Ecological Landscaping of Extraction Sites (HK2.1)

FINAL REPORT:

Design and creation of a landscaped pilot extraction site in the North Sea

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1 Introduction

1.1 Context: Expected Increase in Coastal Nourishments

Coastal development and management in The Netherlands is heavily based on dynamic sand nourishment programmes where possible combined with new (seawards) land development. The expected sea level rise will require an up-scaling of nourishment activities to be able to maintain the current safety level. These nourishments are usually combined with quality enhancement of the coastal living communities, recreational- and protected nature areas. It is expected that the current 12 Mm^3 of sand needed to maintain the coast each year will rise to 40-80Mm^3/year.

This large amount of sand will be dredged from sand extraction sites in the North Sea. The expected scale-increase demands more and larger extraction sites. Although in the short term the dredging will affect the natural seabed and its inhabitants (they are effectively removed), the increase of the dimensions of the extraction sites offers unique opportunities to develop these sites for more than just extraction of sand. Using an ecosystem based approach through an ecological design, realization and using natural processes, the supposed ecological threats may turned into sustainable opportunities.

This pilot project acknowledges these opportunities and approaches the development of sand extraction sites from an alternative point of view. It considers the new conditions to be an opportunity and values the changed physical conditions as a new environment that can trigger the development of new ecological habitats.

1.2 Goal of the Pilot Project: Second Life for Extraction Sites

The ultimate goal is to combine ecology (nature) & economy thereby creating mutual benefit. This project aims at designing and organizing two landscaped pilot locations in a large scale extraction site to research the potential of the ecological development (increase in biodiversity) in the site. The project searches for the best ways to design and create the landscapes so that when extraction is finished, ecology can optimally benefit from the resultant underwater landscape.

Where possible, requirements and technical parameters that are needed in the design are determined and listed. The pilot sites allow for them to be tested in a real life situation to ensure that the final Building with Nature design guidelines are realistic and technically feasible.

In addition to the technical content, the project aims at increasing the awareness for the potential to gain ecological benefits through the designing and landscaping of extraction sites.

The ecological effect of the landscaped physical gradients, i.e. the development of the benthos and fish are studied in another project through a multi-year monitoring programme.

1.3 Project Approach

The project followed several steps aimed at organizing, designing and creating a pilot sand extraction site. These steps are described below and have been used as chapter titles in the report.

<u>Initiation Phase</u>

1. Problem definition and aim of the project. Based on the idea of landscaping the sand extraction sites, the project team brainstormed on which aspects / benefits were considered to be most important (biodiversity) and how the best design and location could be chosen to achieve this;
2. Literature research on previous studies to be used as reference, lessons learned and background data in the project;

3. Study on current Dutch policy and juridical opportunities and restrictions to determine if and how the landscaping could be implemented in new or existing permits;
4. Start search for most suitable location;
5. Stakeholder involvement. After the preliminary stages, a workshop was held to involve the various stakeholders and (international) experts in the project. The chosen aim, location, approach and expected results were discussed and adapted were necessary based on experiences and expert judgement of the stakeholders

Planning and Design Phase

6. Choose extraction site for pilot locations (together with stakeholders)
7. Determine design parameters and points of departure
8. Design landscape shapes (bed forms)
9. Position chosen designs in extraction site
10. Carry out morphological modelling to determine stability and development through time
11. Discuss results with stakeholders
12. Make final design

Construction Phase

13. Inform regulators about pilots
14. Integrate final design in contractor dredging plan
15. Monitor creation of bedforms and confer with contractor and captains of the dredging vessels on workability (practical experiences)

Post-Construction Phase

16. Deliver input for the monitoring programme that will be carried out in a different project.

1.4 Building with Nature Programme

Building with Nature is a five-year innovation and research programme (2008-2012) carried out by the Foundation EcoShape (www.ecoshape.nl). This 30 million Euro program is initiated by the Dutch dredging industry, while partners represent academia, research institutes, consultancies, NGO's and public parties.

The program aims to develop knowledge for the sustainable development of coasts, deltas and rivers by combining practical hands-on experience with state-of-the-art technical and scientific knowledge on the functioning of the ecosystem and its interaction with infrastructures. The key is that infrastructure solutions are sought that utilise and at the same time enhance the natural system, such that ecological and economic interests strengthen each other. It represents the next step in the development of hydraulic engineering: attribute a more active role to natural processes by utilising them, while at the same time creating opportunities for development of new nature: building with nature. The programme searches for ways to instigate a paradigm shift: from building in nature, via building of nature to building with nature. The credo is no longer "*doing less bad*", but has become "*doing more good*".

This approach is reflected in the five program objectives:

1. Develop ecosystem knowledge enabling Building with Nature
2. Develop scientifically sound design rules and norms
3. Develop expertise to apply the BwN concept
4. Make the concept tangible using practical BwN-examples
5. Establish how to bring the BwN-concept forward in society and make it happen

These objectives have been translated into a tailor-made BwN-approach that reflects the notion that from an overall project performance point of view, the best choices are not necessarily the ones that fit best to the individual project phases (early project planning, design, construction, post-construction). Rather we should search for a balance between long-term costs and benefits, in monetary and non-monetary terms.

The term Ecodynamic Development and Design is used to refer to this alternative ecosystem-based design approach. The ecosystem-based approach boils down to:

- Understand the functioning of the system, 'read' the ecosystem, the socio-economic system and the governance system;
- Plan a project or activity taking the system's present and envisaged functions into account, combining functional and ecological specifications;
- Determine how natural processes can be used and stimulated to achieve the project goals and others using the power of nature;
- Determine how governance processes can be used and stimulated to achieve the project goals using the ‘power structures’ in place;
- Monitor the environment during execution, analyse the results statistically, make risk-assessments, if necessary adapt the monitoring program and/or the project execution i.e. monitoring and adaptive management; and
- Monitor the environment after completion, as to assess the project's performance and to learn for future knowledge development.

The core of the program centres around four cases: Holland Coast, Southwest Delta and the Marker- and IJssel Lakes in The Netherlands, plus case Singapore in a tropical environment. Generic research on governance-related topics and nature sciences is carried out by a group of 20 PhD researchers. Throughout the program the interaction between disciplines is promoted, involving ecologists, engineers and policy makers.

The work comes together in a work package called Ecodynamic Development & Design (EDD) that will draft a guideline for ecodynamic design of a.o. marine infrastructure projects. Results will become publicly available throughout the course of the programme, with completion of the design guideline envisaged for December 2012.

1.4.1 BwN and the HK2.1 project

The essence of the Building with Nature philosophy is applied in this project. The involvement of all related stakeholders in the early design stage of the project ensured that an optimally balanced design was made within the range available. The engineers, ecologists, contractors and permitting authorities worked together to find the best possible solution for the existing situation taking into account the current planning, finances, permits, etc.

Furthermore, all BwN key elements were incorporated in the design from the start of the project: ecological benefits, practical engineering, realistic costs and governance issues (involvement of stakeholders).

1.4.2 Links to other BwN Cases and Projects

The project is primarily linked to the cases Dutch Coast and Adaptive Monitoring Strategies. Results from the study are being used in the following work packages and vice versa:

- All work packages of Holland Coast (link to extraction site of the Sand Engine Project) and in particular HK2.3 Monitoring and HK 2.4 Modelling
- Generic BwN research EDD
- Generic BwN research Governance
- Generic BwN research High resolution Monitoring and in particular AMS 3

The physical design is made so as to use the natural processes to enhance the ecological value of the extraction site after dredging is finished.

1.5 Project Team

The constitution of the team was carefully selected to reflect the different expertise areas. The project manager was responsible for the overall coordination including communication with the stakeholders, organizing workshops and reporting in general.

The team consisted of the following members:

Name	Position / expertise	Company
Daan Rijks	Project manager	Boskalis
Stefan Aarninkhof	Morphology, HK Case Study Leader	EcoShape / Boskalis
Martin Baptist	Marine ecology	IMARES
Wilbur van Beijnen	System Engineering (contracts)	Rijkswaterstaat DI
Koos Boom	Dredging contractor	PUMA
Jan van Dalfsen	Benthic ecologist	Deltares
Jasper Fiselier	Coastal morphology and ecology	DHV
Kris Lulofs	Policy and Juridical framework	University Twente
Pieter Roos	Large scale morphodynamics	University Twente

1.6 Acknowledgements

The team would like to thank all parties involved in making the pilot site possible. The positive collaboration and contributions, technical feedback, innovative suggestions and great efforts made by the stakeholders were essential in making this project a success.

The stakeholders involved are:

- The Contractor PUMA (Joint Venture Boskalis and Van Oord) for putting the Maasvlakte 2 extraction site at our disposal, assisting in making a realistic design for the sand ridges and for creating the sand ridges. Without their support this pilot project could not have been realized so quickly and at such a scale. A special thanks to the captains of the dredging ships involved in creating the sand ridges and for their feedback concerning the workability of our designs and suggestions for improvements;
- The Port of Rotterdam is responsible for the construction of the Maasvlakte 2 and kindly allowed the pilot to take place in their extraction site. They actively took part in the technical and juridical discussions and put their considerable expertise, knowledge and data on the coastal area in and around the extraction site at our disposal;
- The Ministry of Transport, Public Works and Water Management, Directorate-General for Public Works and Water Management (Rijkswaterstaat Dienst Noordzee) who is responsible for granting the permits in the extraction area. They also put their impressive knowledge on the Dutch coastal and ecological system and (legal) permit requirements at our disposal;
- EcoShape for assisting in organizing the workshops, inviting stakeholders, making the BwN information available and in providing office support and facilities.

Finally, we would like to thank the many other experts from within and outside the Building with Nature Programme that joined the technical workshops and contributed to the brainstorm sessions.

2 Initiation Phase

2.1 Introduction

The discussion on landscaping extraction sites was started several years ago. It was clear that the full potential of the extraction sites was not being used. At the same time, it was recognized that more research / knowledge was needed on the colonisation processes of sand extraction sites in time. This project was an ideal opportunity to combine the two research topics.

Traditionally, the size, shape and location of extraction sites were determined based on the following main geographical, geological, and physical aspects (in that order):

1. Size: from superficial extraction sites of only a few meters deep to very deep sites of 20m in depth (in relation to seabed);
2. Shape: depends on the depth of the extraction site, the available area in which the site can be excavated, the orientation in relation to the hydraulic situation and the expected work methods when sand of sufficient quality and quantity has been found;
3. Location: prone to spatial limitations such as cable buffer zones, natural reserves, shipwreck locations, paleo morphological objects, military zones etc.

The above listed variables were mostly fixed in permits allowing for little variation. Ecology, with the exception of the expected rehabilitation period, was not one of the main issues.

For the larger extraction sites (>10Mm^3), the basis of the choices / requirements in the permits were made via an EIA report and procedure. These reports generally classify extraction sites to have a negative impact on the local North Sea environment. The general approach was that during the construction of the site, the top layer of sand and its 'inhabitants' (benthos) were removed and replaced with a deeper area with potentially different sediment characteristics. The EIA evaluation considered this to be a negative impact that required a rehabilitation period of 4-6 years.

In the past the mitigation measure was to create shallow extraction sites of maximum 2m depth so that colonisation could take place in similar hydraulic and morphological conditions. However, due to the scale increase in required sand volumes, maintaining a maximum of 2m deep extractions would lead to very large surface areas for the sites. In combination with new research on deeper extraction sites, the perception changed and deeper sites were allowed as they required less surface area in comparison to the larger, more shallow sites.

2.2 Genesis of the Concept of Landscaped Extraction Sites

The combination of dredging and ecological development has been recognized over a longer period of time. In many cases, dredging and managed disposal of dredged material are used as tools to create new environments for nature development. However, these were often dedicated projects which aimed at the actual development of nature.

