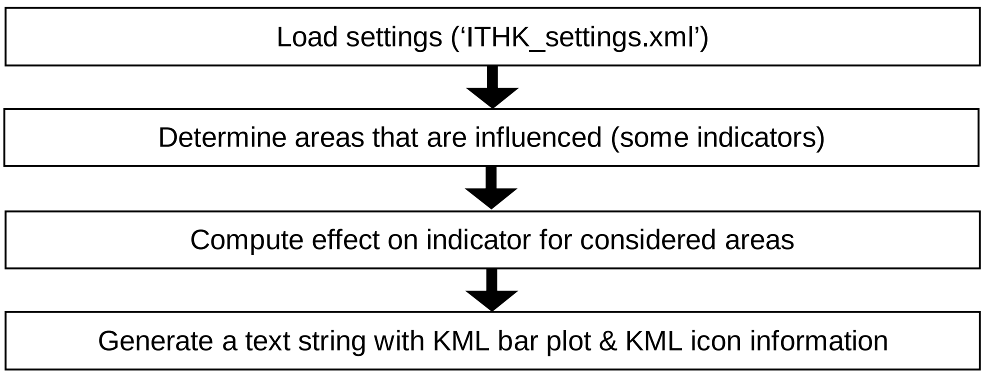

Figure 1: Approach used to assess the impact on a coastal indicator

It is noted that the actual KML files are created in the overall post-processing routine 'ITHK_postprocessing.m'. The actual KML files are composed from a combination of KML text strings from a selection of coastal indicators.

3.4 Changes to the code

The changes that were made to the code of the Interactive Tool for the Holland Coast (ITHK) were made in the post-processing directory and added to a sub-directory of 'postprocessing\indicators\'. The functions containing the post-processing routines are the following:

- *ITHK_ind_safety_dykering.m*

- *ITHK_ind_safety_structures.m*
- *ITHK_ind_economy_drinkwater.m*
- *ITHK_ind_economy_fishery.m*
- *ITHK_ind_residential_groundwater.m*
- *ITHK_ind_residential_realestate.m*
- *ITHK_ind_recreation_beachwidth.m*
- *ITHK_ind_recreation_dunearea.m*
- *ITHK_ind_dunes_dunedynamics.m*

Some of above routines use a file which contain the zones for which the indicator needs to be evaluated (e.g. ITHK_ind_safety_structures.txt'). Such a has the same name as the considered coastal indicator, but with a .txt extension. It is located in the same directory as the considered coastal indicator. A typical file reads like this:

```
% FILE WITH ZONE 1 : SAFETY
% Containing the following columns with information:
%    - X     Centre location of the suppletion [m wrt Hoek van Holland]
%    - B     Width of the zone [m]
116403   3195
107000   3471
95000   5419
65211   1422
37000   2407
32000   1395
19000   2622
5000   2774
```

Furthermore, some functions were added to write the KML text strings for the bar plots and icons and a routine that writes this information to a KML file.

- *ITHK_KMLbarplot.m*
  This function writes the computed impact on the indicators that was generated by one of the routines to a KML text string with bar plots. The KML text string is written to a KML file in the 'ITHK_postprocessing.m' routine and presented in the ITHK web interface or directly in Google Earth.
- *ITHK_KMLicons.m*
  This function writes the computed impact on the indicators that was generated by one of the routines to a KML text string with icons. The KML text string is written to a KML file in the 'ITHK_postprocessing.m' routine and presented in the ITHK web interface or directly in Google Earth.
- *ITHK_io_writeKML.m*
  This function writes the KML text strings for a selection of coastal indicators to a KML file. It is called from the main ITHK post-processing routine ('ITHK_postprocessing.m').

4 Visualisation of coastal indicators

4.1 Introduction

This section presents an overview of the visualisation of coastal indicators (Section 4.2) and an explanation of the icons that are used (Section 4.3).

4.2 Output information

Two types of KML output are generated for each of the considered indicators. First, the information on the indicator is presented along the coast by means of bar plots (item 1 in Figure 2). These bar plots can be mapped in Google Earth on a predefined offshore location, which makes sure that it does not overlap with other indicators. The location and scaling can be set in the settings file ('ITHK_settings.xml'). As an alternative to the bar plots it is also possible to use icons to display the results for a coastal indicator along the coast (item 2 in Figure 2). These icons do present the same information as the bar plots, but are classified in predefined classes (to be adjusted in the post-processing routine of the considered indicator). The class definition in fact allows for the inclusion of some interpretation of the results. It is possible to display multiple indicators at once. For this purpose, an indicator label was added in order to distinguish between the indicators (item 3 in Figure 2).

