Decision making in Dutch coastal research based on coastal management policy assumptions

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Abstract
Rijkswaterstaat is the executive agency of the Ministry of Infrastructure and Water management in the Netherlands. Rijkswaterstaat is tasked with the operation and maintenance of the coast in relation to Coastal Flood and Erosion Risk Management (CFERM). The major part of this work is the nourishment of the coast with sediments to sustainably maintain coastal functions such as protection of the low-lying hinterland against flooding, infrastructure on the dunes and dune habitats. To help with this it continually refines and updates the coastal management policy and practice and leads multiple research programs.

To make sure that these research programs remain up to date and coherent Rijkswaterstaat uses the explicit and implicit strategic, tactical and operational CFERM goals and associated CFERM policy assumptions to guide them. In this paper we use a case study on the planning and implementation of government-initiated coastal research in the Netherlands, to demonstrate how this research feeds back into CFERM policy and practice. Finally we give examples of how the research has helped shape policy and practice.

Introduction
The Netherlands is positioned in the delta of the rivers Rhine, Meuse and Scheldt. Due to this geographical position the coast consists in the main of sediments, no natural bedrock exists, only man made hard structures. As a consequence the coast is by nature vulnerable to coastal erosion. In the Netherlands gradual coastal erosion is occurring due to sea level rise, natural redistribution of sand and human intervention. For longer time scales, this gradual erosion is anticipated to cause increased risk of flooding, erosion of dunes and their infrastructure together with the collective impacts on the natural environment, recreation and potable water extraction. The Netherlands therefore has a coastal erosion management policy aimed at compensating the sediment losses by means of nourishment of the beach or the shoreface. The total average annual volume of nourishment is currently set equal to the annual sediment deficit of the active coastal zone due to sea level rise. Following the current coastal management policy this sediment deficit is calculated by multiplying the area of the active coastal zone with the relative sea level rise at the Dutch coast. The active coastal zone being defined as the morphologically active zone on decadal to centennial time scales. Geographically this zone is defined between the -20m NAP depth contour (NAP is the Dutch ordinance datum, which is close to Mean Sea Level, MSL) and the most landward side of the coastal dunes. In Dutch policy and law this zone is given the term the Coastal Foundation (Kustfundament). This calculation results in an average volume of nourishment of 12 million cubic meters (Mm^3) per year. This nourishment is extracted from the bed of the North Sea, seaward of the Coastal Foundation, at water depths of 20 m or more.

All CFERM policies have underlying assumptions concerning not only natural system behaviour but also governance functioning (Hermans et al., 2013). In this paper we elaborate some of the assumptions underlying the Dutch CFERM policy since 2000, and demonstrate how testing these assumptions is helping the Dutch government to set up research programs that focus on refinement, adaptation and justification of coastal policy and practice. Finally we will illustrate how the results are feeding back into coastal policy and practice.

Coastal Flood and Erosion Risk Management Policy and Goals

The Netherlands has managed its coast for centuries due to the low lying position of the land and the high consequence of flooding. After centuries of gradual coastal retreat a new coastal flood and erosion risk management policy was implemented in 1990, termed: dynamic preservation of the Dutch coast (VenW, 1990). Dynamic preservation was defined as maintaining the coastline at its 1990 position by feeding the near shore zone and the beach with sand, while allowing for a certain degree of natural dynamics depending on the local function of the coast be it protection of the low-lying hinterland against flooding, infrastructure on the dunes or the dune habitats. For the implementation and monitoring of this policy the whole Dutch North Sea coastline is surveyed annually. These surveys are used for an annual assessment of trends in sediment volumes, which are assessed in relation to the 1990 reference volume. If needed nourishments are planned and carried out. In the nearly three decades since then the dynamic preservation policy has been in place. In 2000 the dynamic preservation policy was consolidated and expanded in the third coastal policy paper (VenW, 2000). Since 2001 not only sediment losses in the near shore but also in the deeper parts of the shoreface (i.e. the whole Coastal Foundation) are compensated through nourishment.