2.2.1 Changing perceptions

In recent years, the perception or design approach of coastal development and water-related infrastructure projects has changed. It started with stakeholders and engineers searching for additional opportunities that could be integrated in a project to enhance the final quality without compromising the main 'function' of the project e.g. coastal nourishment in combination with natural dune development or Harbour expansion projects in combination with beach recreation and fish migration routes. Building with Nature goes a step further, in addition to looking at opportunities to enhance the natural value of the project, the project team searches for ways to build with nature i.e. use nature in the construction and later on operation of the project.

In this project, the natural processes are taken into account during the early stages of the design phase as an engineering technique in order to develop the desired functions of a project. Ideally, the project investigates if the (long-term) natural morphological behaviour of the sand ridges (including any changes in sediment constitutions) will help in the development of the ecological habitats.

The philosophy also leads to interesting discussions on using the potential of the new physical characteristics of the extraction sites once sand mining was finished. One of the main focuses of these (ongoing) discussions concerned the choice for rehabilitating the existing habitat versus the creation of new habitats after the project has been completed. I.e. is it better to return the site to its original situation or to create a potential \for a different development with the possibility to enhance local biodiversity and more biomass. Moreover, the question is raised if such a choice is linked to a minimum size and volume of the extraction sites in order to allow for a feasible / measureable different development?

In addition to the ecological and technical considerations, many of the preliminary discussions also concerned the increase of the overall costs when introducing a new function (ecological development) to the project. How can you keep additional costs as low as possible whilst obtaining maximal ecological benefits? And how do you value the added benefits (nature valuation)? Are project owners prepared to pay more for sustainable sand extraction?

This project offers all stakeholders from project initiators and owners to engineers, permit authorities and contractors the opportunity to investigate the added value and consequences of integrating the ecological function (landscaping) in an existing infrastructure project through a hands-on pilot project.

2.2.2 Ecological Background: Basis for the Landscaping

Marine seabed research revealed that different habitats exist related to variations in seabed morphology, hydrodynamic conditions, water depth and sediment composition. Ecological research on tidal ridges shows that there are differences in the benthic community composition of the trough, slope and crest of the ridge. The figure below shows this relationship [1] Baptist et al 2006 [2] Van Dijk et al 2007.

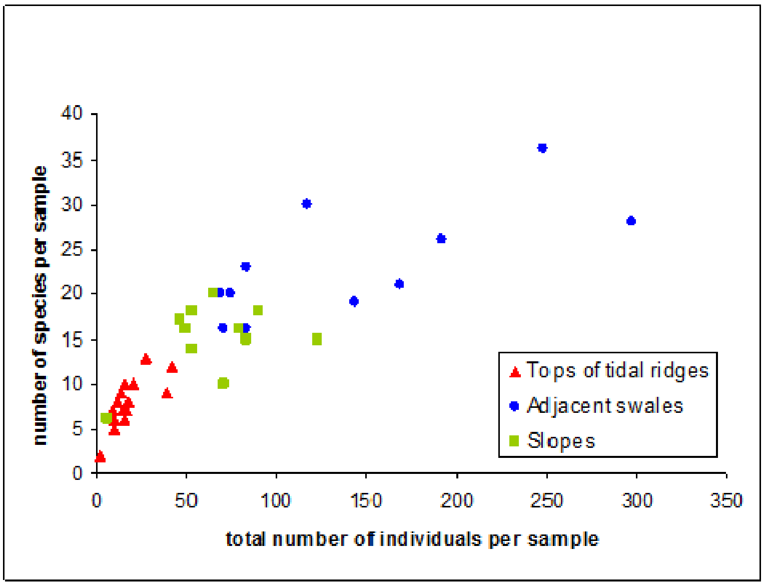

Figure 2-1: Relation between number of species and densities of macrobenthic organisms over tidal ridges (Van Dijk et al. 2007)

There is a general but distinct zonation over tidal ridges in which the sandy crests accommodate relative poor benthic communities and the adjacent slopes and troughs are characterized by communities having larger number of individuals and species. Especially the more muddy troughs are richer in biodiversity and often include shellfish species which increase the total biomass in the area. Benthic organisms are an important food source and as the species also differ in the these zones this attracts different animals such as various fish species. This shows that physical gradients, including bed forms on the sea bed have a positive effect on the overall biodiversity and biomass, also compared to adjacent relatively flat areas. Landscaping of an extraction site aimed at increasing variations in the physical parameters as morphology and hydrodynamic conditions is therefore expected to have a similar effect on the biological components of an area.

In consultation with marine ecologists, it was decided to incorporate these gradients in the design of the landscape for the pilot locations. It is expected that these gradients will have a positive effect on the stimulation of biodiversity and biomass although water depth may also be an important factor. The gradients will be made as large as possible to accentuate any potential for differences. This will assist in determining the actual effects of the gradients with a higher level of accuracy and significance.

2.2.3 Expected Mutual Benefits

The development of the sand extraction site can have mutual benefits for different functions:

1. Nature / ecology (Benthos, Fish, Birds, Sea mammals)
    - Recovery of the seabed and its accompanying communities;
    - Increasing biodiversity in the area;
    - Protection of threatened or endangered species by creating tailor-made resting and spawning areas;
2. Social / Recreation:
    - Creating attractive diving or sport fishing sites
3. Economy:
    - Fisheries: creating habitats that will attract specific types of commercially interesting fish and shellfish (productive fishing grounds);
    - Mining: mine only specific pockets containing desired types of sand, gravel, ore, etc. and leave behind bedforms containing unusable materials.

As described further on in the report (chapter 3.4), this project concentrates on the function ecological habitat development and in particular the increasing of biodiversity, whilst keeping in mind potential attraction for certain types of economically interesting fish.

In addition, the research carried out within the project will be beneficial to more than just the predefined goal of creating a landscaped extraction site. The most important expected results are listed below:

- Increasing the general understanding of the ecosystem in extraction sites. The new data will help allow future EIA reports to be based on proven data instead of theoretical considerations;
- Shortening the current time needed to draft EIA reports and permit procedures by providing a real time example that can be used as reference;
- Changing the traditional view on extraction sites by proving the potential for the enhancement of the ecological value of extraction sites in general;
- Through testing of design parameters, making sure that future designs are realistic and not too costly;
- Offer a unique opportunity for all stakeholders to work together and create an integrated, well-balanced design taking the interests of all stakeholders into account.

2.3 Dutch Legislation and Potential for Landscaping

One of the first steps in the pilot project was to determine if the landscaping could be carried out within the existing Dutch legislation. A desk study was carried out identifying and analysing the opportunities and obstacles in the existing juridical framework and licensing procedures related to extraction sites in national waters (the Netherlands). Policy and legal requirements were assessed by the extent to which and the way in which they stimulate or impede the development of underwater landscaping considering technical dredging aspects and opportunities for the natural environment.

2.3.1 Current legislation

The direct applicable regulations are the *Ontgrondingenwet (OW)*, the *Rijksreglement Ontgrondingen (RRO)* and the *Besluit Ontgrondingen*. The first document is the central formal law, the latter two pieces of regulation related to the formal law. In most cases they further specify general articles in the formal law.

In addition to these regulations, pseudo-regulations are relevant such as plans and policy documents. They normally express intentions, interpretations and ‘soft requirements’, in this case with regard to extraction in the North Sea. The most prominent document was the *Tweede Regionale Ontgrondingenplan Noordzee (RON2 - Regional Plan Extractions North Sea)*. This document has been replaced with a series of guidelines on sand mining in the North Sea called ‘Beleidsregels ontgrondingen in rijkswateren’ from 28 September 2010.

In principle, extractions of sand in Dutch North Sea territory are forbidden on the basis of the above mentioned regulations. However there are a few very important exceptions:

1. The first important exception to the general ban is when actors have a license. In principle anyone can ask for a license to extract sand. The law instructs the licenser to consider interests that are affected by sand extraction and to deliberate and weigh them before issuing a license. The licenser should also consider specific requirements that might be included to protect certain interests. There are several documents that focus on sand extraction in the North Sea:
    - *Integraal Beheerplan Noordzee 2015 (Integral Management Plan North-Sea 2015)* which addresses all North-sea user rights and considers among others zoning (which areas can be licensed for extraction),
    - *Nota Ruimte,* a spatial planning policy document; and,
    - *Mijnwet*, the law with regard to extracting minerals, is relevant with regard to some details.

   There are also some international European Directives relevant within the National 12 miles coastal zone: the European Bird-protection and Habitat Directive and Natura 2000 (biodiversity). These play a significant role as they are implemented in the Dutch *Natuurbeschermingswet (Nbw)* and the *Flora and Fauna Faunawet* (Ffw). International treaties such as the OSPAR-treaty (toxic substances) for protection of the marine environment and MARPOL (emissions by vessels) of course are relevant but are considered as business as usual.
2. Next to the license there is a second category of exceptions to the general extraction ban. This is the legal impart or notification of planned extraction activities. This procedure applies to testing of minerals and research for mining possibilities. This notification (instead of a license) is sufficient if the distance requirements kept to objects are respected and no more than 40.000 m^3 is extracted in no more than ten vessel journeys. Obviously these volumes are by far insufficient for larger nourishments. Therefore the details of these procedures are outside the scope of this project.

In principle, the licensing authority might choose not to comply with the instructions in the above listed documents. However stakeholders can raise objections and appeal to administrative court with regard to a the authorities’ decision. Deliberations and weighting of interests and arguments in court will be done largely on the basis of arguments derived from the same documents that have been considered by the licenser.

2.3.2 Permit Requirements: Constraints for Sand Extraction in the North Sea

The permit requirements cover the following aspects:

1. <u>Extraction volume</u> There are no hard constraints with regard to the amount of sand that can be extracted. However, licenses will state maximum amount allowable;
2. <u>Location</u>: predominantly linked to minimizing transportation distances. The current policy allows only for sand-extractions from the -20 meters depth line seawards. Within the –20 meters depth line extraction is only allowed for maintenance purposes. Between the -20 and –22 depth lines, the area is reserved for future small extractions for coastal defence. It is unlikely that sand-extraction is permitted outside the Dutch Territorial Sea (12 sea-

miles zone) as the *Integraal Beheerplan Noordzee 2015* states that seawards from the 12 miles zone the priority will be on wind parks and not on sand-extraction. Furthermore, it is unlikely that licences will be given for areas that have been designated as areas of special natural and ecological value.
Finally, a buffer zone needs to be taken into account with respect to cables, pipelines, military areas, wind turbine parks, wrecks etc. For mining up to 2 meter depth a distance of 500 meter is required, deeper sites require a larger buffer distance;

3. <u>Size</u>: Size comes with legal consequences. An Environmental Impact Assessment (EIA) is required if an extraction or a series of nearby extractions taken together, exceed 500 hectares or exceed 10 Mm^3 of sand to be extracted. The 10 Mm^3 equals a surface of 500 hectares being extracted to 2 meters;
4. <u>Depth and Shape</u>: The current legal and policy settings make deep sand extraction sites possible and desirable. Generally speaking, in recent years there has been a shift from large scale shallow sand extraction sites (max. 2m) to deeper sites (>10m). The reasoning is that the removal of the same amount of sand in a shallow site means the disturbance of a much larger surface area and thus more benthos than for a deeper site with a smaller surface area. A deeper site minimizes the effects. However, requirements are often noted for maximum allowed depth and related slopes to ensure no oxygen depleted water occurs at the bottom of the site;
5. <u>Work methods</u>: In the North Sea, the most efficient method is usually a Trailer Suction Hopper Dredger (TSHD). Licensees need to submit a work plan to the licensers describing their work methods and equipment choice for consideration and acceptance.
6. <u>Time frames</u>: No constraints are given to work in the sand extraction sites, mostly the constraints are related to the onshore works (e.g. recreational season, nesting- and spawning seasons etc);
7. <u>Required situation in which the site should be left behind</u>: For deep extraction sites, the law stipulates that the contractor should leave the site in such a condition that the deeper, larger grain size sand used for concrete and masonry can be mined;
8. <u>Other site specific considerations</u>.