Figure 2: Visualisation of coastal indicator results

4.3 Overview of indicator icons and icon classes

The applied icons for the indicators are presented in Table 1. This table also provides an overview of the classes that are set by default for the transition between a different status of a coastal indicator. Note that these classes can be set in the ITHK settings file ('ITHK_settings.xml')

Table 1: Icons used for visualisation of impact classes of coastal indicators

Indicator	Improvement	Similar as current	Worsening
Safety dykering	Prograding coast (accretion >30m)	Stable coast	Erosive coast (coastline erosion >30m)
Safety structures	Prograding coast (accretion >30m)	Stable coast	Erosive coast (coastline erosion >30m)
Economy drinkwater	Accreting drinking water dune area (>50m)	Stable drinking water dune area	Eroding drinking water dune area (> -50m)
Economy fishery	More fish potential (>20% foreshore area)	Stable (similar foreshore area)	Less fish potential (20% to 40% less foreshore) Large decrease in fish potential (>40% less foreshore)
Residential groundwater	No buildings present	Similar ground water levels	Higher ground water levels (30 to 60 meter dune accretion) Much higher ground water levels (>60 meter dune accretion)
Residential realestate	Positive impact on real estate value (>50 meter coastal accretion)	No impact	Negative impact on real estate value (>50 meter coastal retreat)
Recreation beachwidth	Wide recreation beach (>40 m extra width) Very wide beach (>80 m extra width)	Standard beach width	
Recreation dune area	More recreation beach (>100 meter coastal accretion)	Similar dune recreation	Narrower recreation beach (>100 meter coastal retreat)
Costs direct	No costs	Moderate costs (less than 30,000 euro/m)	Moderate costs (30 to 60 thousand euro/m) Large costs (more than 60 thousand euro/m)
Ecology benthos		No impact on benthic community	Small impact (<30% population reduction) Moderate impact (30%-60% reduction) Large impact (>60% reduction)
Ecology juvenile fish	> 20% more foreshore area	Similar foreshore area	20% - 40% less foreshore area < 40% less foreshore area
Dunes dune dynamics	Very dynamic dune front (>1 m/yr)	Moderate dune dynamics	Rather stable dune front (<0.5 m/yr)
Dunes classes	Class 3 : Wide beach + potential for new dunes (>100m^3/m/yr accretion) Class 4 - 5 : Extremely wide beach + potential for new dunes + green	Class 2 : Normal + slight progradation (<30 m^3/m/yr erosion and <100 m^3/m/yr accretion)	Class 1 : Erosive dune front (>30m^3/m/yr erosion)

	beach for class 5 (>400m^3/m/yr accretion)	
Dunes habitat richness	Intermediate habitat richness (class 3 and 4) Rich habitat richness (class 5)	Low / Normal habitat richness (class 1 and 2)

5 Example case

5.1 Introduction

In this section a typical example is shown of the results for both ecological indicators that are described in Section 2.2 and 2.3. First, the Holland coast model in the ITHK is described concisely in Section 4.2. Section 4.3 then describes the reference scenarios, for which the results are presented in Section 4.4.

5.2 Holland coast model

The ITHK includes a UNIBEST coastline model that has been setup for the Holland coast (from Hoek van Holland to Den Helder). Structures were included at Scheveningen and IJmuiden to represent the harbour moles at these locations. The model has a length of 118 km and includes 113 cross-shore profile rays for which the sediment transport was computed. An overview of the longshore sediment transport is in the model is provided in Figure 2.

