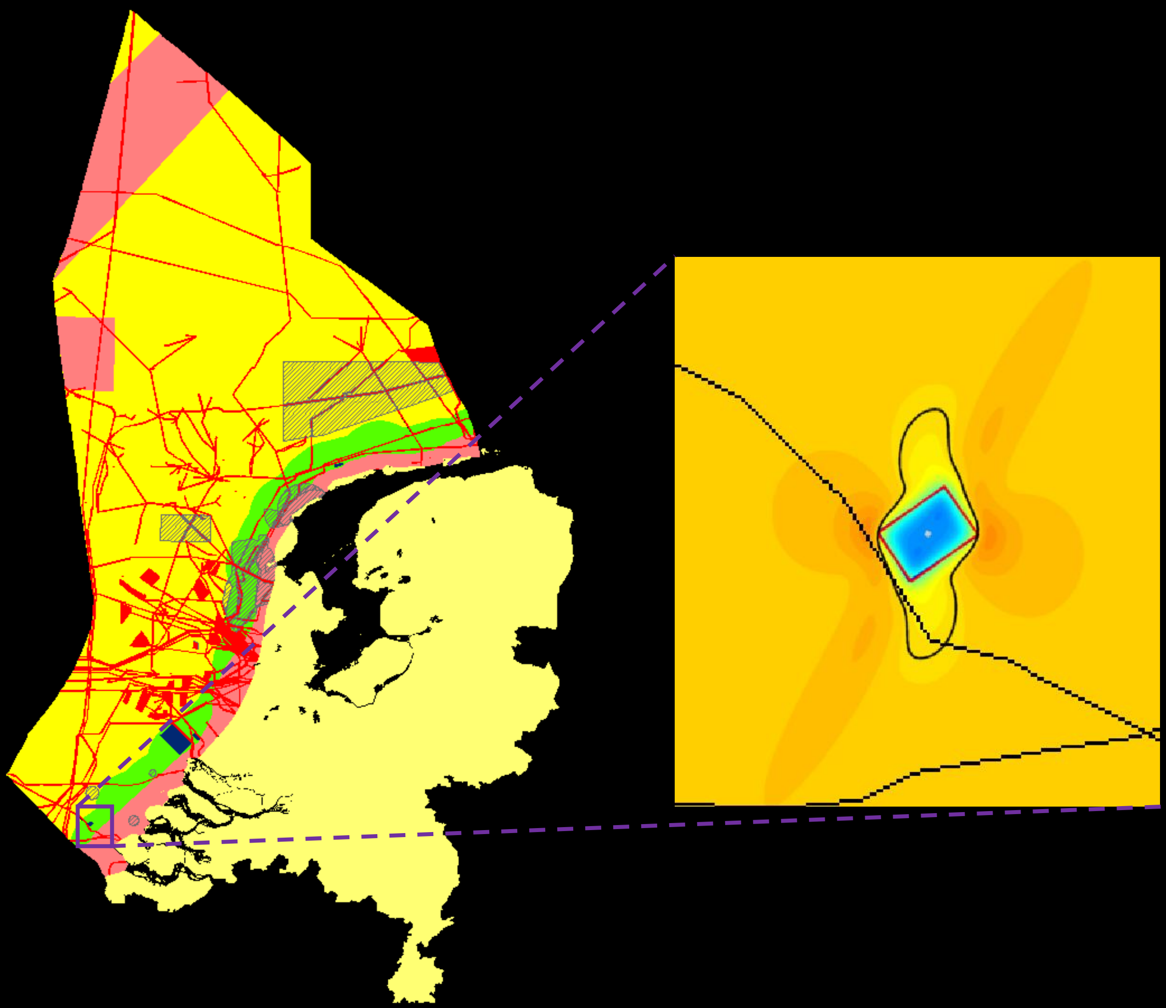
SPATIAL OPTIMISATION OF MARINE SAND EXTRACTION

Development of a tool determining safety areas around sandpits in the North Sea



Master Thesis Water Engineering & Management

Quintijn van Agten

10-12-2010

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Development of a tool determining areas around sandpits in the North Sea

Enschede, 10 December 2010

Master Thesis of:

Quintijn M. van Agten BSc.

Water Engineering & Management
University of Twente
The Netherlands
Quintijnvanagten@gmail.com

Under the supervision of the following committee:

Supervisor:	Dr.J.P.M. Mulder (University of Twente & Deltares)
Supervisor:	R.H. Buijsrogge (University of Twente)
Graduation supervisor:	Prof. dr. S.J.M.H. Hulscher (University of Twente)
External supervisor:	Ir. S.J. Ouwerkerk (Witteveen+Bos & HKV)

UNIVERSITEIT TWENTE.

Summary

The demand for sand from the North Sea used for coastal replenishment and construction sand is expected to grow in the future. In the meantime other user functions such as wind farms, nature, cables and pipes are also expected to grow and will ask for more space in the North Sea. For these reasons, it is expected that the pressure on the available space in the North Sea will grow in the future. Therefore spatial planning in the Dutch North Sea is an important issue. This research focuses on the optimisation of spatial planning and sand extraction from the Dutch North Sea in the future. The objective of this research is to enable optimisation of the available areas for sand extraction in the Dutch North Sea, by developing a tool which determines site specific safety areas around sandpits.

This research started by analysing the available area and demand for sand extraction from the Dutch North Sea. Sand demand is analysed, based on the sand demand scenarios developed by Rijkswaterstaat (Dutch department for water, infrastructure and public works). For the available area for sand extraction, a sand extraction location model is developed in ArcGIS. This model generates a map with the locations where sand extraction is allowed and which locations have priority for sand extraction. The model is based on the current common practice and legislation for sand extraction. It is easy to make adjustments in this model if there are changes in legislation. Based on this new legislation it is easy to make a new map.

Based on the sand demand and priority areas for sand extraction, it can be concluded that there is enough sand available to satisfy the future sand demand until the year 2100. Nevertheless, it is interesting to see if it is possible to optimise the available area for sand extraction. Considering the fact that sand can be extracted as cost effective as possible, by extracting it as close as possible near the coastal or on-shore location of the sand requirement. Every kilometre further away increases the costs of sand extraction by four percent.

In current legislation sand extraction is not permitted in a zone with a width of 500m (safety buffer) around offshore platforms, wind farms, cables and pipes. This safety buffer needs to guarantee that sand extraction will not have a negative effect on offshore platforms, wind farms, cables and pipes. Outside the 500m safety zone, sand extraction is permitted till a depth of 2 meters. For deeper sandpits this 500m buffer is increased with 100m per meter extra excavation depth. By analysing common practice and legislation for sand extraction, there is no morphological underpinning found for the safety areas around user functions.

Realistic safety buffers around sandpits would be depending on the morphological influence around sandpits, which means pit size, shape, orientation (with current direction), current velocity, water depth and morphological time scale. Due to the fact that there is a large variation in current velocity and water depth in the North Sea and the fact that a sandpit can have all kind of dimensions and orientations, it might be better to determine the needed safety buffer for each sandpit individually. In order to do this, an interactive design tool for sand extraction is successfully developed. With this tool it is possible to see where sand extraction is physically possible, considering different existing spatial functions. Furthermore it shows the morphological effects of a sandpit with random dimensions and orientations in any location in the North Sea after a certain number of years.

The tool is built within the MapTable software – originally developed for use in Space for the River projects – by implementing the Twente morphological sand extraction model. In addition a map with the locations where sand extraction is allowed and which locations have priority for sand extraction is used as background within the design tool.

The general conclusion of this research is that with this design tool the available area for sand extraction in the Dutch North Sea can be optimised. It determines the safety zone for each sandpit individually and site specific. In this way, the necessary safety buffer can, in many cases, be much smaller than the currently used fixed safety buffer of 500m, increasing the available space for sand extraction.

The main recommendation of this research is: evaluate the advantages of a new site specific approach relative to the existing general and fixed safety buffer approach for sand extraction in current legislation. The design tool can be used for this individual site specific approach.

Beside this main recommendation there are also recommendations on how the MapTable software and the developed design tool for sandpits could be improved. Most important recommendations are:

- Improve the MapTable so that it can also work with shape files.
- Improve the sand extraction model so that it can work with all kind of shapes and not only with rectangles.
- Improve the tool so that the tool can give the optimal location for sand extraction by a given volume sand and the location where this sand is needed.
- Improve the reliability of the used data on M2 current information.

Finally, it is recommended to do further research on the needed safety area around sandpits which depends on the allowed negative depth change and morphological time scale. To make a good estimation on these allowed negative depth change and morphological time scale further research is needed.

Samenvatting

De vraag naar zand uit de Noordzee voor kustversterking en bouwzand zal naar verwachting toenemen in de toekomst. Tegelijkertijd is de verwachting, dat andere gebruiksfuncties -als windparken, natuur, kabels en pijpleidingen- ook zullen groeien en om meer ruimte in de Noordzee zullen vragen. Om deze redenen is het te verwachten dat de druk op de ruimte in de Noordzee in de toekomst zal toenemen, wat het belang van ruimtelijke planning in de Nederlandse Noordzee zal doen toenemen. Dit onderzoek concentreert zich op de optimalisatie van ruimtelijke planning voor zandwinning in de Nederlandse Noordzee in de toekomst. Het doel van deze studie is het optimaliseren van de beschikbare ruimte voor zandwinning in de Nederlandse Noordzee, door het ontwikkelen van een tool waarmee de veiligheidszones rond zandputten, locatie specifiek bepaald kunnen worden.

Dit onderzoek start met het analyseren van de beschikbare ruimte voor zandwinning en de huidige vraag naar zandwinning uit de Nederlandse Noordzee. Deze zandvraag is gebaseerd op scenario's, ontwikkeld door Rijkswaterstaat. Voor het bepalen van de beschikbare ruimte voor zandwinning is een zandwinning locatie model ontwikkeld in ArcGIS. Hiermee is het mogelijk kaarten te maken van de gebieden waar winning van zand is toegestaan en daarop aan te geven welke locaties daarbij de voorkeur hebben. Het model is gebaseerd op wetgeving en toepassingen uit de praktijk. Het is eenvoudig om aanpassingen in het model te aan te brengen wanneer bijvoorbeeld regelgeving verandert. Op basis van deze nieuwe regelgeving kan dan weer eenvoudig een nieuwe kaart gemaakt worden.

Uitgaande van de zandvraag en de voorkeursgebieden hiervoor, kan geconcludeerd worden dat er in de toekomst genoeg zand aanwezig is om te voldoen aan de zandvraag tot het jaar 2100. Toch blijft het interessant om te kijken of het mogelijk is om de ruimte die geschikt is voor zandwinning te optimaliseren; in het bijzonder vanwege het feit dat kosteneffectieve zandwinning wordt bereikt door winning zo dicht mogelijk te laten plaatsvinden bij de plek van de zandbehoefte aan de kust en op het land. Voor elke kilometre dat het zand verder weg gewonnen wordt, stijgen de kosten met vier procent.