At the moment, there is an ongoing national and European discussion on the protection of the marine ecosystem. New seabed areas are being designated as Natura2000 protected areas. Furthermore, the Water Framework Directive is being expanded into the sea (Marine Strategy Framework Directive). Both these regulations aim at creating and maintaining a healthy environment for ecological development, but limit the possibilities of sand extraction unless under very strict regulations. It will be interesting to see whether an ecologically landscaped sand extraction site can function as compensation areas for sand mining and/or land reclamation.

2.3.3 Results for Landscaping Potential in current Legislation

It can be stated that there are no clearly defined regulations for the way in which the sand extraction site should be left after mining has finished. The exception is the regulation that states that no stratification is allowed that could lead to anaerobe circumstances at the bottom of the site (constraint on Depth and Shape). Furthermore, the ‘conventional’ Dutch permit regulations aim to restore the ecosystem according to the T-0 reference situation, something that can only be achievedwith shallow (2m) extraction sites and not with deeper extraction sites (10-20m). Finally, in some cases, the permits state that the bottom must be levelled after mining is finished similar to the pre-extraction situation (T-0).

Therefore the study concluded that landscaping is possible in the context of discretionary room in at least some contemporary permits for deep extraction sites; and in principle will not be rejected for new sand extraction sites in the North Sea.

For this project, a license had already been given. From discussions with experts and stakeholders, it was concluded that the landscaping could be done by integrating the ecological landscaping plans into the current contractor Work Plan. As long as the design of the landscape remains within the general requirements of the permit, no problems were foreseen.

2.4 Literature Study

At the start of the project (2008), an inventory was made of previous research and literature related to the general topic of sand extraction sites and bed form dynamics. The aim was to create an overview of what has been done up to now and by whom and to find any relevant design parameters and experiences that could be used as a basis for this project.

The study searched for:

- Studies that looked at the extent to which the shape and contours of extraction sites can be landscaped to benefit both nature/ecology and economy;
- Ecologically friendly alternatives that create opportunities for the environment without having an unacceptable drawback on the dredging activity;
- Studies on geometry of the sand extraction area after the cessation of dredging; and
- Projects that stimulate the recovery of benthic life (benthos) at the bottom of an extraction site.

2.4.1 Results

In the literature, the major link between ecological and physical aspects focussed on:

1. The relation between the fines content of the soils and the benthos;
2. The relation between bed forms and presence of benthos.

The main ecological aspects studied in relation to the extraction sites are:

3. Deposition of fines in a sand extraction site;
4. Potential and effects of oxygen depletion at the bottom of the extraction site;
5. Effects of sediment composition and morphology on ecology
6. Time scale of the recovery of benthic communities
7. Effect of increase in water depth on ecology

The main physical aspects studied in relation to sand extraction sites are:

8. Hydraulic response
9. Morphological impact
10. Sediment composition
11. Oxygen concentration
12. Deposition of fines

2.4.2 Main Conclusions

The results of the study were analysed and translated to the potential of creating a landscaped extraction site. The following conclusions were drawn when looking at deep extraction sites (>10m below the existing seabed with more than >30m water depth):

a) There is no oxygen depletion if the slopes are gentle enough and the shape, orientation and location of the site with respect to the main current direction is designed in the right way;
b) The site experiences little to no migration as hydraulic conditions are mild and related sediment transport and sedimentation and erosion processes are very slow (time-scale of decades). Any morphological landscapes (including the larger sand ridges) created in the extraction site will remain relatively stable and in the site for long periods of time, allowing for the development of benthos and other related ecological habitats;
c) The recovery time of benthos and ecological habitats is on average 3-4 years even in larger water depths. This means that a pilot experiment with a duration of 4-5 years is enough to monitor and measure results;
d) The creation of sand ridges in the site by removing the sand in between (reverse landscaping) will lead to a natural distribution of sediment grain sizes with coarser sands on the tops and fine sediment in the troughs (as a result of overflow from the dredging equipment

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2.5 Relevant examples from abroad

During the design phase of the project, the search for relevant examples continued. Whenever possible, experts were asked if they knew of any similar projects and what their experiences were concerning landscaping. This was done on a personal basis, but also during and after several presentations on the project given at (inter)national conferences and seminars.

This resulted in the identification of several relevant projects that aimed for a similar end result but were initiated specifically to create a natural habitat.

Examples of projects are;

1. Seine Estuary cooperation between dredging and fishing industries
2. Creating shallow mounds for fish spawning (USACE, Louisiana)
3. Construction of Artificial Reefs in Japan (2010)

Ad.1: Seine Estuary cooperation between dredging and fishing industries (Michel Desprez)

This is a unique cooperation between the French dredging and fishing sectors in the Seine Bay. Researchers proved that dredging the gravel/pebbles caused a change in the sediment constitution of the bottom (more sand and silt) that attracted different types of fish. As the fishermen are eager to fish there, they swap working areas instead of litigating. The two sectors now collaborate and coordinate their actions so that there is maximal mutual benefits and no hinder of each others' activities.

Ad 2. Creating shallow mounds for fish spawning (USACE, Louisiana)

Beneficial re-use of dredged material to create mounds in shallow waters that can be used as refuge and spawning areas for fish (USACE).

Ad. 3: Construction of Artificial Undersea Ridges in Japan (2010)

A 15m high and ca. 300m long artificial stone undersea ridge was created in 70-80m of water depth to cause upwelling of the nutrient-rich deep-water. The ridges are spaced at 60-80m apart about 8 miles offshore of the Shin-Nagasaki Fishing Port.

The idea is that the upwelling "provides an advantageous environment for the development of a highly productive food chain and therefore rich fishery". This is an example of underwater landscaping that influences the hydrodynamics of the natural system to supply the surface layers with nutrient rich water and create chances for the development of phytoplankton and subsequently fish.

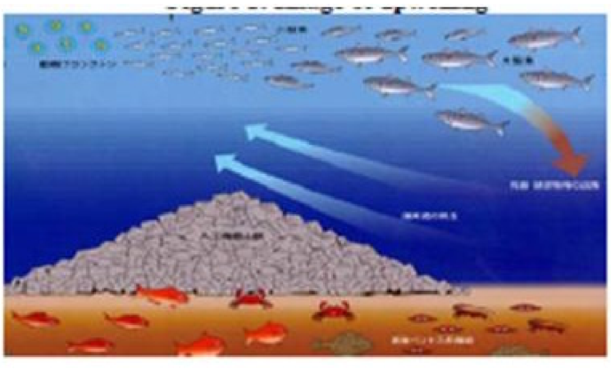


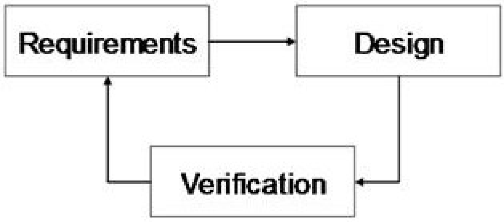
Figure 2-2: schematic figure showing the predicted effect of the underwater searidge on upwelling of current

More information can be found in the article published in Terra et Aqua (Number 121, December 2010) "Establishing a Stone Dumping Process for Constructing Artificial Undersea Ridges" by Y. Haseyama.

3 Planning and Design Phase

3.1 Introduction

The planning and design phase concentrated on searching for an optimal landscape design for the extraction site. It followed a relatively simple method shown below:



Requirements: These are obtained through discussions with stakeholders. It is important to translate the ideas, wishes, technical expertise into requirements which are suitable for the design process. It starts with determining the function of the design and then requirements that can quantify the function;

Design: The design process translates the requirements into a design. This is an iterative process; whilst the design is being made, the way the requirements are formulated can be improved. The result of this process is the actual design;

Verification: This is the check whether the design meets the requirements. When this is not the case, either the requirements or the design is changed.

The following stakeholders were asked for their input based on their role in the project:

- Ecologists: required physical gradients for ecological development and habitat creation
- Morphologists: stability of the design and relation to natural bed forms
- Contractors: workability and practical realisation
- Authorities: realisation within existing permit and legislation structure

3.2 Planning: Choice for the Pilot Location

To be able to test the theoretical design parameters under realistic conditions, an actual pilot sand extraction site is needed. Ideally, the site should be taken into use or be in use in 2009-2010 to match the planning of the Building with Nature research programme. Furthermore, the project owner, permit authority and contractor needed to support the creation of the landscaped site.

After consultation with several stakeholders, a pilot location was found in the sand extraction site for the Port of Rotterdam Maasvlakte 2 port expansion / land reclamation project. The site lies about 20 km offshore from the Port of Rotterdam.

It is the largest extraction site along the Dutch Coast. The sides have a slope of minimal 1:7-1:10 and the extraction depth is between NAP -40 and -42m. It has sufficient capacity (>250 Mm^3) to create several large scale bed forms. These large scale bed forms are often morphologically stable and thus remain in the extraction site long enough for colonisation to take place. Furthermore, it has a permit that allows deep sand mining to an average depth of at least 10m below the existing seabed. Both these aspects are important, especially as future extraction sites are expected to increase to similar sizes.

In addition, the extraction site will be subject to a large-scale monitoring programme for the Maasvlakte 2 project. The Port of Rotterdam is responsible for the monitoring programme that covers both the physical and ecological characteristics of the extraction site and the surrounding areas. This means that there is a lot of information available that can be used as reference points in this project.

The figure below shows the geographical location in the North Sea (green area) and zooms in on the location of the two pilot areas in the extraction site itself. The natural orientation of bed forms in the area is also shown as a reference.

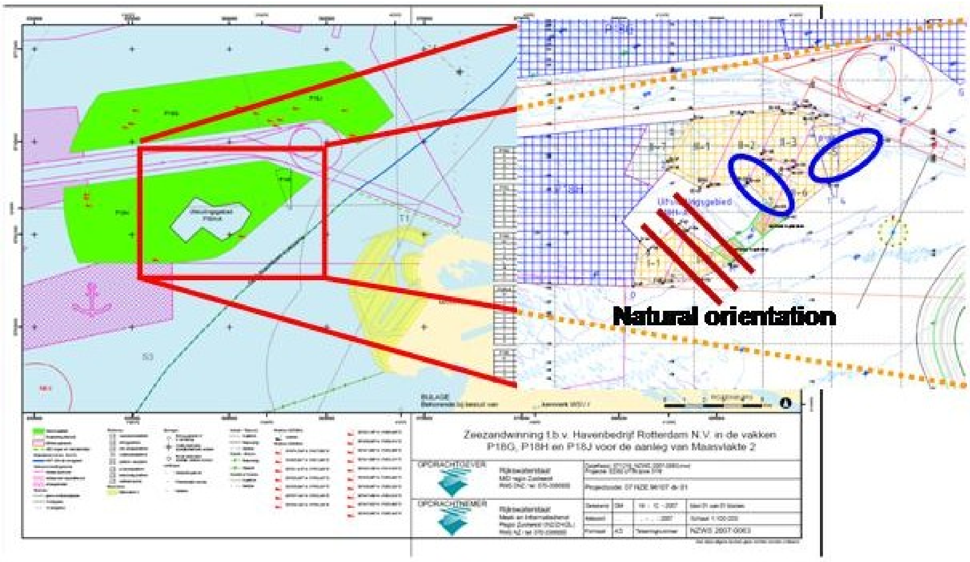


Figure 3-1: location of pilot extraction site in the Maasvlakte 2 port of Rotterdam expansion project.