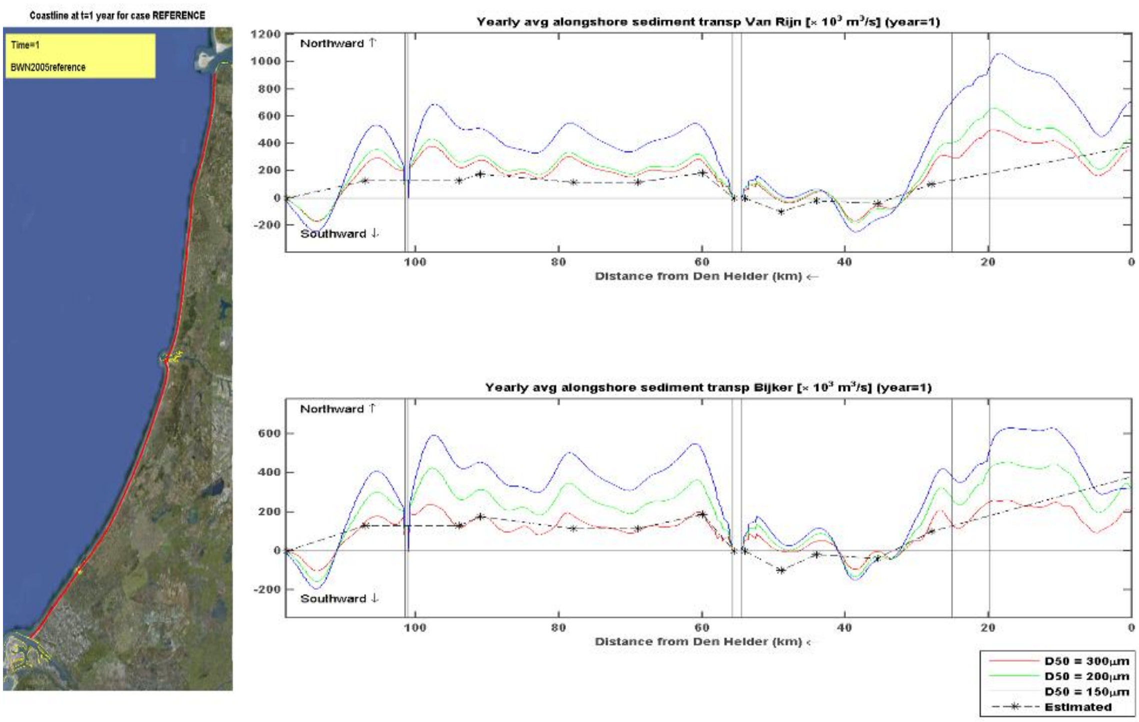

Figure 2: Computed sediment transport for 3 sediment diameters (D50=150, 200 and 300 μm) and two sediment transport formulae (Top: Van Rijn, 2004, Bottom: Bijker, 1977) (Deltares, 2010)

A detailed description of this tool is provided in the memo 'Evaluation of nourishment strategies Cycle 1 : HK4.1: Long-term sustainable strategies for the Holland Coast' (Deltares,2010).

5.3 Reference scenarios

This section provides an overview of reference scenarios for the maintenance of the coast, which are summarised here:

1. *Autonomous*
   Autonomous development without measures
2. *Minimal consolidation: Continuous nourishments*
   Minimal consolidation of the coast at coastal settlements with 5 million m^3/yr of continuous nourishments.
3. *Minimal consolidation: Five yearly nourishments*
   Minimal consolidation of the coast at coastal settlements with 2.5 million m^3/yr of nourishments with an interval of 5 years.
4. *Seaward*
   Seaward extension of the coast with sand engines of 20Mm3 and a return interval of 10 years at 5 locations along the coast (Vlugtenburg, Katwijk, Zandvoort, Egmond and at the Hondsbossche zeewering).
5. *Revetments*
   Revetments protecting the coastal settlements (no additional nourishments)

The model simulations cover a period of 95 years until the year 2100. A moderate sea level rise (2 mm/yr) is included for all scenarios by means of an additional coastal retreat that was computed for a profile with an average slope of 1:500. A moderately fast and a slow recovering species of benthos are included in the model (with growth rates of 1 and 3). It is noted that the aim of these scenarios is to evaluate indicators values and not the actual coastal changes.

5.4 Results

This section presents the results of the model run for the reference scenarios (Figure 5 to Figure 9). The Figures show the coastline position as a yellow line on the coast and the change in coastline position with red and green bars (which improve the visibility of the coastline changes). In offshore waters and on land a number of indicators is presented. These include among the ones in this memo also the ecological (Benthos & Juvenile fish), dune class, habitat richness and costs indicators. It is noted that in practice it may be preferable to present only part of the indicators in order to be able to distinguish the impacts more clearly.