Bij de huidige wetgeving is zandwinning niet toegestaan binnen een zone van 500 meter (veiligheidsbuffer) rondom offshore platforms, windparken, kabels en pijpleidingen. Door deze veiligheidsbuffer wordt gegarandeerd dat zandwinning geen negatief effect zal hebben op deze voorzieningen. Buiten deze 500 meter veiligheidszone is zandwinning tot een diepte van 2 meter toegestaan. Voor diepere zandwinning wordt deze 500 meter buffer vergroot met 100 meter voor elke meter dat er dieper zand wordt gewonnen. Voor deze regelgeving is echter geen morfologische onderbouwing gevonden van deze veiligheidsbuffers.

Realistische veiligheidsbuffers rondom zandputten hangen af van het morfologische invloedsgebied, wat weer afhangt van de putgrootte, de vorm, de oriëntatie (t.o.v. de richting van de stroom), de stroomsnelheid en de waterdiepte. Als gevolg van het feit dat er in de Noordzee een grote variatie is in stroomsnelheden en waterdieptes, evenals het feit dat een zandput allerlei afmetingen en oriëntaties kan hebben, zou het beter zijn om de veiligheidsbuffer voor elke zandput individueel te bepalen. Om dit mogelijk te maken is een interactieve ontwerptool voor zandwinning ontwikkeld. Met deze tool is het mogelijk om te zien waar zandwinning fysiek mogelijk, is kijkend naar de

verschillende bestaande ruimtelijke functies. Verder laat de tool het morfologische effect van een zandput zien met een willekeurige afmeting en oriëntatie op een bepaalde locatie in de Noordzee na een bepaald aantal jaren.

De tool is gemaakt in the MapTable – oorspronkelijk ontwikkeld voor ruimte voor de rivier projecten – door middel van het implementeren van het morfologische Twente zandwinning model. Verder is er een kaart met de locaties waar zandwinning toegestaan is en welke gebieden de voorkeur hebben voor zandwinning als achtergrond aan de tool toegevoegd.

De conclusie van dit onderzoek is dat met de ontwerptool het mogelijk is om het beschikbare gebied voor zandwinning in de Nederlandse Noordzee te optimaliseren ofwel te vergroten. De tool bepaalt de veiligheidszone voor iedere zandput individueel en plaats gebonden. Op deze manier kan de noodzakelijke veiligheidsbuffer in veel gevallen een stuk kleiner zijn dan de vaste veiligheidsbuffer van 500 meter.

De hoofdaanbeveling, voortkomend uit dit onderzoek, is: evalueer de voordelen van een locatie specifieke aanpak in plaats van de huidige algemene en vaste veiligheidsbuffer voor zandwinning in huidige wetgeving. De ontwerptool kan voor deze aanpak gebruikt worden.

Naast deze hoofdaanbeveling zijn er ook aanbevelingen over hoe MapTable software en de ontwikkelde designtool voor zandputten verbeterd kunnen worden. De belangrijkste aanbevelingen hiervoor zijn:

- Verbeter de MapTable zodat deze ook met shape files kan werken.
- Verbeter het zandwinning model zodat deze allerlei vormen kan doorrekenen en niet alleen rechthoeken.
- Verbeter de tool, zodat de tool, de optimale locatie voor zandwinning kan bepalen, bij een gegeven volume zand en de locatie waar dit zand nodig is.
- Verbeter de betrouwbaarheid van de gebruikte M2 stroomsnelheid data.

Ten slotte is het aan te bevelen om verder onderzoek te doen naar de noodzakelijke veiligheidszone rond zandputten. Die hangt af van de toegestane negatieve diepte verandering en de morfologische tijdsperiode. Om een goede aanname te doen over deze toegestane negatieve diepte verandering en de morfologische tijdsperiode is vervolgonderzoek nodig.

Preface

The origin of this research is in my interest in integrating GIS and spatial planning within my Master studies Water Engineering and Management. A meeting with Suzanne Hulscher about the 'Building with Nature' Innovation programme introduced me to the 'Sustainable development Holland coast' case. The idea of this case is to implement models that can show the effects of different measures around the Dutch coast into one software package, the MapTable. I started my research with the implementation of a sand extraction model (Twente model) in the case 'Sustainable development Holland coast'.

During the research another topic arose, as a result of that there was no morphological underpinning found for the used safety buffers around offshore platforms, wind farms, cables and pipes in case of sand extraction. Due to my interest for spatial planning, I saw a challenge to optimise the available area for sand extraction by underpinning these safety buffers for each sandpit individually with the developing sand extraction tool.

These two passages contain a short description of the way my research, which took 6 months, developed. For the University of Twente this research forms the final assignment for my Master Water Engineering and Management. I hope this research will motivate Rijkswaterstaat to make a shift towards a site specific and individually approach to determine the needed safety buffers around offshore platforms, wind farms, cables and pipes in case of sand extraction instead of using a fixed safety buffer.

For me, this thesis initiates the end of my life as a student. Several persons helped me realising this research. I am very grateful for all the advice and criticism given by my graduation committee: Jan Mulder, René Buijsrogge, Suzanne Hulscher and Sonja Ouwerkerk. I also would like to thank Edwin Nieuwland (Witteveen+Bos), Alfons Smale (Witteveen+Bos & Deltares) and Remco Plieger (Deltares) for helping me with the development of my sand extraction tool. In addition I would like to thank Ad Stolk (RWS) for the information on legislation about sand extraction. Furthermore I would like to thank my year group 'Savitor' and my buddies at the 'Afstudeerkamer' for the good times. As last, but certainly not least, a special thanks to my family and Puck, who were always willing to listen to me, talking about this thesis.

As a student, I hope you enjoy reading my final work!

Quintijn van Agten

Enschede, December 2010

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1. Introduction

1.1 Context

The North Sea -one of the most intensively used seas of the world- is a sensitive ecosystem that is under a great deal of pressure from intense human activities such as fishing, sand and gravel extraction, shipping, defence, oil and gas extraction, tourism and industry. This pressure is still growing due to the development of new user functions as wind farms and large constructions, like the enlargement of the Rotterdam Harbour which demands for more offshore resources (sand). At the same time, nature conservation in the marine environment is receiving increasing attention. As more and more sea functions are demanding access to maritime resources, space is simply not unlimited any longer. This is why spatial planning is important in the North Sea (Nationaal water plan 2009-2015, 2009). To improve these spatial planning it is important to know how the marine user functions interact with each other (Van der Wal et al., 2009b).

In the policy plans of the government (Nationaal water plan, 2009) there are made explicit demands for larger areas for sand extraction for coastal replenishment and fill (or construction) sand in the future. There are also discussions about the depth of sand extraction from the North Sea. There are plans to allow excavation depths greater than 2 meters (the currently allowed depth). Actually there are already sandpits with a larger depth for the Maasvlakte 2 (Port of Rotterdam, 2010). In legislation for sand extraction there are safety buffers of 500m around user functions defined for sandpit of maximal 2 meters, yet there is no information known on how these buffers are underpinned. This research takes a closer look at these safety buffers. This research will investigate if there is a better way to deal with these safety buffers, so the available area where sand extraction is allowed and has priority can be optimised.

This research is initiated within the ‘Building with Nature’ innovation programme, within the case called ‘Sustainable development Holland coast’. Aims of this programme are at the development of a perspective for the sustainable development for the Dutch coastal area, over a timescale of 50 to 100 years. This perspective consists of a pallet of possible measures, both for sand extraction as well as coastal interventions, in combination with a management and maintenance strategy.

One of the objectives of ‘Building with Nature’ is the creation of a software tool that enables online calculation and visualisation of morphological effects of different strategies. Such a software tool can play an important role in the design phase, online sharing of knowledge with different stakeholders. MapTable is an example of such a tool that is being developed for ‘Building with Nature’ and currently used for ‘Space for the River projects’ (Ruimte voor de rivier, 2010). Important characteristics of MapTable are short calculation time (meaning that it can be used during interactive design sessions where all parties are involved) and it is easy to use. The idea is to use MapTable also within the case ‘Sustainable development Holland coast’ to show the effects of different interventions in the North Sea (Ouwerkerk, 2009). In this research MapTable is used, focussing on the intervention sand extraction from the Dutch North Sea.

1.2 Background

Programme 'Building with Nature'

The idea of 'Building with Nature' is to solve engineering problems in a new way by using the forces of nature to produce hydraulic engineering infrastructure and to create new opportunities for nature at the same time. It is a new way of engineering by moving away from defensive design approaches with the aim of minimising negative effects and moving forward to design approaches and designs that target the optimisation of system potential.

Study area

The study area is limited to the Dutch part of the North Sea, existent in the Netherlands Exclusive Economic Zone (EEZ) and the Territorial Sea; this is shown in figure 1.

For the interactive design tool the study area is furthermore limited to the used WAQUA schematisation. Most suitable WAQUA schematisation of the Dutch coast is in this case the WAQUA 'SIMONA-kuststrook-fijn-1999-v4' model (this model is provided by Rijkswaterstaat and is operated by Deltares, more information about this WAQUA model can be found in appendix A and Deltares, 2009). Concluding the study area used in the design tool is named 'MapTable study area' and exists in the overlapping area of the 'SIMONA-kuststrook-fijn-1999-v4' schematisation and the Dutch part of the North Sea, this area is shown in figure 1.

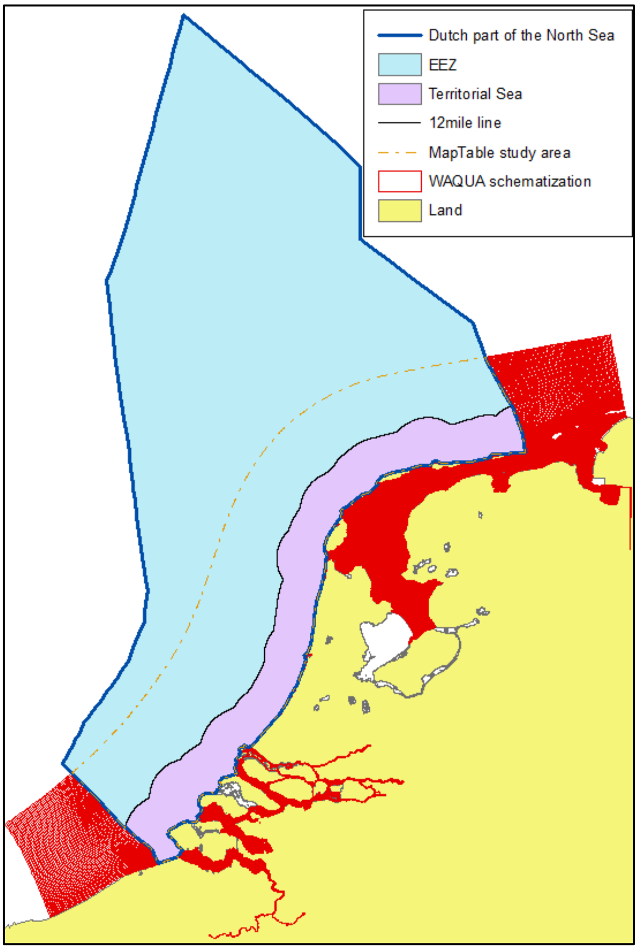


Figure 1: Study area

1.3 Objective and research questions

Research objectives

Expected is that the pressure on the North Sea will grow in the future, as more and more sea functions are demanding access to maritime resources (Nationaal water plan 2009-2015, 2009). This research is focusing on the optimisation of spatial planning for future sand extraction in the Dutch North Sea. The objective of this research is:

To enable optimisation of the available areas for sand extraction in the Dutch North Sea, by developing a tool which determines site specific safety areas around sandpits.