One of the first steps taken when initiating new CFERM research programs has been to determine the explicit and non-explicit assumptions associated with the current CFERM policy. For doing so it is important to distinguish between strategic, tactical and operational goals of the CFERM policy.

The strategic goal for the CFERM policy is to "*sustainably maintain the flood protection and sustainably preserve other functions of the dune areas*" (third coastal policy paper, Min. VenW, 2000, directly translated from Dutch). In other words, preserve the dunes so that they can sustainably function as natural flood defences for the flood prone hinterland (which is nearly everywhere below storm surge level or even MSL) and preserve functions on the dunes like infrastructure and habitats. To achieve these strategic goals a number of tactical goals have been set. These goals are not always explicitly listed in the relevant policy papers, but they can be deduced from the documents. The most important tactical goals are:

- Preservation of sediments in the active coastal system (no sediment extraction);
- Use soft solutions (e.g. sand) when possible, hard solutions (e.g. concrete structures) when needed;
- Keep the sediment budget of the whole coast in equilibrium with sea level rise.

To achieve these goals multiple operational goals have to be met. Examples are:

- Hold the line, the volume in a coastal transect should (in principle) be not less then the 1990 reference volume;
- Nourish 12 Mm^3 of sand to the coast annually, with sand extracted offshore seaward of the -20m NAP depth contour;
- Assess the probability of failure of coastal flood defences every 12 years;
- Allow for natural coastal dynamics when possible given coastal functions;
- Stop sand mining in the active coastal zone, i.e. the Coastal Foundation.

Figure 1 presents a triangle often used in the Dutch CFERM to visualise the hierarchy inherent to the strategic, tactical and operational goals.

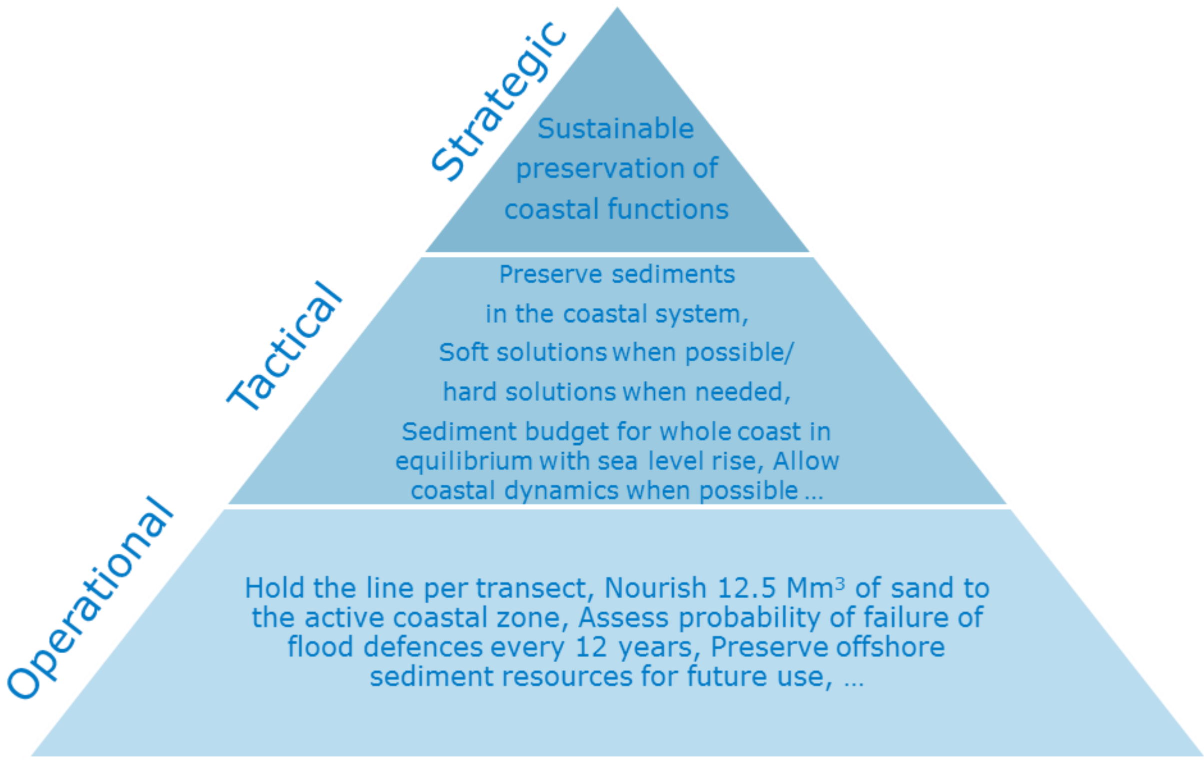

Figure 1: Strategic, Tactical and Operational goals for the Dutch Coastal Flood and Erosion Risk Management