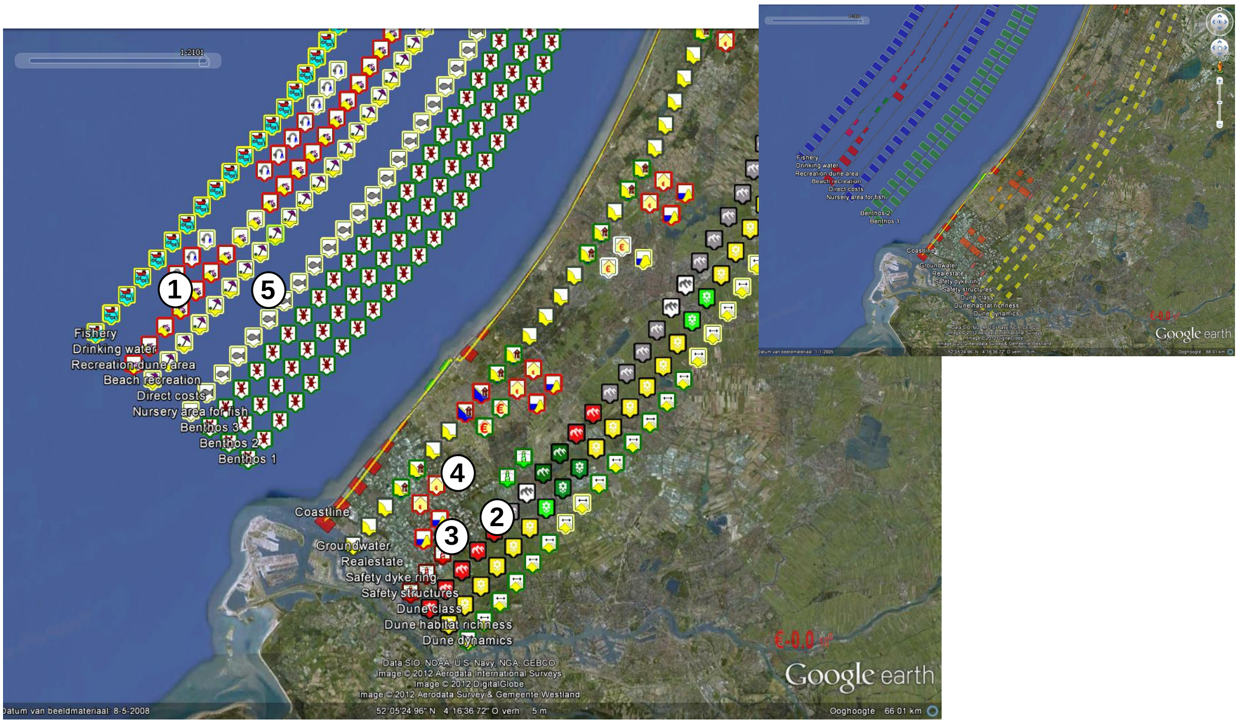

Figure 5: Coastal indicators for reference scenario 1 (Autonomous).

Figure 5 shows considerable erosion along the coast, which is expected for a strategy without coastal maintenance. The impact on drinking water and dune recreation (1) is negative as the dunes erosion is significant in some areas (see erosive class of dunes (2)). Furthermore, the safety of the primary water defenses and structures (3) and real estate value (4) may be impacted negatively by the coastal retreat. Other indicators are mildly impacted (5).