Research questions:
To be able to achieve the objective, three research questions have been formulated. The first question is focusing on the relevance of the objective. The question will focus on the availability of sand in the North Sea and the demand for sand extraction. In the second question current legislation with regard to safety buffers around user functions for sand extraction will have the attention. Especially if there is a better way to define these safety buffers to optimise the available area for sand extraction. The last question deals with an interactive design tool for sand extraction that can check the needed safety area around sandpit with random dimensions and orientations in any location in the North Sea after a certain number of years. These are the research questions:

1. *Is there enough sand available to satisfy the future sand demand until the year 2100? Based on priority areas for sand extraction in the North Sea and future sand extraction scenarios.*
2. *How is the current legislation with regard to safety buffers around user functions for sand extraction regulated? Is there a better way to deal with these safety buffers, to make optimal use of the available area in the North Sea?*
3. *Is it possible to develop an interactive design tool with which we can see where sand extraction is allowed and that shows the morphological effect of a sandpit with random dimensions and orientations in any location in the North Sea after a certain number of years?* This will enable the option to determine the necessary safety areas around sandpits

1.4 Research approach and outline

This paragraph describes the research approach, based on the report outline.

Chapter 2 Literature survey of sand extraction
The project starts with a literature survey of common practice and legislations for sand extraction, user functions in the Dutch part of the North Sea and future sand extraction scenarios. Literature is analysed to get an idea on how different user functions are spatial distributed in the North Sea, how each user function interact with sand extraction, where sand extraction is allowed and the amount of sand that needs to extract from sea in the future.

Chapter 3 Suitable locations for sand extraction
Based on the literature survey in chapter 2 a map is created, with the locations were sand extraction is allowed with the areas that have priority for sand extraction. This is realised by the development of a sand extraction location model within the ArcGIS model builder. This map is used as background in the interactive design tool and to determine the amount of space that has high priority for sand extraction.

Chapter 4 Sand demand vs. available area & safety buffers

In this chapter the first two research questions will be answered. The first one is based on the sand demand scenarios (discussed in chapter 2) and the amount of space that has high priority for sand extraction (calculated in chapter 3). The first part of the second research question can be answered based on the literature survey common practice and legislation discussed in chapter 2. To answer the second part of the second research question, additional research is needed to the morphological influence of sand extraction. In paragraph 4.3 a start is made with this research.

Chapter 5 Interactive design Tool for sand extraction

To answer the third research question an interactive design tool will be developed (in which we can see where sand extraction is allowed and that shows the morphological effect of a sandpit with random dimensions and orientations in any location in the North Sea after a certain number of years). This research is a pilot of the 'Building with Nature' innovation programme, within the case called 'Sustainable development Holland coast'. Therefore MapTable is used to develop this interactive design tool for sand extraction. Due to the fact that MapTable software is already used within other 'Building with Nature' projects in the river environment. To use the MapTable for the marine environment, a new MapTable case 'Holland Coast' needs to be developed, with a WAQUA schematisation of the Dutch coast. In addition a morphological model is needed, therefore we need to find out which morphological model is most suitable to use within the MapTable/design tool. Finally, a way has to be found on how to implement the morphological model into the MapTable. Chapter 5 will elaborate this.

Chapter 6 Discussion

The discussion describes limitations and uncertainties of this research and how these can be solved in the future.

Chapter 7 Conclusion & recommendation

The last chapter provides the conclusions and recommendations. All research questions will be answered according to the structure of the research questions. Afterwards, recommendations for changes in legislation for sand extraction are given and suggestions on how the interactive design tool could be improved for further research.

2. Literature survey of sand extraction

2.1 Introduction

On the Dutch part of the North Sea there are a lot of user functions, which interests must be respected. The most important functions are shown in table 1.

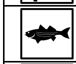
	Extraction of surface minerals
	Shipping
	Military area
	Oil and gas extraction
	Long term safety against flooding from sea
	Cables and pipelines
	Fishing
	Recreation
	Wind farms
	Protected nature
	Mari culture

Table 1: List of symbols used for the user functions in the Dutch part of the North Sea

The locations of the user functions oil and gas extraction, cables and pipelines are shown in figure 2 and the location of military area, wind farms and protected nature in figure 3. The functions recreation, long term safety against flooding from sea, mari culture are taking place in the area landward of the established NAP -20 meter depth contour line (unfortunately there is no spatial distribution found for these user functions). The functions shipping and fishing are widely spread over the North Sea, these functions can be easily combined with sand extraction (paragraph 2.4) therefore the exact locations are not shown in this research but can be found in IBN 2015 (2009).

Sand extraction is covered by the user function 'Extraction of surface minerals' and is described in more detail in the next paragraph (2.2). A detailed description of the other user functions is given appendix B.

Other important information from literature for this research is:

- The common practice and legislation for sand extraction (paragraph 2.3)
- The interaction between sand extraction and other user functions (paragraph 2.4)
- The expected future developments in the user functions that are influencing sand extraction (paragraph 2.5)
- Future sand extraction scenarios (paragraph 2.6)

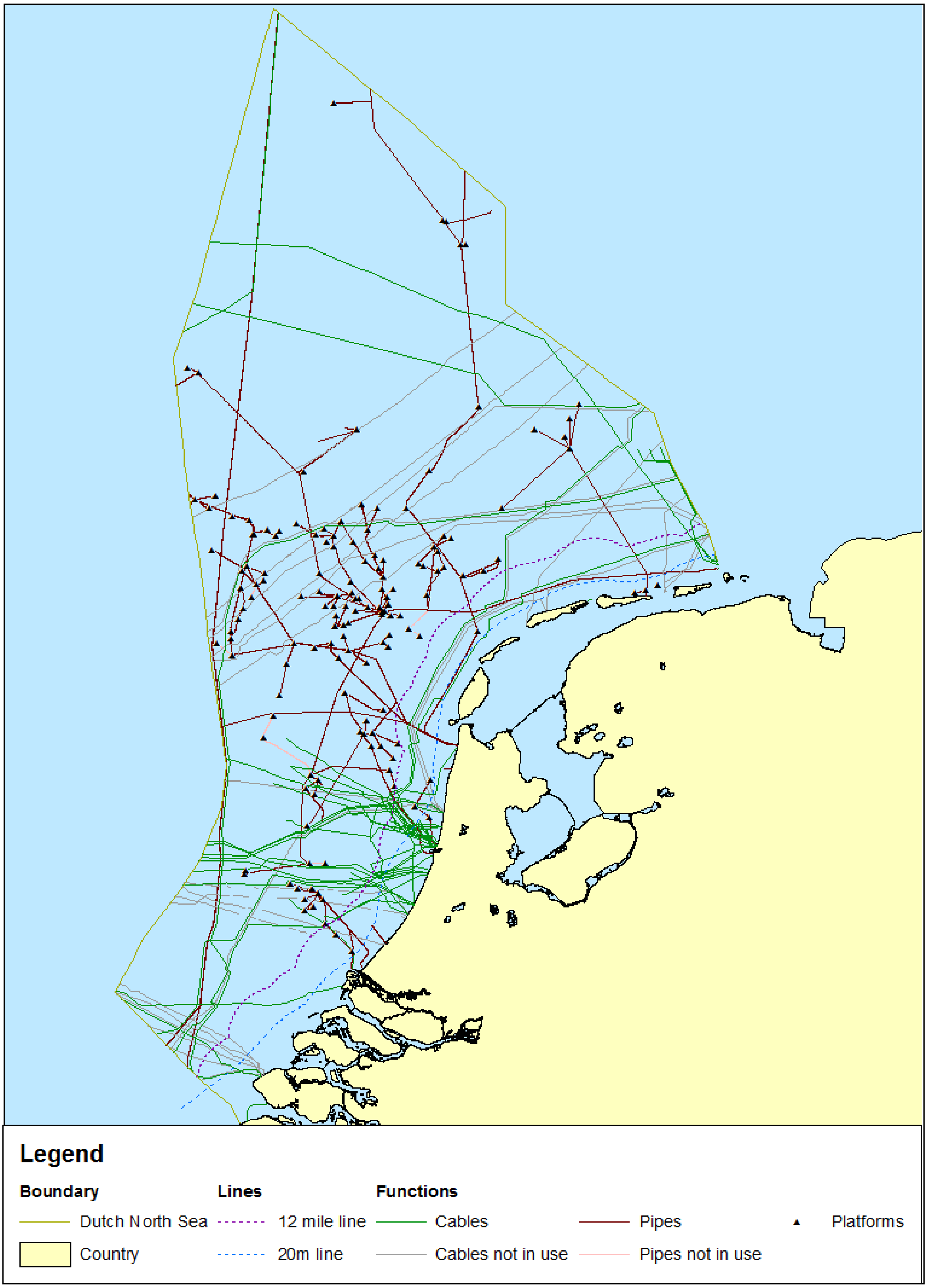


Figure 2: Spatial distribution of the user functions: cables, pipes and platforms

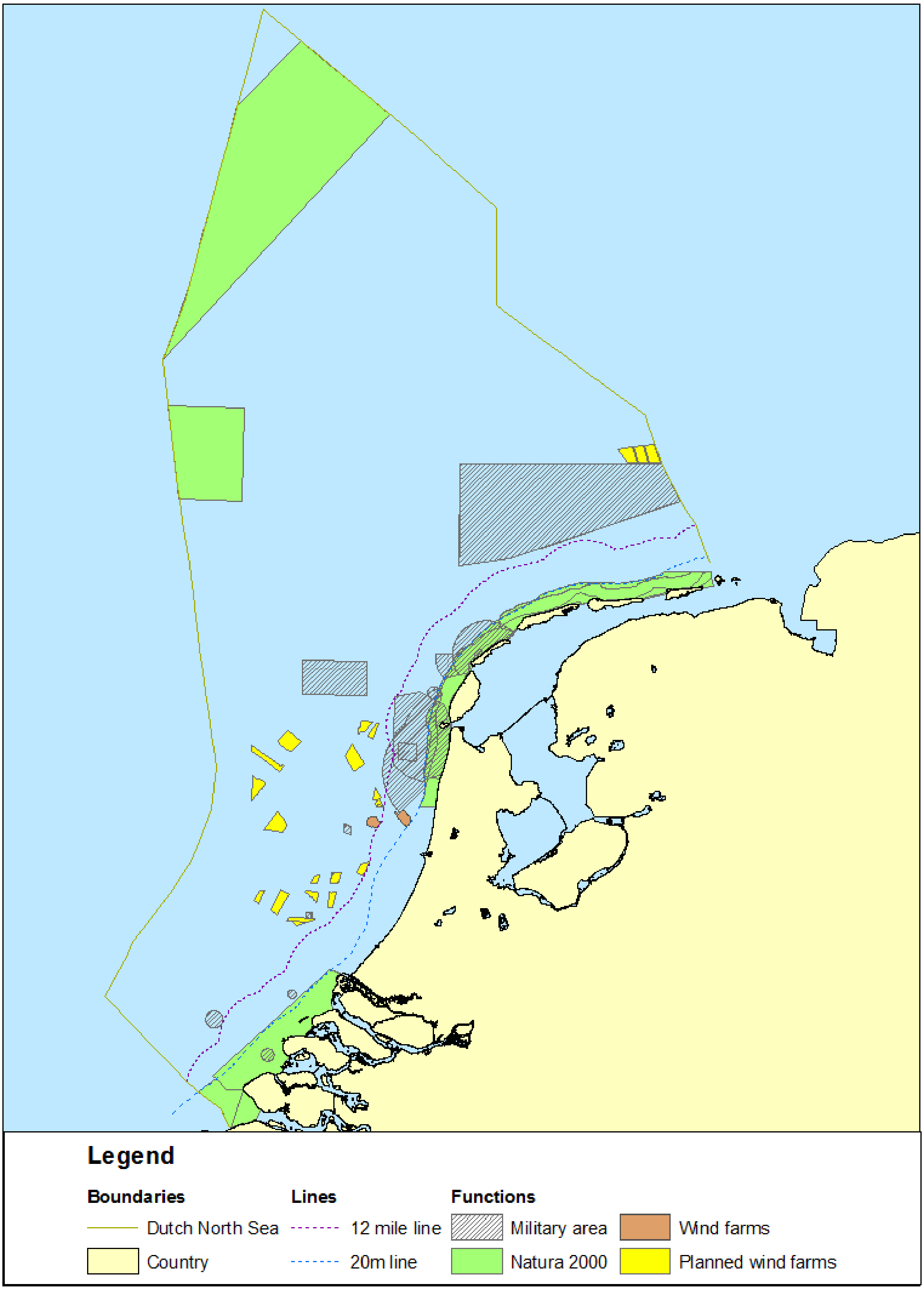


Figure 3: Spatial distribution of the user functions: nature, military area, wind farms and planned wind farms