The project specifically chose to develop a pilot site as it offers the opportunity to test the design parameters to determine if they are realistic and practical. It is important to find parameters that actually fit within the technical boundaries of the sand extraction process and -methods and are therefore a true added value for the creation and development of the sand extraction sites.

The information and lessons learned from the evaluation of the design and construction process are essential in validating and adjusting / sharpening the preliminary decisions and choices.

3.3 Planning: Involvement of stakeholders

The involvement of the various stakeholders in the project team was essential for the success and speed with which the design was made and the pilot locations were chosen and landscaped.

Figure 3-2: Technical brainstorm session at the EcoShape office with stakeholders

The stakeholders involved represent all aspects of the project from technical to, contracting and governance expertise. There were two main groups: the project team and external stakeholders.

The project team consisted of ecological (marine), morphological, contracting and coming from consultants, contractors, research institutes and governmental. Their expertise was strengthened with periodic brainstorming sessions in which (international) experts were asked for their opinion concerning the project.

The external stakeholders were closely involved in the project and formally responsible for the activities at the extraction site. They were responsible for determining the exact location, shape and volume of sand in the designs. The stakeholders involved were:

- The Contractor PUMA (Joint Venture Boskalis and Van Oord) responsible for creating the sand ridges, assisting in the design and giving feedback on the workability of the design;
- The Port of Rotterdam responsible for allowing the pilot sand ridges to be created in their extraction site and for the environmental monitoring programme in and around the extraction site and Dutch Coast;
- The Ministry of Transport, Public Works and Water Management, Directorate-General for Public Works and Water Management (Rijkswaterstaat Dienst Noordzee) responsible for granting the permits in the extraction area.

The stakeholders were asked to contribute to the project through regular meetings with the project team throughout the project phases.

3.4 Design Process

The pilot extraction site aims to create an area that will stimulate the development of marine ecosystems. The team believes that this can be achieved by landscaping the extraction site with morphological bed forms (sand ridges) and varying sediment characteristics.

The design process started with the accumulation of the requirements for the sand ridges, which were then translated into an integrated design. In this project, the design needed to be fitted into an existing extraction site with ongoing dredging works. This asked for flexibility in the design and careful coordination with the contractor, the client and the permit-issuing authority. The requirements for the design were therefore focussed on what was practically possible in the chosen extraction site. The process of accumulating the requirements is as follows:

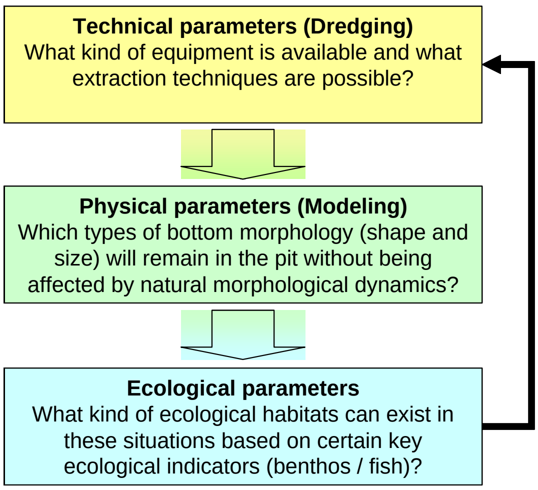


Figure 3-3: flowchart showing the process of identifying requirements in the project

In future projects concerning landscaping, the sequence of the components of the flowchart above can be changed based on the desired end result, the available information and the project phasing. In all cases, the design should enhance the natural conditions of the sand extraction site environment stimulating desired paths of colonisation and/or creation of new habitats but at the same time it should be practical for the dredging operators (cost efficient).

3.4.1 Choice of Technical Parameters

The technical parameters are the result of an analysis of the available equipment, shape of the extraction site, dredging plan and permit requirements concerning the dredging equipment. As mentioned in the previous paragraph, the contractor PUMA was already active in the extraction area with several Trailer Hopper Suction Dredgers (TSHD) varying in size and capacity. The final design took the availability of these ships into account.

Although dredging contractors can create almost any shape, several aspects have to be taken into account to ensure that no unnecessary high costs and loss of time occur making the creation of a landscaped sea bed un-economical. These aspects are:

- Dredging depth of the TSHD allowing for deeper dredging of troughs. The deeper the troughs, the less ships are able to create them;
- Manoeuvrability of the ships to create specific shapes, the sharper or more detailed the contours, the more time / costs it will take to create;
- Capacity of the ships leading to specific sailing lengths needed to fill the hopper. If the proposed landscape shapes are too small or too large, the dredging ships will not reach an optimum dredging volume during one track and thus potentially increase dredging effort and related costs;
- Hydraulic conditions in and around the extraction site. The shapes should preferably not lie perpendicular to the main current directions as the dredging ships are limited in their dredging capacity in these circumstances. Once again, this will lead to sub-optimal dredging conditions with a loss in efficiency and increase in time and costs.

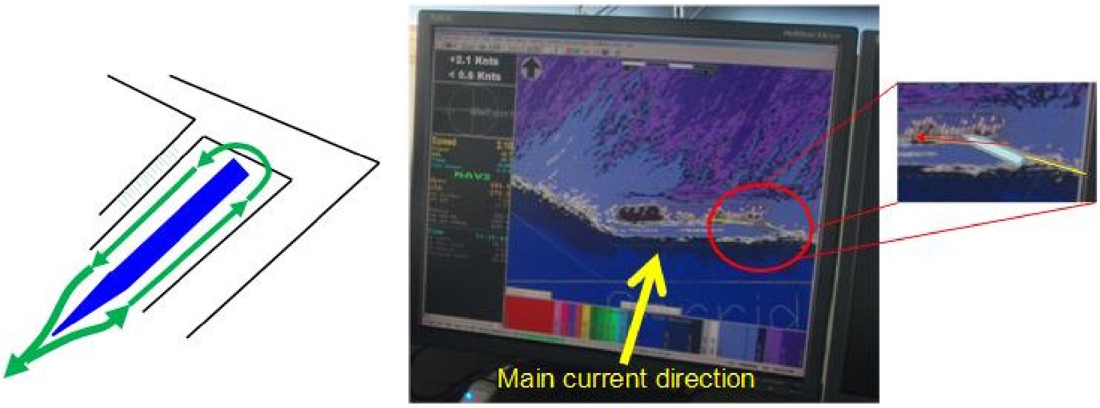


Figure 3-4: track for dredging ships (left) and skewing effect of currents on dredging operations (right)

Due to the fact that the contractor had several smaller and larger ships working in the area and that the extraction site was large enough to always be able to dredge a full track, there were hardly any limitations for the technical design. However, several technical parameters played an important role in determining the final design:

- Length and size of the bed form was chosen to allow for most efficient dredging;
- Depth of the trough could be deeper as there were larger ships in the area;
- Orientation of the sand ridges;
- Total volume needed to be dredged to create the bed forms was large as there were many ships working in the site.

It should be noted that if the landscaping design is incorporated in the tendering phase as a requirement or an actual design, the contractor can choose equipment that will be able to create the landscapes efficiently. If the bed forms are included afterwards, this may lead to less efficiency in the dredging process. It is therefore advisable to involve the contractor on beforehand to discuss the best options and alternatives for the design or to assist in listing and quantifying the specific ecological and physical requirements. This will also ensure the practicality of the ideas.

3.4.2 Choice of Physical Parameters

The physical parameters that are used to design the landscape bed forms result from the actual system. There are several aspects that will determine these parameters:

- Location of the extraction site: the overall location determines the conditions in and around the site including the hydraulic, metocean, bathymetric, geotechnical, etc;
- Shape of the extraction site: the shape of the extraction site is often determined by the available area. Wherever there is sufficient space, any shape can be chosen often based on minimal sailing distance and availability of optimal sand. Where there are restrictions due to conflicts with other users and functions, the extraction site may be limited or shaped in specific way. The shape will determine what kind of landscape can be planned in the extraction site;
- Constitution and available volume of the sediment: the extraction site needs to avail of sufficient sand with the desired grain size. Depending on the size, certain areas of the site will contain sand with more or less fines and with varying grain size which can or cannot be used by the contractor. This natural variation can be used as a playing-field for the creation of different landscapes and related ecological habitats. By dredging only the areas that contain the predefined sand or by dredging in patterns leaving certain areas of the sand extraction site untouched a landscape can be created. The areas that are left untouched because they contain low quality sand, have the advantage that the ecological 'content' remains intact increasing the speed at which the site will be re-colonized after the sand extraction has finished. If needed, overflow from dredging equipment can be stimulated to ensure that more fines are left behind in the troughs of the bed forms for the development of habitats;
- Natural occurrence of morphological bed forms: It is important to know what kind of bed forms already occur naturally in the wider area of the extraction site. If feasible, these bed forms can be copied in the extraction site although they may receive another orientation;
- Presence of wrecks, cables and pipelines, etc: this will determine the shape of the extraction site, spatial restrictions and the maximum allowable dynamics of the bed forms to stop any uncovering. Their presence (and buffers) are also a form of landscaping.

The above aspects can be translated into several physical parameters that are used in the design of the landscape bed forms:

- *Orientation* of the bed form to mitigate the natural hydraulic and metocean conditions that may negatively influence the dredging methods and equipment;
- *Orientation and size* chosen for morphological stability;
- *Grain size distribution*: fines in trough (e.g. maximise overflow), larger sizes on the top;
- *Currents*: In some cases the bed forms may need to minimize current speeds for optimal ecological development, whilst in others a large amount of hydraulic dynamics may be needed (e.g. or transport of nutrients);
- *Height and size* of the bed form can limit the type of dredging ships that can be used because of maximum water depth and length of sailing tracks.

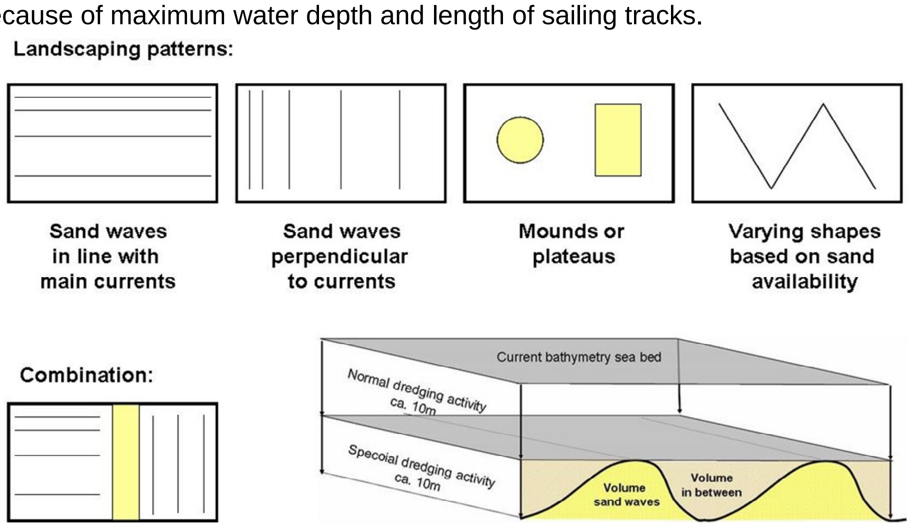


Figure 3-5: Different alternatives for the design and scheme of dredging volume

3.4.3 Choice of Ecological Parameters

When determining the desired ecological habitat, the most important criteria are the basic physical characteristics of the sand extraction site. This includes depth, availability of slopes and of course sediment characteristics after sand extraction has finished. For example, some benthos species appear to prefer quiet environments with higher fines content, while others are more likely to be found in higher energy environments with moderate to large grain sizes. The first can be found in the troughs of the bed forms, the second at the slopes and crests. Ecological habitats should be chosen on the basis of these parameters and taking into account the natural habitats in the area. A higher diversity is usually appreciated / valued more, both for benthos and for fish.