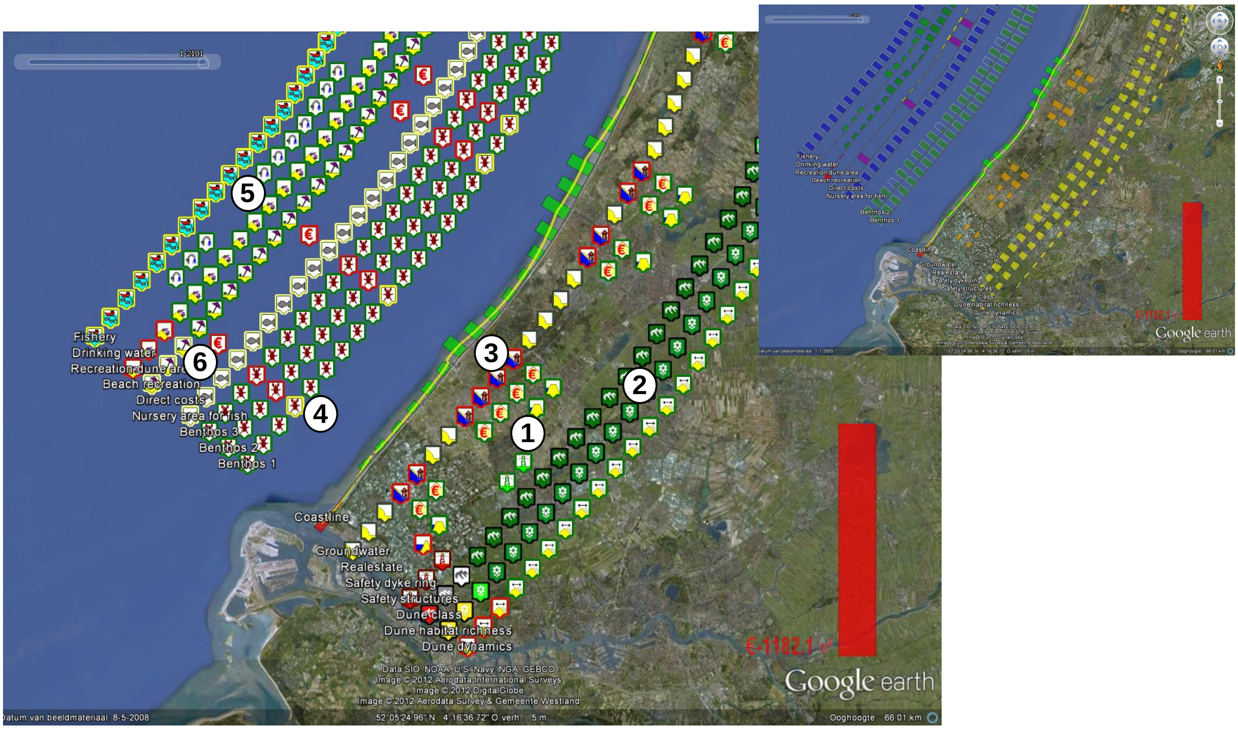

Figure 6 Coastal indicators for reference scenario 2 (Minimal consolidation: Continuous nourishments).

A continuous (i.e. yearly) nourishment (Figure 6) will have an impact on some coastal indicators. The safety indicators will be positively impacted at the location of the noutishments (1). Furthermore, dune dynamics and habitats (2) are positively impacted as a result of the continuous sediment supply. Attention should, however, be paid to the ground water levels at residential areas (3). Locally the benthic community is negatively impacted by the nourishments (4) while the drinking water supply and recreation are positively impacted (5) as a result of the accreting coast and dunes. The costs of the measures can be considerable (6) as all nourishments are placed at the same location.