2.2 Introduction on sand extraction

Current use

Minerals are extracted from the sea bed of the North Sea; these are mainly sand and gravel. Of all the countries around the North Sea, the Netherlands extracts most sand of all, annually 25 million m^3 per year (Van der Wal et al., 2009a). Sand can be extracted from dredged navigational routes, and the shelf itself. Sand extraction in the North Sea includes the extraction of replenishment sand, fill sand (also known as construction sand), concrete and masonry sand. Replenishment sand is used for coastal reinforcement through sand replenishment. Fill sand, concrete and masonry sand are used for construction and infrastructure, while fill sand is also used to prevent flood risks (in dykes). Furthermore there is additional extraction sand needed for projects like the Maasvlakte 2 (Beleidsnota Noordzee 2009-2015, 2009).

In The Netherlands sand extraction, apart from a few exceptions, is only permitted outside the established NAP -20 meter depth contour line (Noordzeeloket, 2010). A permit is needed to extract sand, more detailed information about the legislation for sand extraction can be found in chapter 2.3.

Future developments

The general expectation is that the demand to sand from the North Sea will increase in the future, as a consequence of expected sea level rise, demand for more sand to maintain the coast line and limited availability of sand on land (Beleidsnota Noordzee 2009-2015, 2009). Sand extraction could also increase due to potential projects like the construction of the Westerschelde container terminal or an airport in sea. Future sand extraction scenarios are described in paragraph 2.6.

2.3 Common practice and legislation for Sand extraction

Legislations vs common practice

Legislation in the Netherlands has been provided by the government and international law. Policy has been developed in parallel with the legislation. Policy and legislation together ensure that permits are needed for activities such as sand extraction. Before a permit is given an Environmental Impact Assessment (EIA) study is frequently necessary. Eventually permission for sand extraction is granted under certain conditions. These conditions are the common practice of legislation. The relation between legislation and common practice is shown in figure 4.

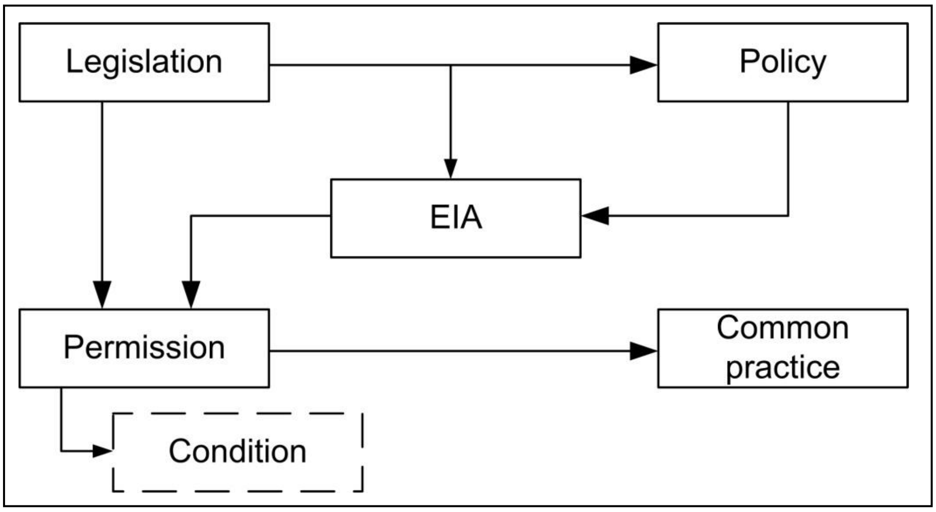


Figure 4: Legislation vs common practice

Regulation and policy for sand extraction in the Netherlands have been elaborated in the 'National Water Plan' and in the past in 'Regionaal Ontgrondingenplan Noordzee' (RON2, 2004), 'Nota Ruimte' (2006) and 'Beleidsnota 2009-2015' (2009). International North Sea legislation is largely determined by international frameworks, like the UN Convention on the Law of the Sea (UNCLOS) (the legal framework within which all marine measures must be taken), OSPAR Convention (the regional convention for the protection of the environment of the North-East Atlantic), the Birds and Habitats Directives and the Marine Strategy Framework Directive. The aim of the last two is to achieve a sound environmental water system and a sustainable balance between economy and ecology.

Terms and Conditions

Sand extraction is not allowed in all situations, due to the fact that sand extraction can have negative effects on the morphology and ecology. This results in that some user functions could not be combined with sand extraction (more information about which user functions could not be combined with sand extraction is given in paragraph 2.4). To identify where sand extraction is allowed, there are terms and conditions for sand extraction. These terms and conditions are preventing or minimising negative effects.

General terms and conditions are:

- Sand extraction is not permitted in the near shore zone landward of the established NAP -20 meter depth contour line. Exceptions to this are sand extraction from fairways (Euromaasgeul en IJgeul), the construction of transhipment pits, extraction where removal of sand at this location contributes to coastal protection, and shell mining (RON2, 2004).
- Between the established NAP -20 meter depth contour line and the 12-mile line there are areas reserved for sand extraction. In these areas, sand extraction has priority over other designated uses. But seaward of the 12 mile line other functions of national importance have preference over sand extraction (Beleidsnota 2009-2015, 2009).
- Excavation within military training areas is possible where this is compatible with military training (RON2, 2004).
- Sand extraction is neither permitted in a zone with a width of 500m (safety zone) around offshore platforms, wind farms, cables and pipes. This safety buffer guaranteed that sand extraction will not have a negative effect on offshore platforms, wind farms, cables and pipes (RON2, 2004).

This last condition about a 500m safety zone is only applicable for a sandpit with a maximal depth of 2 meters. In common practice this 500m zone will increase for deeper extraction, the safety buffer will increase for every meter deeper with 100 meters (personal communication: Ad Stolk, RWS North Sea Directorate). Yet there is no morphological underpin found for these safety buffers in the literature.

In order to guarantee the availability of sand for extraction in the area between the 12-mile line and the established NAP -20 meter depth contour line for as long as possible. The central government is looking to the possibilities of sand extraction at larger depths than the current 2 meters. In the past policy sand extraction was limited to a depth of 2 meters (National Water Plan, 2009). Nowadays there is a distinction for sand extraction in the North Sea between regular sand extraction (shallow 2m maximum and small < 500 ha) and large-scale and / or deeper sand extraction. For large-scale and/or deeper sand extraction additional research like an EIA or an ecological study is needed to get permission, this is shown in table 2 (RON2, 2004).

amount	area	Extraction depth	research
< 10 million m^3	< 500 ha	2 m maximum	-
< 10 million m^3	< 500 ha	> 2 m	Ecological study
> 10 million m^3	< 500 ha	>2 m	EIA
> 10 million m^3	> 500 ha	2 m maximum	EIA
> 10 million m^3	> 500 ha	>2 m	EIA

Table 2: Criteria for additional studies related to sand extraction

Furthermore there is a financial issue for the location of the sandpits. Sand extraction can be cost effective by extracting it as close to the coastal or on-shore location of the sand requirement as possible. Every kilometre further away increases the cost of sand extraction by four percent (Beleidsnota 2009-2015, 2009).

Environmental impact assessment (EIA)

The extraction of sand from the seabed can have significant physical and biological effects on the marine and coastal environment. The significance and extent of the environmental effects are depending on a range of factors listed in the 'ICES guidelines for the management of marine sediment extraction' (ICES, 2009) including:

- The location of the extraction area
- The nature of the surface and underlying sediment
- Coastal processes
- The design of the sandpit
- Method of extraction
- Amount of the extraction and duration/frequency
- The sensitivity of habitats and assorted biodiversity,
- Fisheries
- Other uses in the locality.

These factors are discussed in an EIA. Organisations that are responsible for authorising sand extraction use this EIA to evaluate the nature and scale of the effects and to decide whether a proposal can be proceed. It is necessary that an adequate assessment of the environmental effects is executed. As an example, it is important, to determine whether the application is likely to have an effect on the coastline, or have potential impact on fisheries and the marine environment (ICES, 2009).

Permit

To receive a permit the reasons of major public importance to extract surface minerals are very important. These reasons can be substantiated in the following way (Beleidsnota 2009-2015, 2009):

- The extraction of surface minerals to prevent floods by means of coastal replenishment and for the benefit of infrastructure, housing and industry meets a key basic need for performance of Dutch society.
- Economical and high-quality use is a key principle. Nevertheless, the Netherlands requires approx. 60 million m^3 of sand (fill sand and concrete and masonry sand) a year. Extraction in the Netherlands limits the transfer of the spatial problems to neighbouring countries and to other environmental themes, such as transport problems and additional energy consumption that result from supply over longer distances.
- North Sea sand is the only real possibility for protecting the Dutch coast against flooding by means of sand replenishment.

A permit contains limitations regarding the area that can be mined and the volume to be extracted. The permit is limited to a number of years for which it is valid.

The authorisation process takes a maximum of 6 months that starts at the moment of filing in the permit. Another 6 weeks will be added if there is an appeal (Noordzeeloket, 2010). In case that there is an EIA needed, another 5 weeks are needed to judge the EIA. The EIA has to be submitted at the same time of filling in the permit. The time to create an EIA is not included in the authorisation process (personal communication: Ad Stolk, RWS North Sea Directorate).

2.4 Interaction between sand extraction and the other user functions

This chapter describes the interaction between sand extraction and the other user functions in the North Sea.

Table 3 gives an overview of which sea user function can be combined (green) or is temporally allowed (orange) or not allowed (red) with sand extraction. This is based on the following literature: Beleidsnota Noordzee 2009-2015 (2009), IBN 2015 (2009), Nationaal water plan 2009-2015 (2009) and information from Noordzeeloket (2010). A more detailed description is given in appendix C.