The biodiversity depends on the hydro-geo-morpho-dynamic gradient:

- "hydro": current patterns (speed, direction and variation) and origin (tidal, waves)
- "geo": grain size distribution, porosity, packing, physical and chemical composition, type, organic content
- "morpho": height, orientation, slope, length
- "dynamic": short- and long-term variations, transport volumes

It is generally accepted that the steeper the gradient, the better differences can be measured.

Several design requirements and preferences that determine these gradients are:

- The amplitude should be minimum +/-3m and maximum +/-5m (= 10m height difference). With an amplitude of less than +/-3m it will be difficult to determine if there are any significant effects because the natural variation could have the upper hand;
- The sand ridges should be of a certain size to be able to carry out a monitoring program that is sufficient to determine any significant effects;
- The orientation of the sand ridges should be such that they can be created reasonably easily. Ideally this is parallel to the dominant current direction, but as the natural orientation of the sand ridges is perpendicular to this current it means that parallel ridges can be unstable. On the other hand, ridges perpendicular to the currents are very difficult to make, both in this pilot and future projects, and need special (expensive) dredging methods;
- The sand ridges should be created preferably before the spawning season;
- The sand ridges must remain untouched for a period of more than 4-6 years;
- The amount of fines can influence the biodiversity. Although this project will not investigate this aspect by setting up experiments on this issue, it could be interesting to see if higher fines content can be created on the downstream side of the sand wave by continuously dredging in the same direction. In theory, the overflow starts after the hopper has dredged for about 1km so the first kilometre will have less fines. Typical 'gardens' or 'farmlands' can be made for shellfish such as Ensis or Norwegian lobsters that can then be farmed. This will have additional benefits for the project were the dredged material is used, especially if fines are not allowed in the material for geotechnical stability or construction purposes. The monitoring of the fines should also look at the relation between the organic content and chemical constitution and biodiversity.

Ideally, the resultant landscape is a conscious choice in which a substrate is created with a predetermined amount of fines containing a series of slopes (bed forms) of a certain steepness and orientation. Each combination is tailor made for a certain ecological habitat (benthos and/or fish). This means that the relation between marine landscapes and ecology must be clear when determining the potential goals of landscaping.

In all cases, a marine ecologist needs to be involved in the project to help determine which kind of ecological habitat is realistic and desired taking into account the physical design input parameters and scale of the extraction site.

Current situation

In this project, not much information was available on the actual relationship between benthos and fish with sediment characteristics, water depth, current velocities, bed forms in general etc.

This meant that the ecological input for the design concentrated on obtaining as large physical gradients as possible to make sure statistically significant data on ecological habitats could be collected from various points along the bed form. The same applies for the two extreme orientations that were chosen: one is perpendicular to the dominant current direction (natural orientation, difficult to create), the other lies parallel to the current and is easier to make.

3.5 Stability of the Sand Ridges (Large-scale Morphological Model Tests)

The ecological development of habitats can depend on the stability of the bed form, sometimes maximum stability is needed and in other cases maximum dynamics. However, each design parameter has its own time- and space scale. The scheme below shows the relation between the physical parameters and their related size- and time scales (macro, meso and micro). These scales need to be taken into account when designing the bed forms in sand extraction site.

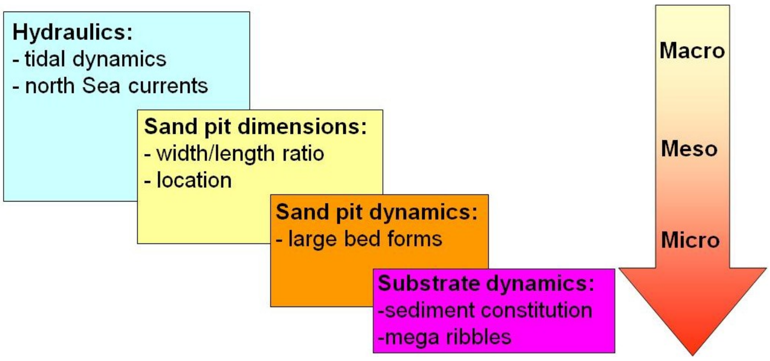


Figure 3-6:Morphological scales of bed forms

Figure 3-6 shows that morphological movements of large bed forms take place on different timescales than the smaller bed forms. The smaller forms migrate at a much faster rate. The various ecological timescales of habitat development should therefore related to these morphological scales and be taken into account when designing the landscaped extraction site.

In the case of this project, stability was chosen. It was therefore important to determine if the chosen design for the large scale bed form was indeed stable. The natural movements of the larger morphological bed forms were modelled to make sure that they are relatively stable and do not migrate out of the extraction site too quickly.

A large-scale morphological model was used for this. The model: “Large-scale Offshore Sandpit Model” of Roos et.al. 2008 simulated the behaviour of the sand ridges in time. It is an idealized model covering sandbank dynamics in both horizontal dimensions. The physical input parameters are mean depth, tidal flow, latitude (orientation), friction coefficients, sediment transport parameters and length, width and depth of the sand extraction site.

A simplified sand extraction site was chosen with a rectangular shape, containing several sand ridges of 3-10m height. Estimates of the behaviour in the short- and long-term of the sand extraction site bed and its expected sea bed composition were calculated to determine if the shapes were lasting or if they disappeared in time. The results did not focus on a location specific situation but on a more generic level i.e. different location within a coastal zone, sand extraction site depth and hydraulic circumstances. An example of one of the bed forms is shown below: 3m high with a width of 40m and a spacing of 220m, comparable to sand waves.

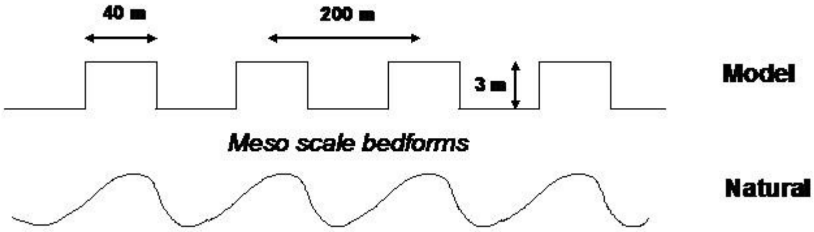


Figure 3-7: Example of morphological scales of bed forms

The results were discussed with the ecological experts to determine their probable effect on the populations of benthos, fish, etc. It appeared that the preferred wavelength of the sand ridges is approximately 300-400m but a larger height was needed to ensure sufficient gradient. The model predicted that due to the large water depth in the pilot extraction site, the dynamics of the system are very slow. The chosen dimensions were therefore relatively stable in the long run (100 years).

It is important to realize that modelling of such bed forms in the extraction is also important with respect to the risk of uncovering cables and pipelines, explosives and wrecks.

Finally, it was noted that natural sand waves developed within 2 years after sand extraction in a site at the Kwintebank (Belgium). However, their height was only 2 meter as opposed to 5 m before the sand extraction. Furthermore, the undisturbed seabed lies at circa 15 m below mean sea level instead of 20m in the Netherlands. The sand waves just migrate out of the sand extraction site when they reach its end.

3.6 Seasonal Considerations

The planning of the construction of bed forms also depends on several seasonal influences such as:

1. Natural seasons with specific ecological development (e.g. spawning)
2. Meteorological and hydraulic season
3. Recurrent extraction

Ad.1: Natural seasons
As with every project concerning natural development of ecological habitats, the design and especially the planning needs to be tuned with the natural seasons. For maximum effectiveness, it is important that the bed forms are completed before e.g. the spawning season. This means that the colonisation takes place as quickly as possible as it is able to profit maximally from the 'new' benthos and fish larvae.

It could therefore be beneficial to plan the completion of the creation of the bed forms before spawning seasons. However, this is a specific issue that depends on the desired / expected ecological habitat and geographical location (including hydraulics and morphology). It is essential that it is checked with local marine ecology experts.

Within reasonable bounds, the overall planning of the extraction dredging works can be adapted, leaving the creation of the bed forms in a later stage in the project. This could imply that a shorter or maybe even a longer extraction period is actually more beneficial as the ecosystem development is seasonal.

Ad.2: Meteorological and hydraulic season
In other cases, the bed forms need to be created before or after certain hydraulic events, such as storm seasons or high river discharges bringing fresh water into the estuarine system. Again, it is important to check these seasonal variations with the ecologists and then plan the creation of the bed forms in accordance with these variations to get optimal results.

Ad.3: Recurrent exploitation

The planning and design should also take into account that sand extraction sites can be exploited over several years. This means that certain parts of the site can be exploited, left alone for a long time and then exploited again. Any habitats created in that period will be affected when the extraction processes start again. In addition, some of the sites have a permit for extraction of deeper sand layers that can be used for concrete and masonry purposes. Once again, existing ecological habitats will be affected.

It is therefore important to find out if and when future extractions will take place and take this into account in the decision process whether or not ecological landscaping should be considered in the design process.

3.7 Final Design Sand Ridge

During the design of the pilot extraction area, it was important to search for opportunities to create several different landscapes that could be compared (statistically) through monitoring programmes. The choice was made based on the following considerations:

- Bed form: sand ridges as these are similar to the morphological bed forms (sand ridges) found naturally along the sea bed . However, the design increased the height of the bed form to create a maximal physical gradient. Design fits in existing permit requirements;
- Location: along the edges of the site gives an extra slope and trough;
- Orientation: both natural (perpendicular to currents) and anthropogenic (parallel to currents)
- Biodiversity: try and create a diverse habitat. Fines in the trough are considered welcome.

The pictures below show the preliminary sketches of the location of the sand ridges and the designed profiles that were to be made.

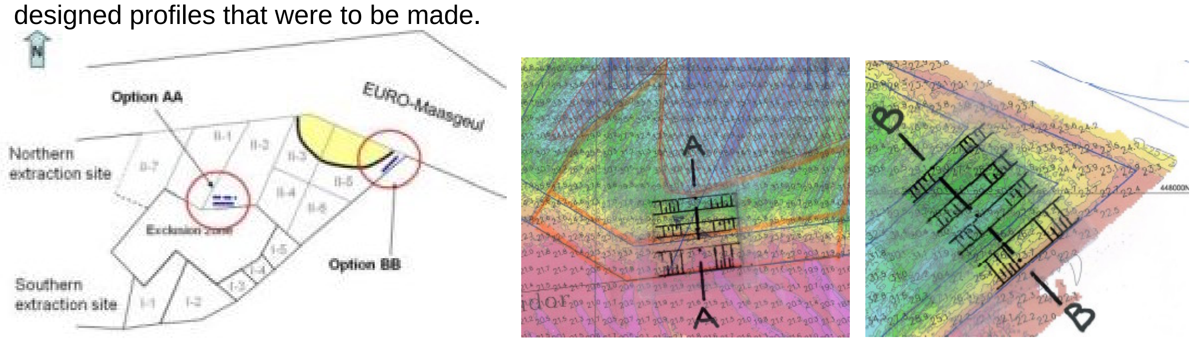


Figure 3-8: Location of two sand ridges (left), sketch of perpendicular (middle) and parallel ridge (right)

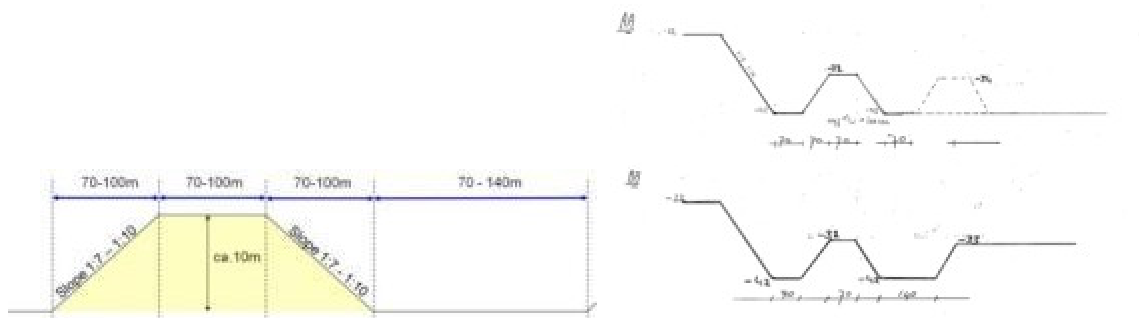


Figure 3-9: Theoretical design profile of the sand ridges and placement in the extraction site

Ultimately, the results of the monitoring programme will show if landscaping is effective i.e. if there is a difference between the creation of sand ridges or not (reference measurements), and when it is effective (design) on the short and if possible also on the long term.