Policy Assumptions

The long term coastal research programs of the Dutch government are focused on testing the assumptions and hypotheses that are associated with the strategic, tactical and operational CFERM goals. In principle many assumptions and hypotheses can be identified, especially when zooming in to the details of the tactical and operational goals. However, the number of main assumptions and key hypotheses is limited.

For example one of the main assumptions is that when operational goals are achieved, so are the tactical and strategic goals. For the purpose of this paper we elaborate some of the main assumptions that have guided us for example the ongoing research programs Coastal Genesis 2.0 and O&M Coast. The goal of this is not to be complete but to demonstrate how deducing and making policy goals and assumptions can help in setting up coherent research programs.

The projects used in this case study concern research programs initiated and led by the government. These projects are closely related but have different goals. The goal of the Coastal Genesis 2.0 project is to advise the Ministry of Infrastructure and Water management on possible new CFERM policy in 2020. The primary goal of the O&M Coast project is to inform and refine the implementation of the current CFERM policy. The total invested value of these projects is over 6M€.

Long term sediment budget of the Dutch coast and annual nourishment volume

As can be seen in Figure 1, one of the tactical goals of the Dutch CFERM policy is to keep the sediment budget for the whole active Dutch coast in equilibrium with sea level rise. To be able to quantify what should be done to reach this goal the following main research question needs to be answered:

- What is the sediment budget of the Dutch coast?

The following sub questions underlying this research question can be formulated:

- What were sediment budgets of the Dutch coast at geological and historical timescales?
- What are the dimensions of the Dutch active coastal zone?

- What is the annual sediment deficit in the coastal zone due to relative sea level rise?
- What is the gross and net sediment exchange between the open coast and the connected tidal basins and estuaries?
- What will the future sediment budget be?

Since not all of these research questions can be answered, with enough confidence, assumptions have been made for the sub questions and the main research question. These assumptions are the basis for the implementation of the current CFERM policy.

Since the third coastal policy paper (Min. VenW, 2000) was accepted by the parliament it has been assumed (based on the evidence then available, e.g. Mulder, 2000 and VenW, 1995 2nd Coastal Policy Paper) that the annual sediment budget of the Dutch coast is negative. The annual sediment deficit is assumed to be equal to the area of the active coastal zone, on a timescale of decades to 200 years, times the annual local relative sea level rise (Mulder, 2000, Nederbragt, 2005, Lodder, 2016). In total this amounts to a sediment deficit of 12.5 Mm^3 per year for the whole Dutch coast including the Wadden Sea and the Western Scheldt estuary. Based on this, it has been the aim to nourish the Dutch active coastal zone with on average 12 Mm^3 per year since 2001. In reality, on average 11 - 13 Mm^3 per year has been nourished since then, depending on which nourishments are taken into account (see figure 2).