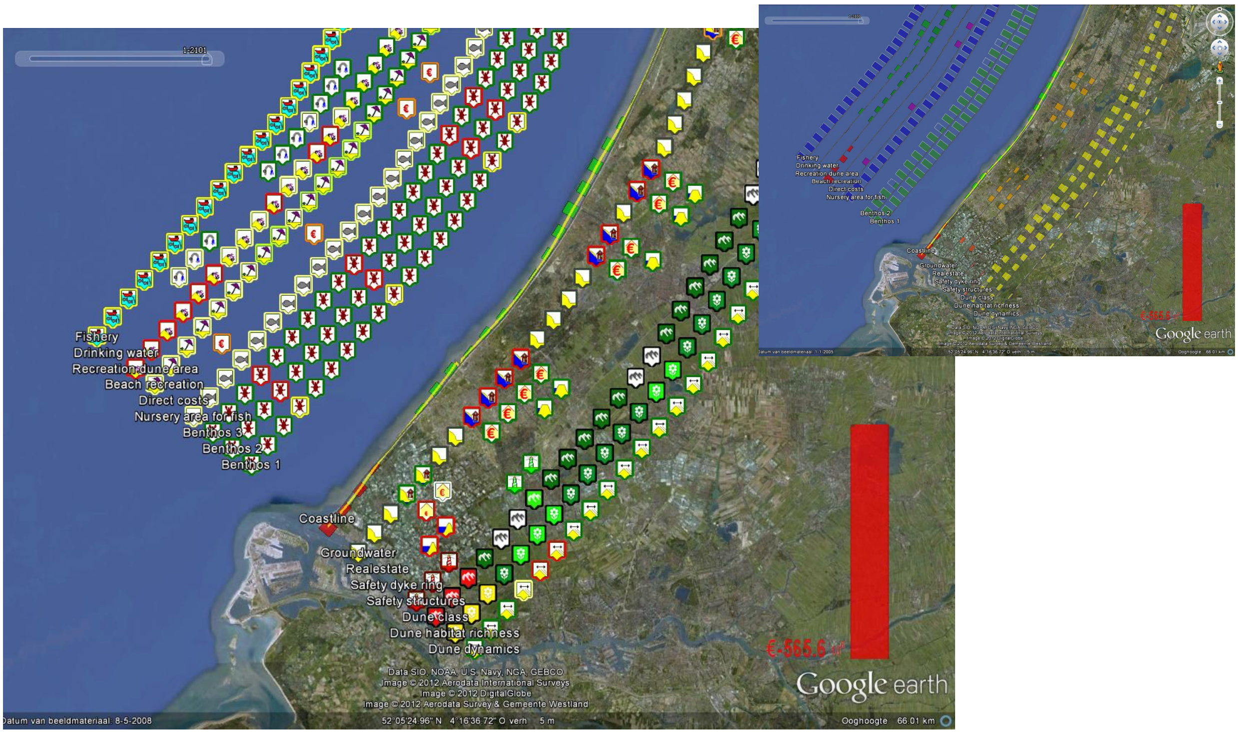

Figure 7: Coastal indicators for reference scenario 3 (Minimal consolidation: Five yearly nourishments). Moments in time before and after a nourishment took place.

Scenario 3 (with nourishments with a regular interval of five years) shows more or less similar impacts as scenario 2 (Figure 7). The positive impacts on the dunes (recreation, drinking water, habitats etc) and recreation beaches, however, are smaller due to the smaller nourishment volumes.

The coastal development for a seaward scenario (Figure 8) showed that the coast can be build out considerably in such a period. The impact on the most indicators is even more pronounced than for the other scenarios (e.g. for safety and benthos, see nr. 1). Furthermore, it shows that the foreshore area (2) may significantly be impacted in this scenario, which may have an impact on the juvenile fish and fishery (3) in general.