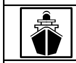
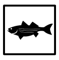
	Interaction with sand extraction	
	Shipping and sand extraction interact mainly positive with each other.	
	Fishing and sand extraction are allowed in the same areas at this moment, on the long term there are no direct negative effects expected.	
	Sand extraction and military areas can interact in a positive way to open military areas for sand extraction when there are no military trainings in those areas. Sand extraction is not allowed at military ammo dump locations in sea.	
	Recreation takes place landward of the established NAP -20 meter depth contour line, in this area sand extraction is very limited. If sand extraction is needed in a recreation area this could take place when the area is not in use by recreation, like the winter.	
	Sand extraction is mostly not allowed in Natura2000 areas, some exceptions are possible. The rules for these areas are similar to the area landward of the established NAP -20 meter depth contour line.	
	Oil and gas extraction interact negative with sand extraction. Sand extraction is not allowed within a circle with a radius of 500 m around the platforms.	
	To maintain the sand balance in the coastal area and prevent erosion on large scale, sand extraction inland of the established NAP -20 meter depth contour line is not allowed. There are some exceptions possible.	
	Cables and pipes could not be combined with sand extraction. Sand extracted within an area of 500 metres on either side of cables and pipes is not allowed.	
	Around wind farms sand extraction is not allowed in a zone of 500 meters around the farms.	
	Sand extraction cannot be combined with Mari culture.	

Table 3: User functions in relation with sand extraction.

2.5 Expected future developments in the user functions that are influencing sand extraction.

The expected future development for each user function in the Dutch North Sea can be found in appendix B. In this paragraph, only the future developments in user functions that are influencing the available area for sand extraction in the future are discussed. These user functions are wind farms, power cables and protected nature.

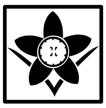
Future developments wind farms

In 2005, the North Sea is released for further development of wind farms. Ever since, many new initiatives are developed and in 2011 the wind energy will grow with 950 MW. At the same time the government, companies and civil society organisations are working on a strategy for developing more wind parks for the period 2010-2020. With the intention that, for the longer term, offshore wind energy will provide a substantial share of sustainable energy in the Netherlands.

The target of the government programme ‘Clean and Efficient’ is to generate 20% sustainable energy by 2020, with the target to increase to 40% by 2050. In addition, a target figure of an installed power capacity of 6,000 MW of wind energy in the North Sea in 2020 has been formulated; a total area of 400 up to 1000 km^2 is needed to achieve this (figure 3 shows planned wind farms until the year 2020). Achieving this object is of national importance (Beleidsnota Noordzee 2009-2015, 2009).

Future developments cables and pipes

Expected future developments for cables are that the amount of power cables is likely to increase; because of the liberalisation of the European electricity market there is a demand for an international power supply link (interconnectors). The interconnector cable between the Netherlands and Norway (NorNed cable) is already present and another interconnector is currently under construction between the Netherlands and the UK (BritNed cable). Other reasons for the growth of power cables are the growth of wind farms at the North Sea; the construction of wind farms will generate an additional need for power cables between the wind farms and the Dutch coast. The government is exploring possibilities for so called ‘sockets at sea’ for the benefit of large-scale wind farms. (Beleidsnota Noordzee 2009-2015, 2009)



Future developments protected nature

The marine biodiversity is under increasing pressure, and natural resources are being depleted. It is essential that in the future additional attention will be paid to this growing spatial pressure on Nature. This is also what The Delta commission (2008) suggests, by advising to provide more space than is currently given to nature (Nationaal water plan 2009-2015, 2009). It is expected that the Natura2000 network will experience future adaptation e.g. to include more marine species or habitats in the future.

Conclusion future developments

Due to the growth of the user functions wind farms, power cables and protected nature, the pressure on space in the North Sea will increase. This could result in conflicts between user functions in the future.

2.6 Future sand extraction scenarios

Each year approximately 25 million m^3 of sand is extracted from the Dutch North Sea. At this moment 12 million m^3 is extracted for coastal replenishment and 13 million m^3 for fill sand (construction sand). The general expectation is that future demand to sand from the North Sea will increase (paragraph 2.2), due to expected sea level rise, demanding more sand to maintain the coast line and limited availability of sand on land (Beleidsnota Noordzee 2009-2015, 2009).

In the past a lot of different scenarios have been developed for the sand demand from the North Sea, like the survey of Verdonkschot et al. (1997). In this survey Verdonkschot et al. described a minimum, middle and maximum scenario, but these scenarios are dated. Rijkswaterstaat is currently developing new scenarios for the expected sand demand from Sea. A preview of these scenarios is provided by Ad Stolk (RWS, North Sea Directorate). This preview is used as a basis for the scenarios used in this research:

Scenarios

1. Low scenario, based on the replenishment quantities listed in the National Water Plan (2009):
   Coastal replenishment: 20 million m^3 per year
   Fill sand: 13 million m^3 per year
   Total needed: 33 million m^3 per year
2. Middle scenario, based on the high sea level rise scenario (W+) from KNMI (2006):
   Coastal replenishment: 40 million m^3 per year
   Fill sand: 25 million m^3 per year
   Total needed: 65 million m^3 per year
3. High scenario, based on the maximum sea level rise scenario from the Delta Commission (2008):
   Coastal replenishment: 85 million m^3 per year
   Fill sand: 25 million m^3 per year
   Total needed: 110 million m^3 per year

It is assumed that the various scenarios occur in phases that will go on to 2100. The decision should be made before executing a scenario and the necessary capacity needs to be available.

Expected is that from 2015 sand for coastal replenishment will reach a yearly amount of 20 million m^3 in each scenario (National Water Plan, 2009). For scenario 2 it is expected that this 40 million m^3 per year sand for coastal replenishment is needed in 2025 and for scenario 3 the 85 million m^3 in 2050. The 25 million m^3 per year fill sand for scenario 2 and 3 is expected to be needed in 2025.

The scenarios in time are shown in figure 5.

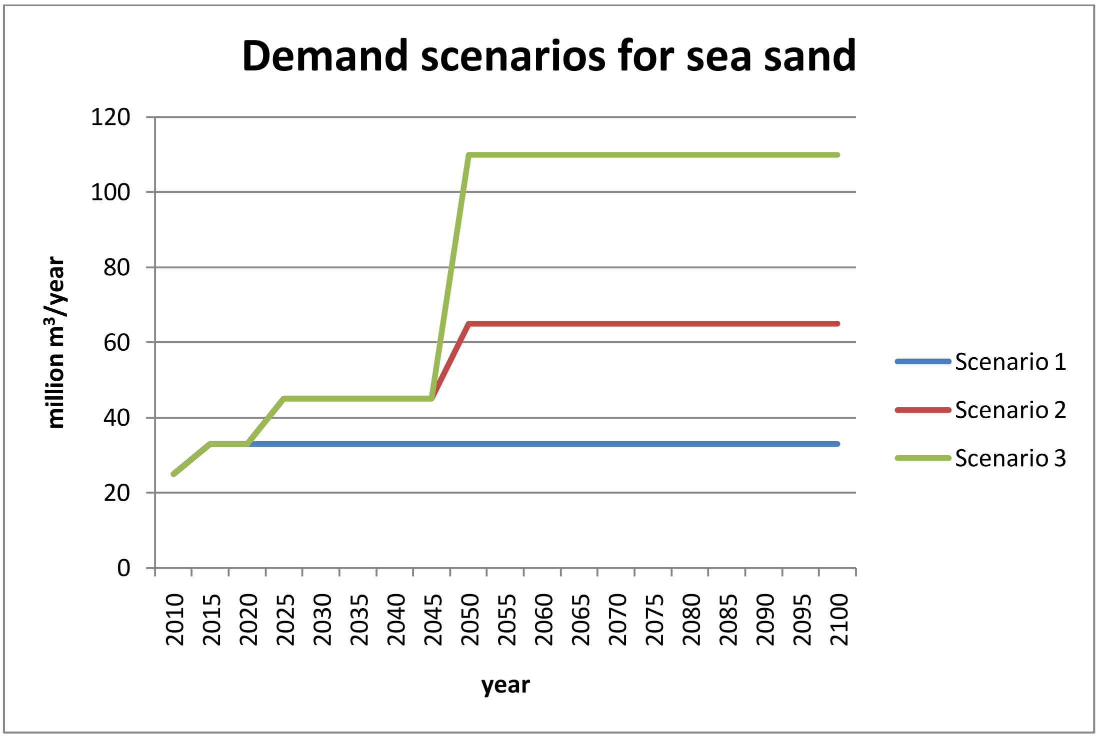


Figure 5: Demand scenarios for sea sand from the North Sea in the Netherlands

Demarcation of the scenarios

The following activities suggested by the Delta Commission (2008) are not taken into account in the scenarios: Building residential or industrial areas on artificial hills (terpen), construction of very wide dikes to prevent flooding and extending the coastline by one kilometre.

Furthermore, potential projects are not taken into account, like for example the construction of the Westerschelde container terminal and an airport in sea.

Necessary area

Table 4 shows the total amount of sand (in million m^3) that is needed for coastal replenishment and fill sand for each scenario until the year 2100. In table 5 is the amount of sand converted into the area that is needed for sand extraction for different excavation depths.

Period	Scenario 1	Scenario 2	Scenario 3
2010 - 2015	125	125	125
2010 - 2025	455	455	455
2010 - 2050	1280	1580	1580
2010 - 2100	2930	4830	7080

Table 4: Volume sand needed in million m^3 for each scenario until the year 2100 starting from 2010

Depth	Scenario 1	Scenario 2	Scenario 3
2m	1465	2415	3540
4m	733	1208	1770
6m	488	805	1180

Table 5: Sand extraction area in km^2 for the period 2010-2100 needed for each scenario with different depths

3. Suitable locations for sand extraction

3.1 Introduction

Based on the information of chapter 2 a map with the locations where sand extraction is allowed and which locations have priority for sand extraction can be created.

This map is important during this research for two reasons:

1. To be able to calculate the amount of space (volume) that has high priority for sand extraction.
2. This map is used in the interactive design tool for sand extraction.

This map is created by the development of a sand extraction location model within the ArcGIS model builder, a software package from ESRI (2010). Within the model builder all needed ArcGIS functions can be combined to one model. When the model has been built, it is easy to make adjustments, like changing shape files with changed spatial distribution of any user function or changing the safety buffer of 500 meters around cables in a safety buffer of 1 km if there are changes in legislation. After any adjustment the model can be used again and the new output map is based on these adjustments. In this way it is easy to adjust the map when there are changes in legislation.

To create this sand extraction location model the common practice and legislation for the allowed locations and priority for sand extraction needs to be transformed into basic GIS rules. These GIS rules are implemented in the model builder to create the sand extraction location model. The output of the model is a map with the locations in the Dutch part of the North Sea where sand extraction is allowed and which areas have priority for sand extraction. This model gives as an extra output the area of each priority zone and the exclusion zone. These calculated areas can be used to see how much space there is available for sand extraction. The ArcGIS model can be used only within ArcGIS software and is used separated from the interactive design tool for sand extraction (MapTable).

This chapter starts with the transforming of common practice and legislation for sand extraction into GIS rules (3.2). After the transformation, the rules are implemented in the ArcGIS model builder (3.3). Finally, after processing the model, the output map is shown in paragraph 3.4.