3.7.1 Parallel to Main Current Direction

The first pilot location lays in the north-eastern part of the Maasvlakte 2 extraction site and consists of a 700m long sand ridge of 10m high and about 70-100m wide on top. It lies between the edge of the site and the adjacent plateau (reserved for mining of concrete and masonry sand).

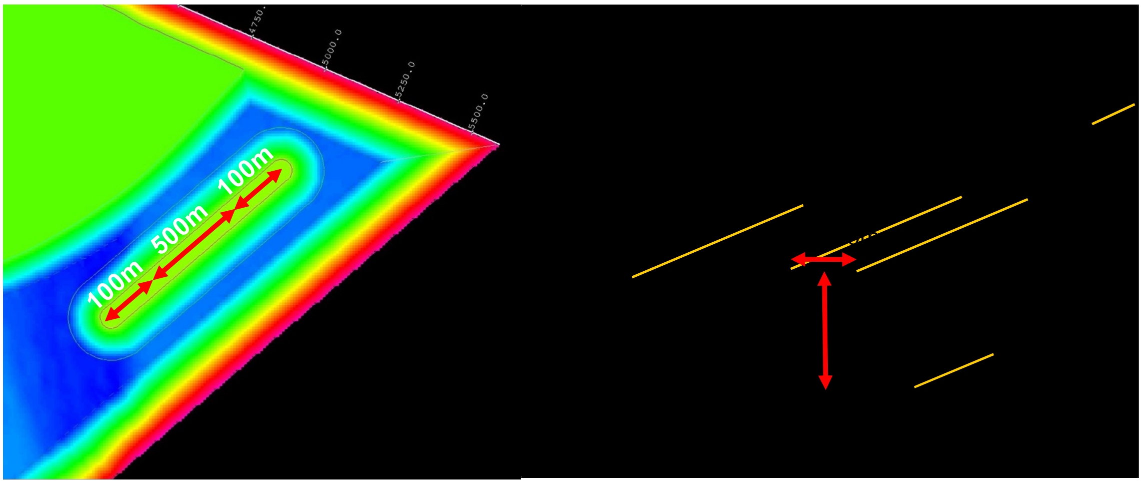


Figure 3-10: Sand ridge design in GIS system (left) and profile (right)

The plots below show the results of the dredging. In total 1.2-1.5 million m^3 of sand were dredged to create the landscaped bed form. As the orientation of the sand ridge lies in the same direction as the normal / preferred dredging operations, the dredging was carried out without any difficulties.

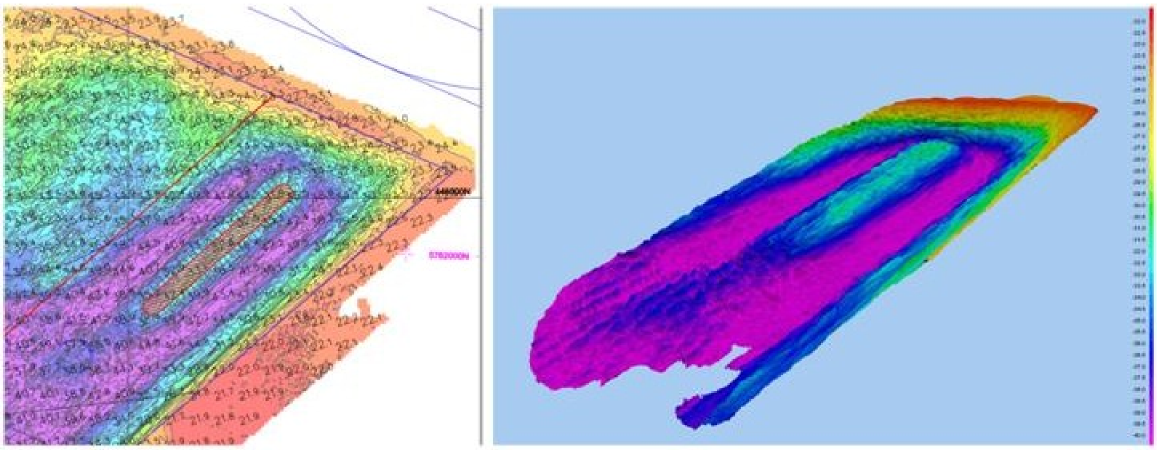


Figure 3-11: current bathymetry (left) and final design (right)

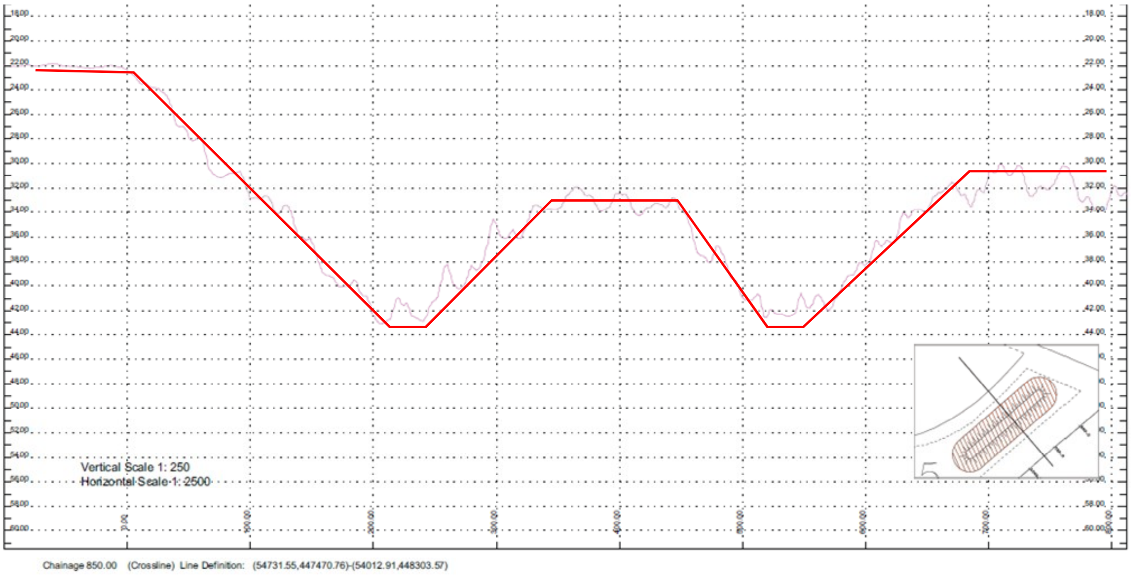


Figure 3-12: actual bathymetry (light red colour) and design profile (dark red colour) of the Sand Ridge

The ‘Parallel Sand Ridge’ bed form was finished in June 2010 and after a detailed survey, monitoring immediately started to determine the presence of benthos and fish.

3.7.2 Perpendicular to Main Current Direction

The second pilot location lays along the southern edge of the Maasvlakte 2 sand extraction site. It has a natural orientation perpendicular to the main current direction. This location was much more difficult to dredge as the ships could only dredge along the ridge during slack tides when the currents were very low. With higher currents, the ship could be swept over the dredging arm and cause considerable damage and danger to the ship.

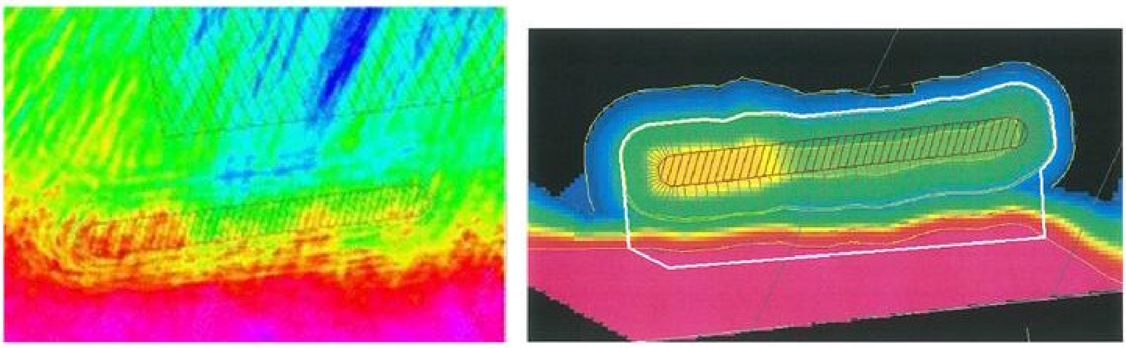


Figure 3-13: current bathymetry (left) with superimposed the final design (right)

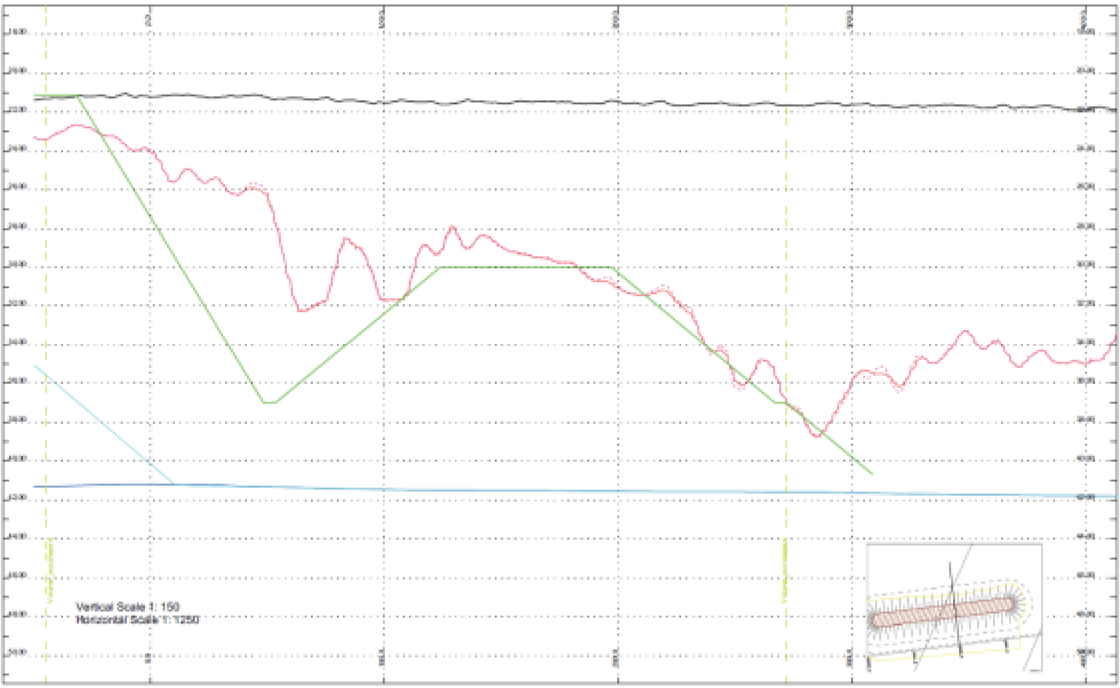


Figure 3-14: Bathymetry and profile of the perpendicular Sand Ridge (under construction at the time of reporting)

4 Construction Phase

4.1 Introduction

After the design was finalized, dredging of the sand ridges was started. In this project, the pilot locations were situated within an active sand extraction site. This meant that a special dredging plan had to be made to ensure that the regular work was not hindered.