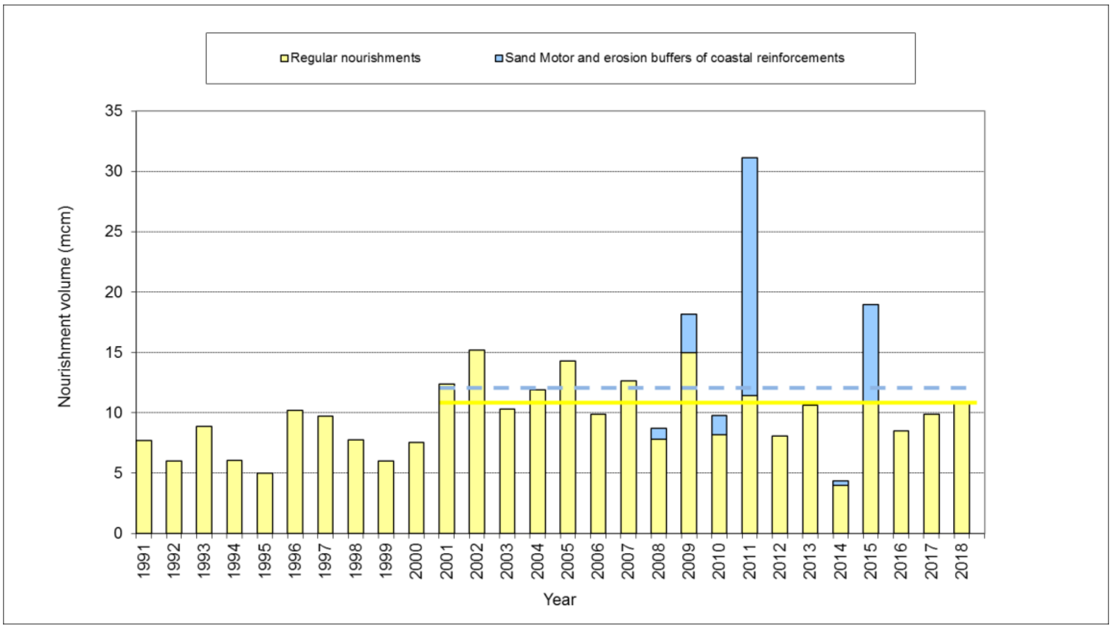

Figure 2: Nourishment volumes for whole of the Dutch Coast. Yellow bars, annual volume regular nourishments which are part of the national nourishment program. Blue bars, volume of nourishments that are not part of the national nourishment program. These nourishments include the Sand Motor (Stive et al., 2011) and the erosion buffers of coastal reinforcements that are part of the so called "Weak Links", coastal reinforcements program (2007 – 2016), (Min VenW, 2003, Algemene rekenkamer, 2009). Yellow solid line, average volume regular nourishments 2001 – 2018. Blue dashed line, average volume nourishments including the Sand Motor and the "Weak Links". Data by Rijkswaterstaat.

Distribution of nourished sand over the Coastal System

One of the other tactical goals of the Dutch CFERM policy is to keep the sediment budget for the whole Dutch coast in equilibrium with sea level rise. One of the assumptions related to the nourishment strategy, which aims to fulfil the tactical goals, is that on longer timescales nourished sediments spread naturally over the whole active coastal zone. By doing so it balances the negative sediment budgets of the coastal zone. To be able to validate this assumption the following research questions need to be answered:

- What nourishment volumes were placed, when and where?
- How have these nourishments spread over the coastal zone?
- How do these nourishments interact with the original morphological system?

From bathymetrical surveys and large scale volume analysis, carried out as part of the coastal research led by the Dutch government, it is known that the nourished sediments spread over large parts of the coastal zone. However, there is also evidence that the deeper parts of the shoreface do not receive (enough) nourished sediments or that these sediments are not able to compensate for the structural lowering of the shoreface (e.g. Elias et al., 2012; Van der Spek and Lodder, 2015; Elias et al., 2018). Figure 3 provides an example of a representative transect at the North Holland Coast where, despite frequent nourishments, lowering of the shoreface is happening. Since 1965 the isobaths from -11 m to -15 m NAP have migrated 150m landward. Despite the seemingly ongoing lowering of the shoreface, the applied nourishments have stopped the chronic coastal retreat of the beach and the dunes (e.g. van der Spek and Lodder, 2015; Mastbergen et al., 2018). So the observed lowering of the shoreface currently does not pose a threat for the stability of the nearshore zone including the dunes (that are natural flood defences). However, on longer timescales it could cause significant risks for the dunes. Therefore, based on these insights, morphological processes of the deeper shoreface are more intensively monitored and investigated in the Coastal Genesis 2.0 project and pilot nourishment was carried out at a depth of -10 to -11 m NAP in 2017. The morphological development of this nourishment will be monitored and evaluated in the O&M Coast project.