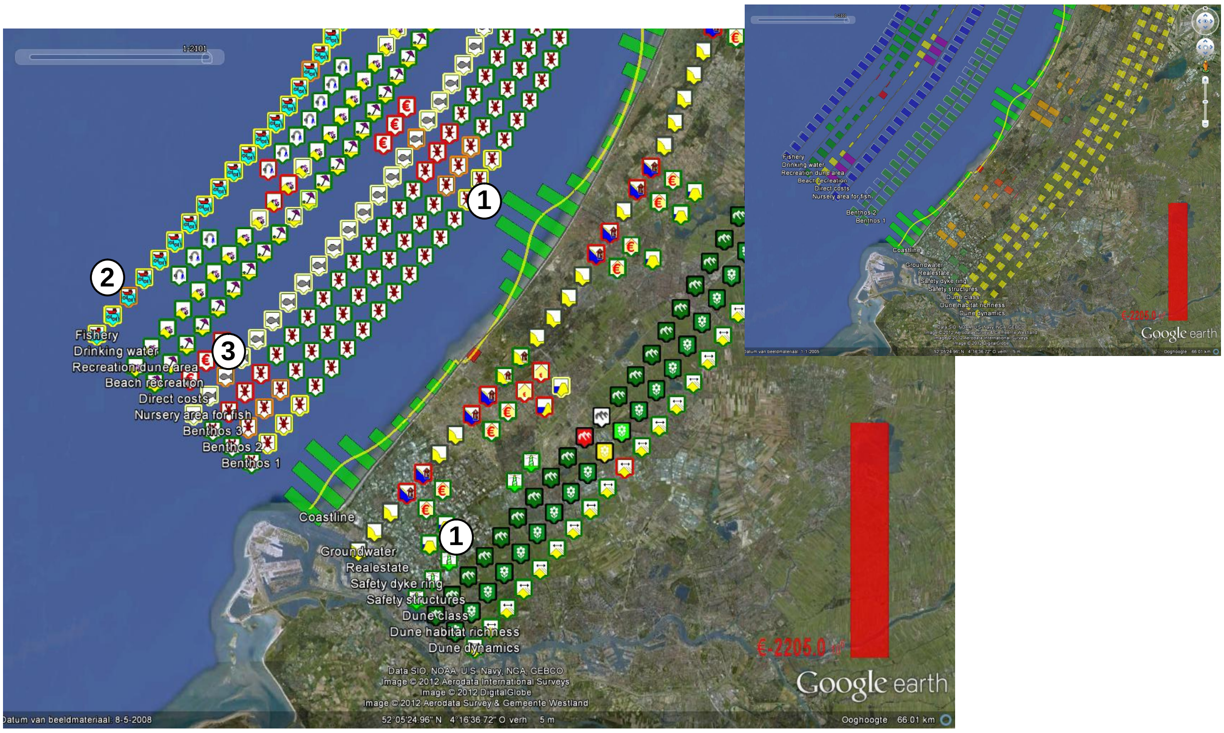

Figure 8: Coastal indicators for reference scenario 4 (Seaward). Moments in time before and after a nourishment took place.

The coastal indicators for a scenario with coastal revetments is shown in Figure 9. The impact on the considered indicators is small as there are no nourishments. Consequently, many parameters, like dune habitat richness (1) and beach recreation (2), are only moderate.

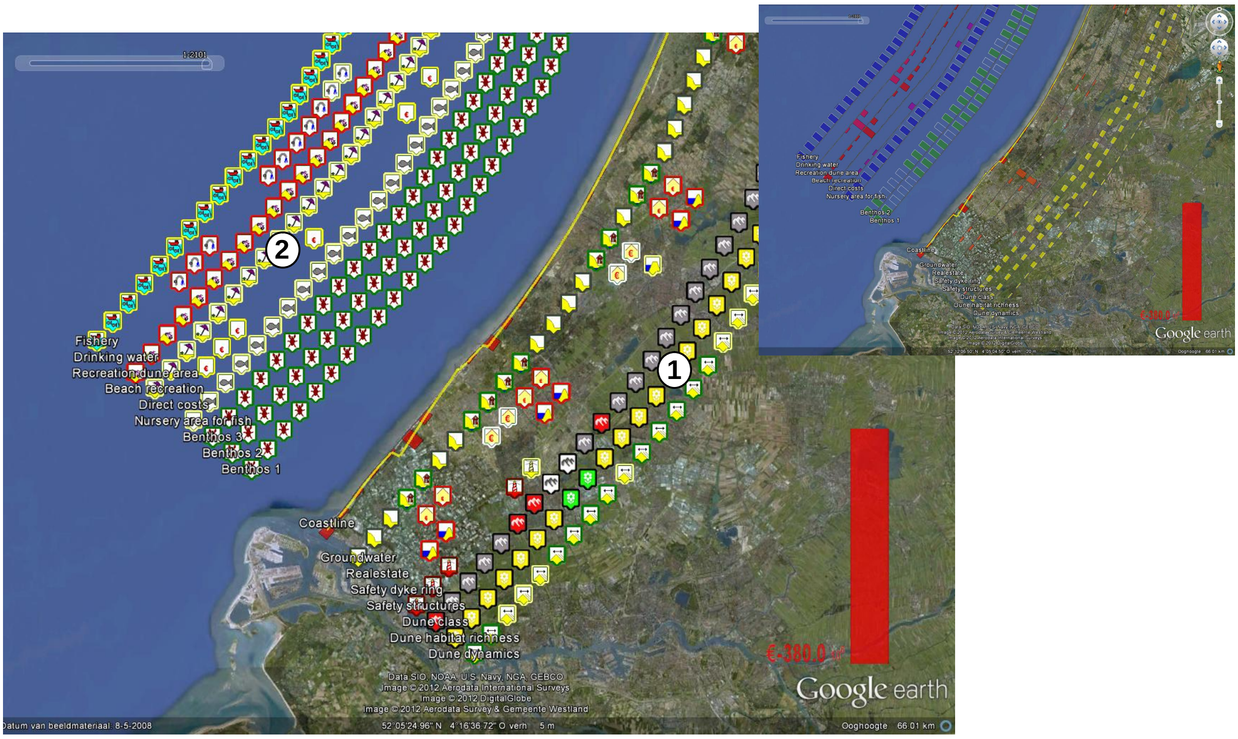

Figure 9: Coastal indicators for reference scenario 5 (Revetments).

6 Conclusions

The implementation of various coastal indicators is described in this document. A theoretical description of the method of valuing of these indicators is provided. Furthermore, an application for a test case then showed the proper functioning of the implemented changes.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
1.0 (Draft)	June 2012	B.J.A. Huisman W.P. de Boer		A.P. Luijendijk		K.J. Bos	

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