The following steps were taken:

1. The local bathymetry in the extraction site was studied in more detail together with the contractor to determine exactly where the sand ridges could be made;
2. Based on expert judgement concerning a.o. hydraulics, morphology and ecology, a choice was made for the preferred locations. In both cases, the sand ridges were positioned near the existing slopes of the sand extraction site to ensure an extra slope and trough in the total design;
3. The contractor designated a temporary buffer around the preferred locations exempting the area from sand extraction until the final position and design was determined;
4. The design was integrated into the existing GIS system, which is also used by the contractors ships, containing the bathymetry and sediment composition data. Based on a GIS calculation, total dredging volumes and grain size were determined. The results were used to fine tune the locations for optimal working conditions;
5. The final dredging volumes and related grain sizes were integrated into the overall dredging plans, and captains received instructions on how to dredge the sand ridges;
6. The temporary exemption areas were removed and the ships were asked to create the sand ridges.

4.2 GIS Tools used to Create the Sand Ridges

The contractor availed of dredging ships with the latest positioning systems and GIS tools. The combined system ensured that the contractor had the latest bathymetric data, allowing each ship to determine to a high degree of accuracy where they needed to dredge to create the sand ridge (see figures below).

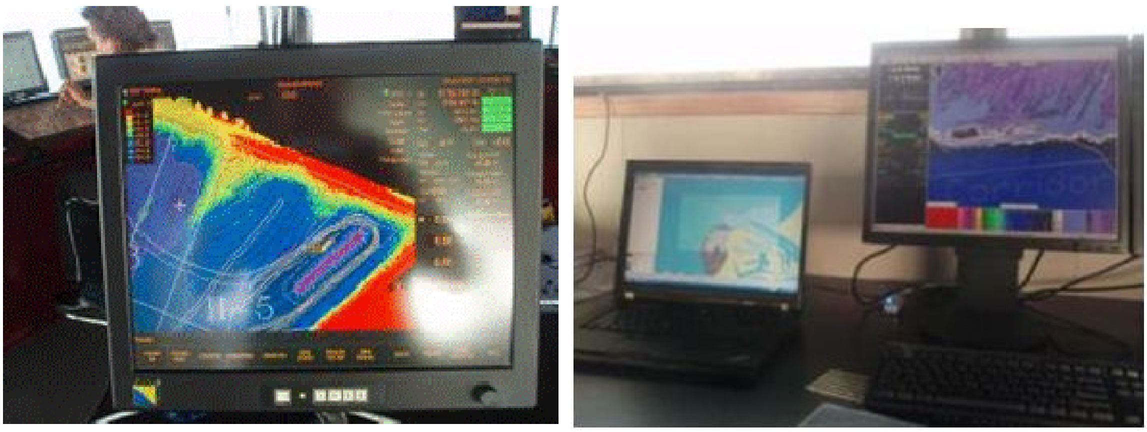


Figure 4-1: GIS positioning and bathymetric systems (right=parallel, left=perpendicular)

The system allowed the contractor to create the ridge in real-time and in accordance to the predefined designs.

4.3 Work methods

The contractor used specialised TSHD ships (Trailer Hopper Suction Dredgers). These ships are able to dredge to great depths with high precision. The TSHD approached the chosen locations in various ways depending on the currents, waves, presence of other ships and overall dredging plan. In all cases, they aimed to sail a pattern that was as efficient possible.

It should be clear that landscaping of the extraction sites requires modern equipment, the dredgers have to be well instructed and the shapes have to be checked by the contractor on beforehand so as to ensure that they can be realised with the equipment at hand.

Figure 4-2: Dredging ships creating the parallel sand ridge that lies to the left of the ship.

5 Post-Construction Phase

5.1 Introduction

Current knowledge of seabed ecology in relation to morphological bed forms is mostly based on expert judgement and some scattered datasets. It has proven to be difficult to predict the presence, diversity and mass of certain ecological species and habitats in extraction areas. Predictions are generic and made on the highest abstraction level i.e. an expected increase or decrease of biodiversity. This means that post-construction monitoring of the extraction site is extremely important and needs to be done as comprehensively and accurately as possible.

The monitoring campaign should start as early as possible to collect a sufficiently large background data set of the existing ecological, morphological and hydraulic situation. This means that monitoring should start immediately after the extraction site has been selected, but before the landscaped bed forms have been created. It is important that the reference situation is determined and agreed upon to allow for comparison and evaluation of the effectiveness of landscaping measures during and after the creation.

5.2 Monitoring

The monitoring programme starts with the reference situation i.e. the situation in which no extraction site was created. In this project, the Port of Rotterdam collected this data and kindly put it at our disposal. The data will be compared to the data gathered in the extraction site during the recovery period. Previous monitoring results have shown that there is no benthos in the area immediately after dredging has taken place. This means that the initial monitoring can be carried out quickly and with a minimum of samples. Later on, the sampling strategy will intensify.

The monitoring aims at collecting information on the actual effect of the creation of the sand ridges in the extraction site. Several questions need to be answered:

1. Do the sand ridges have a beneficial effect on the local ecological system?
2. Are the chosen physical characteristics effective in stimulating biodiversity and biomass as predicted by the experts?
3. What is the natural development of sand ridges in the extraction site? (morphodynamics)

Examples of sampling locations with respect to different landscaping elements are given below.

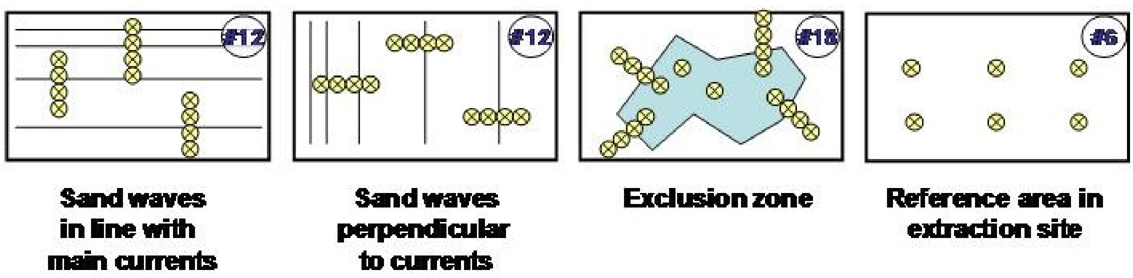


Figure 5-1: Landscaping patterns and monitoring locations

The monitoring activities for the extraction site are coordinated with the Port of Rotterdam monitoring plan for the Maasvlakte 2 Port Expansion Project and with the regular bathymetric surveys carried out by the contractor PUMA. Project-specific small-scale bathymetry (e.g. around the sand ridges) and ecological and sediment sampling are obtained through an additional sampling campaign. The results of these programmes are made available separately on the Building with Nature website through the projects listed in Paragraph 5.4 below.

The monitoring will focus on short-term development of the biodiversity and long-term trends (within the project duration). Long-term trends “flatten or filter out” much of the natural dynamics and variability, thereby enabling researchers to find specific relations between the bed forms and development of the ecological habitats. It is important to be able to (statistically) separate the various influences on the increase in biodiversity and find out the major “driving forces”.

Initial results from the monitoring study of the Port of Rotterdam show that pioneer species (benthos, flora, fish) settle very quickly in the area. Reference measurements should be carried out quickly during or shortly after the area has been landscaped.

5.3 Modelling

In addition to monitoring, the Building with Nature post construction programme includes extensive modelling projects (BwN codes HK2.3, HK2.4, HK3.3 and HK3.6). These projects use the data gathered during the monitoring period to validate the models describing the interaction between the morphodynamics, hydraulic circumstances, and ecological development.

The validated models can be used in future landscaping projects to support the designers and decisionmakers in their choices.

5.4 Continuation in the Building with Nature Programme

The project is continued through subsequent monitoring and modelling projects in the Building with Nature programme.

1. HK2.2: Monitoring ecological extraction site- and silt dynamics North Sea
   - Monitoring focuses on the endo- and epibenthic fauna, before and after sand mining, and both inside and outside the ecological extraction site. Additional measurements will be done as part of work package AMS3, in close consultation with Port of Rotterdam.
   - Silt measurements will be taken across the North Sea and sand extraction areas, to provide ground-truth data for the validation of large-scale models to describe North Sea silt dynamics.

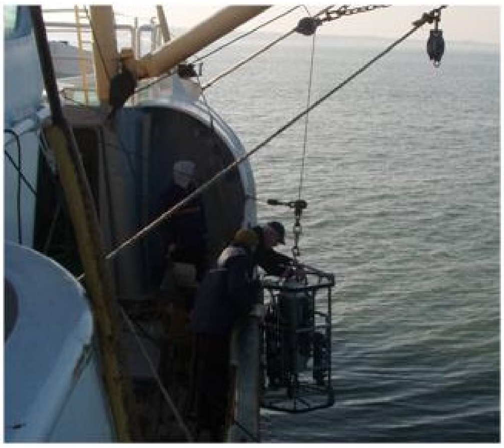


Figure 5-2: Turbidity & CTD sampling (left), benthos sampling (right)

2. HK2.3: Ecological potential extraction sites
   - Develop insight in the ecological potential of extraction sites by studying the expected biogeomorphological and hydrodynamic changes as a consequence of the changed physical characteristics of the sea bed.
   - Improve the capability to predict the ecological consequences in time and space, and develop concepts and methods to create ecologically valuable habitats through under water landscaping attracting fish, birds and mammals.

3. HK 2.4 Prediction of eco-morphological evolution in an extraction site
    - Develop a validated eco-morphological model to support the design process of landscaped extraction sites based on state-of-the-art knowledge of shoreface processes;
    - The model aims to bridge the gap between the smaller and shorter scale of process measurements in extraction sites (often used for model development and validation) and the management time scale that is expressed in years to decades;
    - Validation of the model through eco-morphological field data sampled from the overall monitoring program.

Figure 5-3: fishing gear and catch used to monitor occurrence of fish

6 Contracting

6.1 Introduction

Although the project concentrated on the technical development (morphology and ecology), construction and organisation of the pilot site, the team also looked at different ways in which a landscaped extraction can be included in a contract.

There are many different contract types with variations in client and contractor responsibilities concerning design, planning, work methods and quality of the end result. Looking at potential future projects in which landscaping can take place (minimal extraction site size >10Mm^3), it can be expected that many of the projects can be contracted with an early contractor involvement.

<u>Early Contractor Involvement (e.g. Design & Construct projects)</u>
This is important as the contractor can assist in creating the best design by searching for the most optimal work methods (equipment) based on the location and shape of the extraction site, locations of layers or pockets of suitable sand, project planning, transportation distances etc. By including the expertise of the contractor in the design phase, it will ensure that the final design is tailor made for the project and can be created with a minimum of additional costs or time.

<u>Conventional contracts</u>
As an alternative, in traditional contracts the contractor can be asked to submit a suggested landscaped design for the extraction site during the tendering phase. The project owner has to prepare a list of design criteria to which the landscaped design has to adhere and the contractor can search for the best solution / integration of the design in the extraction site.