3.2 Transform common practice and legislation into GIS rules

Based on the interaction of sea user functions with sand extraction (paragraph 2.4) and the common practice and legislation (paragraph 2.3) an exclusion zone is defined, by the following rules where sand extraction is not allowed (there are no exceptions):

User function	Rules defining where sand extraction is NOT allowed
Wind farms	Create a buffer of 500 meters around the wind farm*
Oil and gas extraction	Create a buffer of 500 meters around the platforms*
Cables and pipes	
Pipes	Create a buffer of 500 meters on both sides of the pipes*^
Cables	Create a buffer of 500 meters on both sides of the cables*^
Military areas ammo dump locations	Ammo dump locations

Table 6: User functions and rules for exclusion zone. * Maximal 2 meters excavation, ^ when cables or pipes are no longer in use an exclusion zone is not necessary.

The rules in table 6 are implemented in the model builder, by using the functions *buffer* to create a buffer around the user functions. Planned wind farms, pipes and cables that will be realised before 2020 are taken into account by creating the exclusion zone. With the function *union* these buffers and the ammo dump locations are combined to the **exclusion zone**.

The North Sea can be distinguished in three zones. The zone landward from the established NAP -20 meter depth contour line (20m_zone), the zone between the established NAP -20 meter depth contour line and the 12mile line (20m_12mile_zone) and the zone seaward from the 12mile line (EEZ). The different zones are shown in figure 6. These zones are used to analyze the suitable locations for sand extraction.

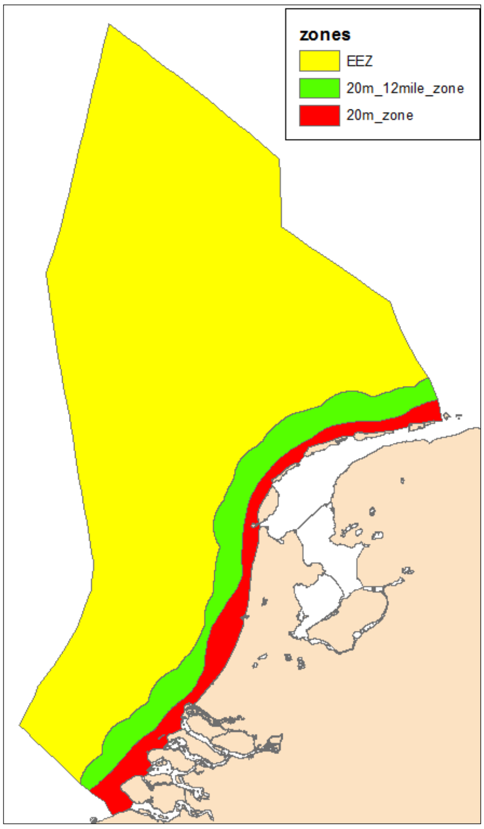


Figure 6: Different zones in the Dutch North Sea continental shelf

The user functions long term safety against flooding, mari culture and protected nature are laying in most situations in the 20m_zone, these functions cannot be combined with sand extraction. In legislation sand extraction is not allowed in the 20m_zone (some exceptions are possible). For this reason the 20m_zone gets the lowest priority for sand extraction. There are some parts of the protected nature (Natura2000) that are laying outside of the 20m_zone, the legislation for these areas is the same as for nature that lays inside of the 20m_zone, therefore these nature areas have the same priority as the 20m_zone (lowest priority).

In the zone between the established NAP -20 meter depth contour line and the 12-mile line (20m_12mile_zone) sand extraction has priority over other designated uses (paragraph 2.3). This zone gets the highest priority for sand extraction. The zone seaward of the 12-mile line (EEZ) gets middle priority, based on considerations of cost efficiency and priority for other user functions as wind farms.

Sand extraction in military areas is possible (except for ammo dump sites), but this needs to go in consultation with the department of Defence. Therefore the military areas are mentioned separately in table 7. This table gives a legend of the priority distribution for sand extraction.

Priority 1	20m_12mile_zone and no military area	
Priority 1 (Military)	Military area in the 20m_12mile_zone	
Priority 2	EEZ and no military area	
Priority 2 (Military)	Military are in the EEZ	
Priority 3	20m_zone and no military area	
Priority 3 (Military)	Military are in the 20m_zone	
Exclusion zone	Areas where sand extraction is not allowed	

Table 7: Priority zones with legend

3.3 ArcGIS model builder, development of the sand extraction location model

Needed data

Different data layers are used in the sand extraction location model. All the data is provided by Rijkswaterstaat and is downloaded from the website 'Noordzeeloket.nl' (with an account). For the user functions the following shape files are used (table 8):

Use function	Shape file
Protect nature	Natura2000
Pipes (except abandon pipes)	DNZ_leidingen_ETRS89
Cables (except abandon cables)	DNZ_electra_telecom_kabels_ETRS89
Wind farms	DNZ_bestaande_windparken_ETRS89
Planned wind farms	DNZ_toekomstige_windparken_ETRS89
Military	DNZ_militair_ETRS89
Oil and gas extraction	Platforms

Table 8: Needed user function data

The following shape files (table 9) are used as boundaries to construct the different zones (20m_zone, 20m_12mile_zone and EEZ) shown in figure 6.

Boundary	Shape file
Established NAP -20 meter depth contour line	nap20door
12 mile line	DNZ_12_mijl_grens_ETRS89
EEZ border	DNZ_grens_EEZ_ETRS89

Table 9: Needed boundary data

To use these shape files in MapTable a transformation is needed to the 'RD_new' projected coordinate system.

Description of the model created with ArcGIS model builder

An overview of the model built with the ArcGIS model builder is shown in the appendix D, figure 7 shows a simplification of this model.

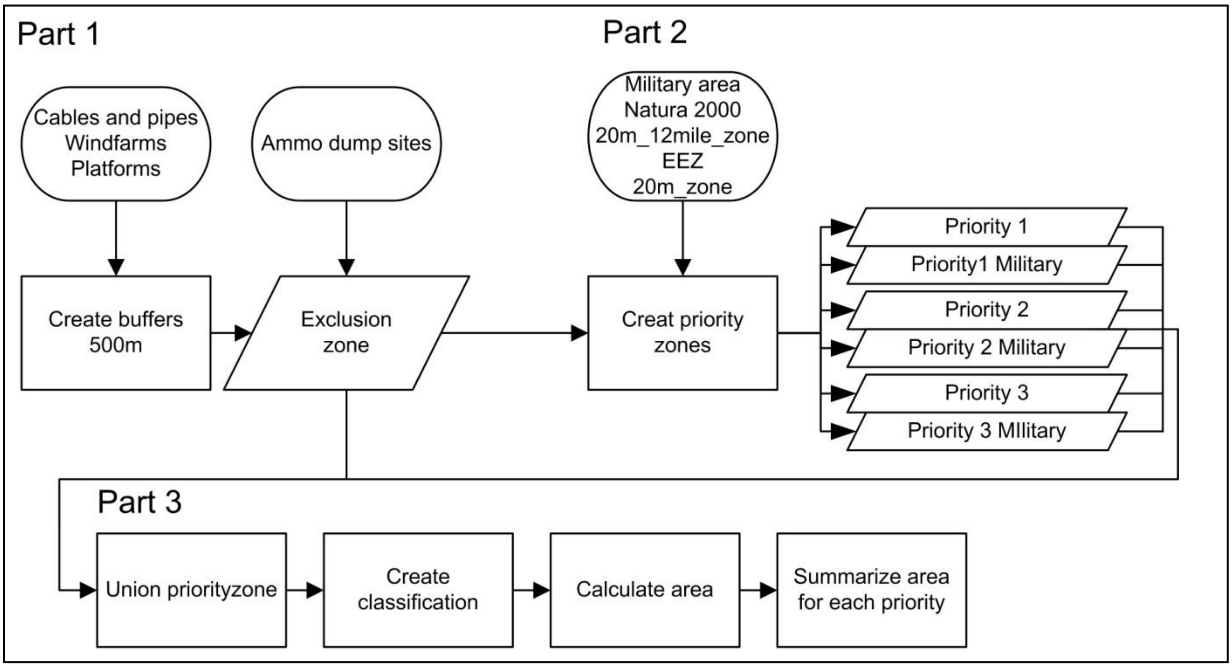


Figure 7: Simplification of the model built in the ArcGIS model builder

The model is defined in three parts. In the first part the exclusion zone is created, this is described in the first part of paragraph 3.2. The only extra step is the limitation of the exclusion zone to the Dutch part of the North Sea. In the second part the priority zones for sand extraction are defined, as mentioned in paragraph 3.2. The highest priority for the 20m_12mile_zone (without the exclusion zone and Natura2000), the second priority for the EEZ (without the exclusion zone and Natura2000) and the area in the 20m_zone plus the Natura2000 (without the exclusion zone) have the lowest priority. Military areas in each zone have the same priority of the zone but are distinguished by shade lines. A legend of each zone is shown in table 7.

The third part is realised in a separate model. In this part the area is calculated for each priority zone (class). First the priorities and exclusion zone are combined in priority_union.shp, then two extra fields are added 'class' and 'area'. In addition the union layer is *explode,* in this way each polygon can be selected separately. In the field class the different priority are defined and in the field area the total area of each polygon is calculated. Finally the total area of each priority zone is calculated by using the Summary Statistics tool. Taking into account areas bigger than 1 km^2 only; this is realised by selecting only areas bigger than 1 km^2 before using the summary statistics tool.

3.4 Results: map with suitable locations for sand extraction

After processing the sand extraction location model the following map (figure 8) with priority areas and exclusion areas for sand extraction is created.