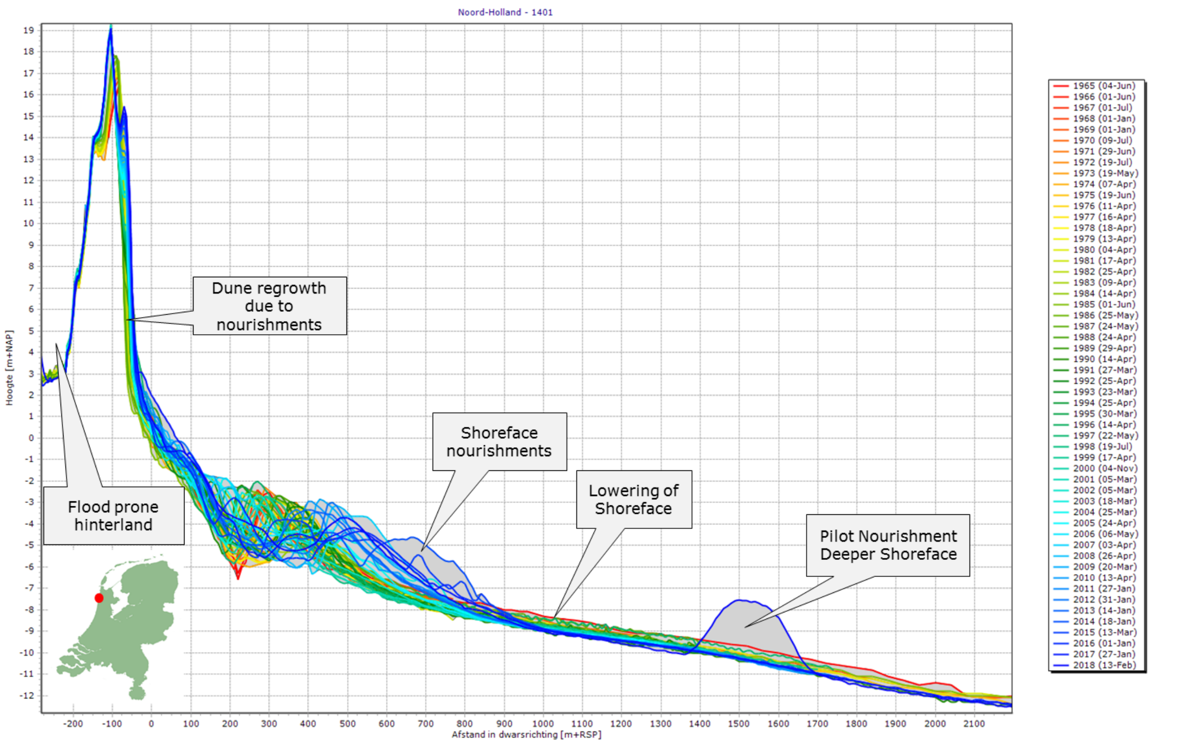

Figure 3: Example of Shoreface lowering, nourishments and dune regrowth at the North Holland coast, 13 km south of Den Helder (red dot). Each line is an annual survey (1965-2018).

From assumptions to research programs

As mentioned earlier, the Dutch government leads multiple long-term research programs that aim to inform, refine and update coastal management policy and practice. In Table 1 we provide examples of the main policy assumptions, how these are tested, results of the tests and their effects on shaping policy and practice.

Table 1: Overview of selected policy assumptions and the research done to test these assumptions