Functional requirements need be formulated SMART (specific, measurable, attainable, realisable, time bounded). In this case, the difficulty is in the experimental nature of the project. If the highest functional requirement is defined as being “increasing biodiversity”, defining a “measurable requirement” is difficult as the effectiveness and possibilities of landscaping are not known yet.

After the pilot project has been carried out, a set of functional requirements and technical parameters should be identified with which the extraction site and final landscaping situation can be designed. These requirements and parameters must be defined in such a way that they do not pose restrictions concerning dredging techniques and -methods but that the end result is as expected.

6.2 System engineering

In both of the contract types mentioned above, it is advisable to have a clear view of the aim of the landscaped design before construction works start. It should be clear that the choice to include ecological landscaping of sand extraction sites in a project should be made in the design phase of the project.

System engineering offers a structured approach to determining the design criteria based on the functions of the final situation.

A preliminary set up was made for the project starting with the identification of all the requirements of the stakeholders regarding the aim or function of the final result of the project. Then a functional analysis and requirements analysis is carried out.

To get the functional requirements by answering the following questions.

- *What* ecological value should be improved?
- *Where* should the ecological value be improved?
- *What* is the planning of the project?
- *How* much ecological value should be ‘constructed’?
- *Who* is going to do the work?

There are many ways to improve ecological value. The most obvious way is by increasing the biodiversity and biomass in the sand extraction site. In this case the study focuses on biodiversity. Once the requirements have been found, they need to be verified with a predefined verification method.

The objective of the verification method is to measure whether the intended increase of biodiversity of benthos is being accomplished when compared to a reference site.

Apart from the functional requirements different non-functional requirements need to be mentioned such as construction phase requirements (orientation of the sand ridges in relation to the current, dredging plans and date finish construction phase.

7 Conclusions and Recommendations

7.1 Main conclusions

The project sets out to organize a pilot location to accommodate a landscaped sea bed. The team was fortunate to find a suitable site and stakeholders who were willing to help in organizing the project.

The team searched for an ecological design for the extraction site that turns supposed ecological threats into sustainable opportunities. It considers the new conditions to be an opportunity and values the changed physical conditions as a new environment that can trigger the development of new ecological habitats.

It should be clear that the landscaping design chosen in this pilot project is an example. The main aim of the design was to create a series of maximum gradients within the existing sand extraction site. The goal of the pilot site was to gain knowledge on the potential of landscaping:

1. Can landscaping be useful or not in creating ecological opportunities by using natural processes, and;
2. Gaining knowledge to be able to optimize the landscaping design for future projects.

The project was also a learning process in itself; for example to find out what the possibilities and difficulties of landscaping are with regard to permits or from a contractors point of view.

The experiment has shown that the creation of landscaped bed forms in an extraction site is possible, the effectiveness of these shapes, in terms of enhanced biodiversity, will be monitored and known in several years time.

7.2 Lessons Learned

Throughout the project, new insights were gained concerning technical aspects of the design as well as the organisation of the project and the process that was followed to reach the actual creation of the sand ridges. Also it started a discussion on how changing physical conditions can trigger the development of new ecological habitats.

The most important lessons from the project were to apply landscaping only if:

- Sand extraction volume and site are large enough for landscaping to have added value;
- Landscaping is expected to result in added ecological value;
- Landscaping can be carried out during the extraction process (no additional work equipment mobilisation, as little extra work as possible)

It must be clear that in all cases, landscaping needs to be considered carefully before it is prescribed since each situation will be unique. Prescribing the landscaping of the extraction site in future permits could be very restrictive to the use of sites and extraction processes.

7.2.1 Process Guidelines

The most important lessons learned are:

1. Take a joint approach and involve all stakeholders from initiator, consultant, contractor to permiting authority;
2. Make sure the decision for including landscaping in the design is taken at an early moment, involve the contractor in the design process;
3. Base the design on a mix of ecological, engineering and practical expertise and should be developed by such a team;
4. Clearly specify the aim of the landscaping on beforehand, although some degree of uncertainty will always remain as a result of natural variations;
5. Make sure all stakeholders are informed in a clear and transparent way (minutes of meetings, technical documentation, overall process guidelines, etc.) and continuously inform them of the progress and new ideas etc. (permanent liaison).

7.2.2 Technical Parameters

The main focus when determining the technical parameters should be on the following issues:

- Physical gradients that are attractive for ecological habitats
- Workability
- Costs

There are several lessons learned from the determination of the technical parameters:

1. The technical parameters need to be determined in close cooperation with (marine) ecologists to determine their effectiveness and with contractors to determine their workability (realistic / pragmatic approach);
2. It is important to use numerical models to predict the behaviour of the bed forms in the extraction site and make sure that they are relatively stable allowing sufficient time for the ecosystems to develop.
3. The size of the extraction sites determines the type and number of bed forms that can be placed in the site. Modelling will determine the side effects (if any) of the bed forms (e.g. flow contraction). It should be noted that in smaller extraction sites, limited space makes it difficult for the dredging equipment to manoeuvre, potentially making it expensive to create any bed forms;
4. It is advisable to determine if the natural distribution of grain sizes creates sufficient gradients so that additional design is not necessary;
5. Short bed forms are more difficult to create as the ships need to manoeuvre more. This will result in a loss of production and increase in costs. Also, bed forms that have an orientation that is more than 20-30 off the main current direction are much more difficult to create.

7.2.3 Ecological Parameters

Allocation of permits and related monitoring often concentrate on ‘recovery periods’ of ecological habitats in sand extraction sites. The basic idea is that re-establishment of a community similar to that which existed prior to dredging can only be attained if the topography and original sediment composition are restored (Boyd et al. 2003). This can only be guaranteed when the extraction sites remain shallow (2m). Unfortunately, it is often unclear whether ‘recovery’ concerns the restoration of previous habitats or creation of new habitats, especially when the conditions at that location have changed (deeper water, more fines, etc.). This is more in agreement with Seiderer and Newell (1999), highlighting the occurrences of “natural” fluctuations in the benthic community composition. Rather than expecting a total recovery to the area dredged to a situation prior to dredging, they suggest that recovery could be interpreted as the ‘*establishment of sufficient species diversity following cessation of dredging to allow the biological resources to progress towards the diverse “equilibrium” communities which characterise stable deposits of coastal waters*’.

In the case of sand extraction sites, it is therefore advisable to use ‘establishing of habitats’ instead of ‘recovery of habitats’. This allows for the creation of (new) habitats that are tailored to the new circumstances and thus have much higher chance of survival. In addition, no large changes or adaptations are needed to adjust the physical situation to a desired habitat that does not naturally occur under the conditions after dredging. For example, the original sea bed may have been fished intensively and turned into an ‘ecological desert’ whereas the sea bed on the bottom of the site is landscaped and left alone and becomes rich in life. If the original habitat would have been restored, the site would have had to be kept as a desert.

7.2.4 Governance Issues

The project team worked closely with the stakeholders and was able to formulate several lessons learned concerning governance issues:

1. Make sure all relevant stakeholders are identified and contacted beforehand. Determine who will be politically and administratively responsible for approving the permit and make sure they are involved or regularly updated on the process;
2. Discuss and research the potential of landscaping extraction sites within permit requirements before the design is made (input for design);

3. Use technical documentation and workshops to inform the permitting authorities and explain the reasoning and effect of the landscaping;
4. Approach the permit application procedure in an opportunity-driven manner, searching for possibilities rather than restrictions.

The stakeholders acknowledged that the project offered an excellent opportunity to determine the actual effects of the landscaping and are looking forward to the results.

7.2.5 Construction works

There are several important lessons that were learned during the construction works. They were obtained first hand through visits to the ships and discussions with the captains. The lessons concentrated on the 'workability' of the design and the consequences of the creation of a specific landscape in comparison to a case without predefined bed forms.

The lessons learned are:

1. Make sure that there is sufficient data on bathymetry, sediment properties, local currents and tidal windows. This is essential data for contractors to determine how they can dredge and what the dredging sequence will be;
2. Involve the contractors early on in the design phase so that the final design fits easily into the dredging plans and methods and can therefore be created cost-efficiently i.e. without loss of production rates. Use their knowledge on sediment properties, ship types, planning (how and which sand will be used at what moment in the project) and general dredging expertise for the design and planning of the location;
3. Make the decision on landscaping as early as possible and provide data on requirements and/or locations so that the contractors can fit in the bed forms in their dredging plans and therefore also in the permits;
4. Maintain an open communication with contractors / captains to determine the actual workability of the design and to discuss the need for any optimisations;
5. Ensure frequent updates on the bathymetry of the chosen bed form to make sure the design is feasible and can be made;
6. If the scope of the project and /or available fleet of TSHD's changes, confer with contractor to determine if the design needs to be adapted (e.g. concerning dredging depths).

7.3 Recommendations for Future Research

There are several areas that need additional research before landscaping can be applied freely.

<u>Juridical research</u>

More information is needed on the room available to create landscaped extraction sites in current legislation and specifically what the consequence is of new national (National Water Plan) EU laws and legislation.

It is worthwhile to evaluate current legislation with the results of this pilot project to determine whether they need to be updated to leave sufficient room for landscaping or already have this room but need proven examples to support the positive effect of landscaping. This includes any general requirements stating that extraction sites need to be leveled after extraction has finished.

A guideline could be made for when and how to include such requirements in tender documents e.g. by working with Systems Engineering.

<u>Technical research</u>

More information is needed on the behavior of the bed forms in the extraction site, both morphologically and concerning the grain size distribution. This can be done with modeling, that will also be able to look at any hydraulic pattern changes.

Ecological research

Most research is needed to be able to predict the ecological development in a landscaped site. It is important to understand more about the relationship between the presence and development of ecological habitats and the physical characteristics in the area. Several topics that need further studying are:

(a) General study on which ecological systems will profit from certain landscaping aspects (depth, slope, sediment characteristics such as silt enrichment, gradients, surface etc) – where do what kind of ecological habitats occur?

(b) Determine what kind of ecological habitats need dynamic morphological systems (i.e. eroding landscape) and which need stable systems (i.e. fixed shapes);

(c) Determine which ecological systems need certain hydraulic conditions to survive i.e. strong or weak currents, minimal wave influence etc;

(d) Combine the results of the ecological and morphological studies to make a first classification of landscapes and ecological habitats taking into account changes in time (natural progression). The landscapes are aimed at stimulating natural habitat creation so that the colonisation of the extraction site occurs as naturally as possible.

(e) Determine which level of detail is necessary for monitoring the effects of the landscaping? Optimum combination of technical and practical monitoring and reasonable costs.

The analysis of the data obtained through the current monitoring programmes will help in understanding several of the mechanisms, but more information is needed.

Potentially in the long run it will be able to choose a specific landscaping element in certain extraction sites that will ensure the colonisation of predefined ecological habitats, ultimately resulting in different opportunities ranging from the protection of endangered species to the establishment of habitats attractive to commercially interesting shellfish or fish species.

8 Colophon

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Project:	Ecological Landscaping of Extraction Sites
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Report number:	08001-3-R-01-1-DCRI
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9 Literature

[1] Baptist, M. J., J. Van Dalfsen, A. Weber, S. Passchier and S. Van Heteren (2006). "The distribution of macrozoobenthos in the southern North Sea in relation to meso-scale bedforms." Estuarine, Coastal and Shelf Science 68(3-4): 538-546.

[2] Van Dijk, T.A.G.P., J. Van Dalfsen, P.J. Doornenbal, I. Du Four, V. Van Lancker, and S. Van Heteren (2007). Benthic habitat variation over tidal ridges. GeoHab2007 international conference, Marine Benthic Habitats of the Pacific and other oceans: status, use and management, Nouméa, New Caledonia.

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