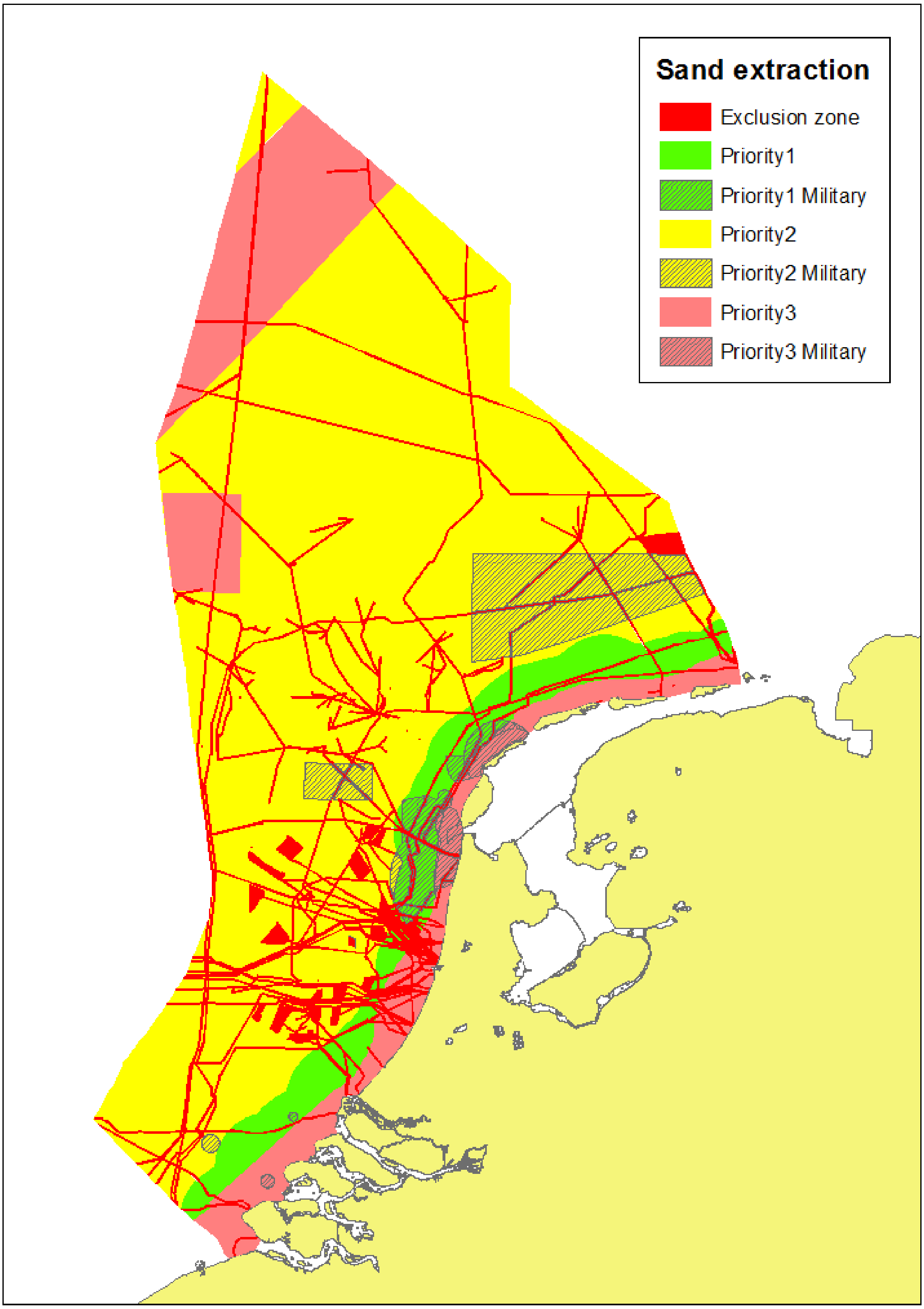


Figure 8: Priority zones and exclusion zones for sand extraction in the Dutch North Sea

The green zones (priority 1) are the most suitable zones to extract sand based on common practice and legislation for sand extraction. The red zones (exclusion zone) are the zones where sand extraction is not allowed. In the yellow zones sand extraction is allowed but the priority is lower because of the long distance from the shore. In the pink zones sand extraction is in most situations not allowed only in special situations sand extraction could be possible. Military areas are distinguished by gray shade lines.

The specific area of each zone is given in table 10 (areas smaller than 1 km^2 are neglected):

	Area (km^2)		
Priority	Normal	Military	Total
Priority 1	3464	721	4185
Priority 2	35584	3233	38817
Priority 3	8200	493	8693
Exclusion zone			7836

Table 10: Specific area of each zone in km^2

4. Sand demand vs. available area & safety buffers

4.1 Introduction

The most important developments around sand extraction that have been discussed in chapter 2 are:

- Expected increase in sand demand (scenarios)
- Focusing on sand extraction at larger depths then the current 2 meters
- There is no morphological underpinning for the used safety buffers around offshore platforms, wind farms, cables and pipes.

Furthermore new planned activities as wind farms and international power supply link cables in the Dutch North Sea with the expected increase demand for sand will increase the pressure on the available area in sea. Based on these developments the spatial pressure on the Dutch part of the North Sea is evaluated on a point of view of sand extraction. This will be described in paragraph 4.2 where the sand demand will be compared with the amount of sand that is available for sand extraction.

Another interesting point is that safety buffers around offshore platforms, wind farms, cables and pipes are not morphologically underpinned. Secondly there is no official legislation found for safety buffers in case of sandpits deeper than 2 meters. This shortcoming in legislation gives rise to investigate the needed safety buffers based on morphological influence. Based on this investigation a start on the morphological underpinning of the necessary safety buffers with different depths is made. This investigation and morphological underpinning for safety buffers is described in paragraph 4.3.

4.2 Comparing sand demand with the amount of sand that is available for sand extraction

The area needed for sand demand is based on the different sand scenarios, discussed in chapter 2.6 table 5. The amount of area that is available for sand extraction per priority zone is discussed in chapter 3.4 table 10. These tables are combined in table 11.

Area needed per sand demand scenarios					Specific area of each zone			
	Area (Km^2)					Area (km^2)		
Depth	Scenario 1	Scenario 2	Scenario 3		Priority	Normal	Military	Total
2m	1465	2415	**3540**		Priority 1	3464	721	**4185**
4m	733	1208	1770		Priority 2	35584	3233	38817
6m	488	805	1180		Priority 3	8200	493	8693
Needed sand until the year 2100					Exclusion zone			7831

Table 11: Compare area for sand demand scenarios with available area for each zone (in km^2)

Table 11 shows the needed space for sand demand per scenario with present space for sand extraction in the priority zone 1 (the area designated for sand extraction). A comparison shows that there is enough sand available in the priority zone 1 for each sand demand scenario (until the year

2100) and excavation depth of minimal 2 meters. Planned wind farms, cables and pipes until the year 2020 are only taken into account in this comparison.

Given there is sufficient sand available, in the area that has priority for sand extraction, it does not mean that, in the future, no conflicts will arise between user functions on spatial planning. The pressure on the spatial planning in the North Sea will increase more in the future due to the following two facts:

- Developments after 2020, which are unknown at this moment, as new wind farms or other constructions in sea.
- Sand can be extracted cost effective by extracting it as close as possible to the coastal or on-shore location of the sand requirement. Every kilometre further away increases the costs of sand extraction by four percent (Beleidsnota 2009-2015, 2009). Due to this financial issue the pressure will be high on available areas close to the coast or areas where sand is needed.

Based on these two reasons it is interesting to look closer on how the available areas for sand extraction can be optimised. Therefore a closer look to the safety buffers that are necessary around offshore platforms, wind farms, cables and pipes is taken in the next paragraph.

4.3 Safety buffers around offshore platforms, wind farms, cables and pipes for different extraction depths

There is no morphologically underpinning found for the safety buffers (500 meters for sandpits with a maximum depth of 2 meters and plus 100 meters for every meter deeper) around offshore platforms, wind farms, cables and pipes (paragraph 2.3).

To make a morphological underpinning it is important to know what the maximum depth change above or very close to offshore platforms, wind farms, cables and pipes is after a given morphological time scale. In principle this maximal allowed depth change is zero, however a small morphological depth change is allowed due to the fact that natural processes will change also the morphological depth when there is no sandpit. For this reason the allowed morphological depth change is assumed to be 10 cm. Also, there is no information found on the morphological time scale. Therefore it is necessary to make an assumption on the morphological time scale. Actually this time scale should be based on the lifespan of a user function. This could be 1 year up to more than 100 years. In this case a morphological time scale of 10 years is assumed.

Based on these 2 assumptions the safety area of 500m is evaluated with the Twente morphological sand extraction model developed by Roos and Hulscher (2004) and adjusted by van der Veen (2008); this model is described in appendix E. This is realised by using an extreme situation based on Roos et al. (2008) who concludes that the morphological influence area around the sandpit depends on pit size, shape, orientation (with current direction), current velocity and water depth. Larger pits or a high current velocity will increase the area of morphological influence. The largest morphological influences are obtained for long and narrow pits, with a counter clockwise orientation roughly between 30° and 60°. Based on this information the parameters in table 12 are taken for an extreme situation.

M2 velocity	Water depth	Angle pit with M2	Length	Width
0.8 m/s	25 m	40 degrees	15000 m	1500 m

Table 12: Extreme conditions for a sandpit so that the morphological influence is large.

The M2 velocity and water depth are based on simulations with the WAQUA 'SIMONA-kuststrook-fijn-1999-v4' model. The angle of the pit with respect to M2 current, length and width are based on Roos et al. (2008).

To evaluate the safety buffer of 500m, a contour line of 500m is drawn around the sandpit (red line figure 9). If the morphological depth change contour line (blue line figure 9) stays inside this 500m buffer, offshore platforms, wind farms, cables or pipes will not be affected by morphological changes. This is the case in figure 9; the 500m safety buffer is content in this situation.

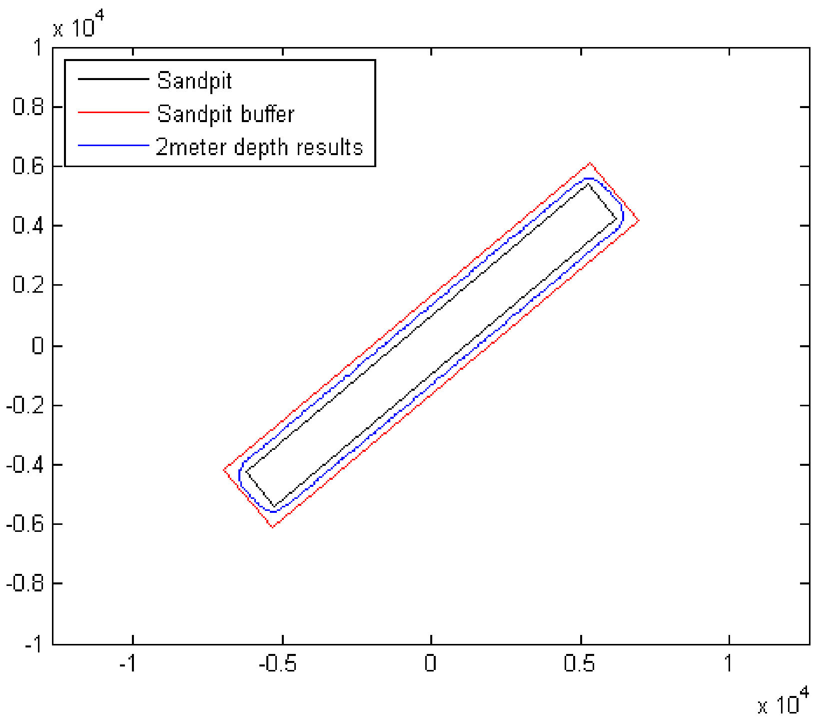


Figure 9: Morphological depth change for a sandpit of 2 meters deep with a safety buffer of 500 meters (current goes from left to right)

Now it is interesting to evaluate whether this buffer (500m) is as well suitable for an excavation depth larger than 2 meters. This is simulated for sandpits with an excavation depth of 4 and 6 meters. For sandpits deeper than 6 meters this model is not suitable. The resulting morphological depth change contour lines are shown in figure 10. This figure shows that the allowed morphological depth change contour line for 4 and 6 meters depth exceeds the safety buffer. This means that a larger safety buffer needed is for sandpits deeper than 2 meters. Based on these results the maximum distance between the sandpit and the allowed morphological depth change contour line is calculated. With these distances it is possible to determine the safety buffers for deeper sandpits. This is shown in table 13.