Policy assumption	**Research type and methods**	**Example results**	**Example effects on policy and practice**	**Example references**
Annual sediment deficit is equal	- Annual bathymetrical surveys	- Lowering of Shoreface is happening	- Intensified monitoring of the Shoreface	- Elias et al., 2012 - Elias et al., 2017

to the area of the active coastal zone times local relative sea level rise	- Sediment budget analysis - Gauge station water level statistics - Small scale and large scale subsidence monitoring and modelling - Hydro- and morphodynamic measurements modelling of the shoreface	despite nourishments - Sediment deficit is larger then the area of the active coastal zone times local relative sea level rise due to sediment export from the coastal zone into tidal basins and estuaries - Geological and anthropogenic subsidence significantly influences the long term sediment deficit of the coastal zone	- Pilot nourishment placed on deeper part of the Shoreface (2017) - Intensified monitoring and modelling of tidal inlets to better understand the role of tidal inlets on the sediment deficits on the coastal zone - Assessment studies on the need for nourishments to compensate effects of subsidence on the coastal zone	- Van der Spek and Lodder, 2015 - Baart et al., 2019 - Hijma et al., 2018 - Grasmeijer et al., 2018
Sediment export from the North Sea coast to the Wadden Sea Basins is equal to the basin area times local relative sea level rise	- Annual bathymetrical surveys - Sediment budget analysis - Sediment sampling and tracking around the tidal inlets - Hydro- and morphodynamic measurements and modelling of tidal inlets (Ameland inlet)	- The Wadden Sea is an important sink for sediments in the coastal system. The sediment export is also largely dependent on anthropogenic changes in the Wadden Sea Basins - Improved insights in possible and probable pathways for nourished sands - Improved insight in large scale morphological tidal inlet processes like cyclic channel shifting and shoal migration	- Pilot nourishment of 5 Mm^3 placed at the Ameland tidal inlet (2018) - Refined nourishment strategy for Ameland mainland coast - Possible future adjustment of annual nourishment volume, decision foreseen 2020/2021	- Wang, 2018 - Elias, 2018 - Wang et al., 2018
Nourished sediments spread naturally over the whole active coastal zone	- Dedicated surveys of shoreface nourishments, up to 6 years after placement - Sediment budget analysis of nourishments	- Sand nourished on the Shoreface spreads naturally over large parts of the active coastal zone including the near shore and beach. In many places Shoreface	- Shoreface nourishments have become the preferred nourishment method for large parts of the Dutch coast, reducing costs and impact on beach use	- Vermaas et al., 2017 - Bruins, 2016 - Lodder and Sørensen, 2015

		nourishments are able to stop chronical erosion of the beach and dunes	- Upscaling in nourishment volume and size including the Sand Motor pilot nourishment	

Multiple uses of research

While doing more "fundamental' research to test the policy assumptions a knowledge base is generated which is actively used for more practical and shorter term coastal management issues and projects. In this way research is informing long-term policy refinement but also short-term "on the ground" coastal management. For example, insights in the large scale dynamics of the Wadden Sea ebb tidal deltas (Elias et al., 2012, 2017, 2018) is actively being used for Coastal Management. The timing and amounts for nourishment at the up- and downdrift sides of the Dutch Wadden Islands Texel, Vlieland, Terschelling, Ameland and Schiermonnikoog are determined based on these insights.

From testing assumptions to policy refinement

The ultimate goal of our coastal research is to test the CFERM policy assumptions. When it is clear that policy assumptions should be revised based on the results of the research a process is started to advise political decision makers on policy adjustments. This eventually may lead to a new formal CFERM policy which is then embedded in a policy paper. With the implementation of new CFERM policy, new strategic, tactical and operational goals might need to be set. With these goals new explicit and implicit assumptions are set. Then in setting up new research to test the new assumptions the policy refinement loop is restarted.

The presented case study shows how explicit and implicit strategic, tactical and operational CFERM goals and the associated CFERM policy assumptions can be used to guide research programs that focus on refinement, adaptation and justification of coastal policy and practice. The results of these research programs have helped the Dutch government making the decisions needed to continually refine and adapt coastal Flood Risk and Erosion Management Policy. The research conducted in the previous years and decades have demonstrably resulted in shaping Dutch coastal policy and practice.

Weblinks

Coastal Genesis 2.0 (mostly in Dutch, linked reports mostly in English):
https://www.helpdeskwater.nl/onderwerpen/waterveiligheid/programma-projecten/kustgenese-2-0/

O&M Coast (Beheer en Onderhoud Kust, mostly in Dutch, linked reports partly in English):
https://www.helpdeskwater.nl/onderwerpen/waterveiligheid/programma-projecten/beheer-onderhoud/

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