Pit depth (m)	Max distance pit – 10 cm depth contour line (m)	Safety buffer (m)
2	400	500*
3	556	600
4	845	850
5	1133	1150
6	1384	1400
*already in use (in legislation and common practice)		

Table 13: Calculated maximum distance between allowed depth change contour line and the sandpit & new buffers for pit depths of 3, 4, 5 and 6 meters

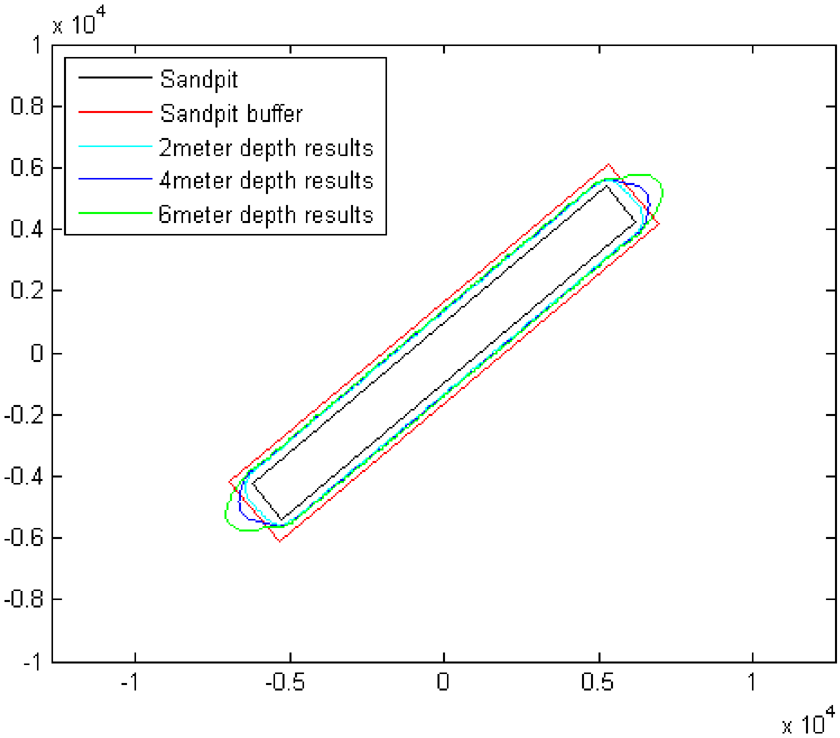


Figure 10: Morphological depth change for a sandpit of 2, 4 and 6 meters deep with a safety buffer of 500 meters

Table 13 shows that, the in common practice used rule for sandpits deeper than 2 meters (buffer increases with 100 meters for every meters deeper) is not applicable for sandpits with a larger depth than 3 meters.

Due to the fact that the morphological model uses a symmetric approach, these determined safety buffers could be underestimated. However there is also a reason for overestimation of the safety buffers, due to the fact that an extreme situation is used and these extreme conditions will take place only in a very small part of the North Sea. A site specific approach for individual sandpits to determine the needed safety buffer should be more suitable. This approach is also recommended due to the large variation in current velocity and water depth in the North Sea (figure 11).

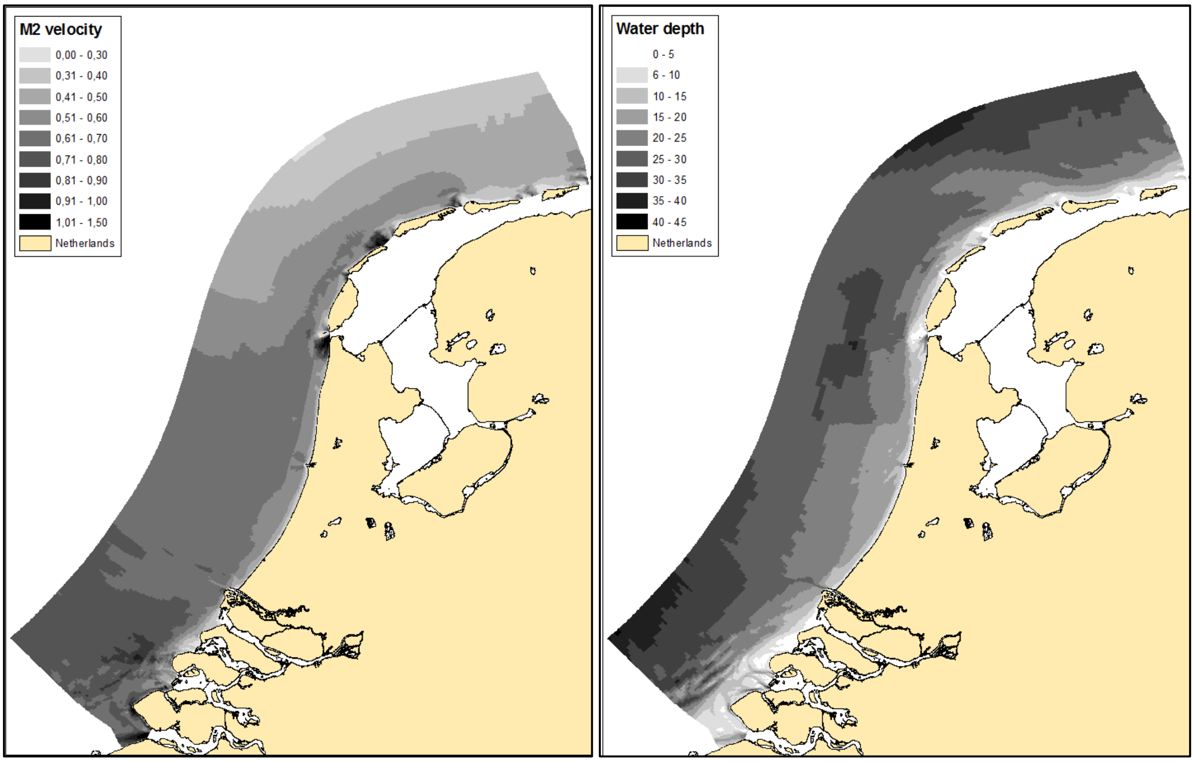


Figure 11: Current M2 velocity (left) and water depth (right) North Sea generated from WAQUA schematisation 'SIMONA-kuststrook-fijn-1999-v4'

5. Interactive design tool for sand extraction

5.1 Introduction

Paragraph 4.3 shows that the safety buffer around sandpits depends on the morphological influence area of sandpits, which depends on pit size, shape, orientation (with current direction), current velocity and water depth. Another conclusion from paragraph 4.3 was that it is interesting to use a site specific approach for individual sandpits to determine the needed safety buffer. The reason for this approach is that there is a huge variation in the needed safety buffer around a sandpit due to the large variation in current velocity and water depth in the North Sea and the fact that sandpits can have all kind of dimensions and orientations.

To deal with this site specific approach for individual sandpits an interactive design tool is developed in this chapter. With this tool it is possible to see where sand extraction is allowed and it shows the morphological effects of a sandpit with random dimensions and orientations in any location in the North Sea after a certain number of years. This tool enables us to determine the necessary safety areas around sandpits and the suitability of the selected location.

Due to the fact that this research is initiated within the 'Building with Nature' Innovation programme, within the case called 'Sustainable development Holland coast', MapTable software is used to develop this design tool. Because there are already plans for using this software within the case 'Sustainable development Holland coast' to show the effects of different possible interventions in the North Sea (Ouwerkerk 2009). MapTable is a software tool that is developed for 'Building with Nature'; developed by Meander/ Arcadis (Van der Werff ten Bosch, 2009) and financed by Rijkswaterstaat. The software plays an important role in the design phase and in online sharing of knowledge with different stakeholders in Space for the River projects. More information on the MapTable can be found in appendix F.

To develop an interactive design tool for sand extraction, by using the MapTable software, the following steps need to be taken into account:

- Decide which morphological model is most suitable to use in the MapTable to create an interactive design tool for sand extraction.
- Prepare the MapTable so it can be used for the Dutch North Sea, case 'Holland coast'.
- Implement the morphological model.

These steps are described in this chapter, followed by some example calculations.

5.2 Sand extraction models

There are different types of morphological models that describe the morphological effects around sandpits, Idier et al. (2010) distinguished three main classes of models and these are:

- The full process-based models (FPBM), which describe small-scale processes and resolve physical equations in the physical space (x,y,z,time).
- The idealised process-based models (IPBM), which take into account processes relevant to the scale of interest and resolve physical equations partly in the spectral space (wave vector, time), partly in the physical space.
- The conceptual models (CM), which aim to describe the general behaviour of a phenomenon, without describing the details of the underlying physical processes.

Idier et al. (2010) has describes the characteristics of a number of models belonging to these classes and Hommes et al. (2007) gives some example models for each class. Table 14 shows an overview of the characteristics per model type: advantages, disadvantages, output, time/space scale, needed licences and examples are shown for each class.

	full process-based models	**idealised process-based models**	**conceptual models**
General	Contain descriptions of all processes	Resolve physical equations partly in the spectral space, partly in the physical space	Use of calculation rules for describing a phenomenon
Advantages	Quite reliable results, on the short- or mid-term (Van Rijn et al., 1999; Tonnon et al., 2007; Sutherland et al., 2004)	Takes only processes into account relevant to the scale of interest Much faster than full process-based models	No time consuming Essay to use
Disadvantages	Highly sensitive to quality of local boundary and initial conditions Time-consuming, for sensitivity analysis	Can be of limited use for specific situations. (In case of linear approximation, calculations on deep sandpits or in shallow water are not possible (Roos and Hulscher, 2004))	Field data required Require qualitative support from process-based model results, or from field experience (to validate) limited in output
Outputs	Various parameters	Limited parameters	Very limited parameters
Time/space	Few meters to hundreds km Minutes to decades	Few meters to hundreds km Decades to century	Event scale or long-term
licences	Most are expensive	Freeware	Freeware
Examples	Delft2D/3D Telemac mu-SEDIM SUTRENCH	Twente model (Roos and Hulscher, 2004, Van der Veen, 2008). Utrecht model (De Swart and Calvete, 2003)	Amplitude-Evolution Model

Table 14: Characteristics of full process-based, idealised process-based and conceptual models.

Appendix F shows that models that are implemented in MapTable need to have a short calculation time and needs to be free to use. For this reason full process-based models are not suitable to use in

MapTable, in addition it is difficult to represent the actual environmental data for the whole North Sea in full process-based models (van der Veen, 2008). Conceptual models are not suitable because there is no good field data available for sand extractions in the North Sea that can validate and calibrate the model. Additional, a weakness of conceptual models is that they have limited output. More suitable are idealised process-based models because they have a short calculation time, operate on a large scale and are free to use. For this reason an idealised process-based model is selected to extend the functionality of MapTable with a design tool for sand extraction.

As idealised process-based models, the Twente model and Utrecht Model are known. The Utrecht model developed by De Swart and Calvete (2003) can be used to gain an understanding about the formation and characteristics of shoreface-connected sand ridges and tidal sand ridges on the continental shelf. This model is less suitable to connect with MapTable as sand extraction model due to the fact that it's only looking to ridges on the continental shelf, so the model is not suitable in a lot of situations in the North Sea. The Twente model developed by Roos and Hulscher (2004) is more suitable due to the fact that this model is developed specific for sand extraction. Furthermore Van der Veen (2008) already has made some adjustments (in MATLAB) on the Roos and Hulscher model and has made a start by implementing this model in another software package (ArcGIS). With this implementation it is possible to draw a sandpit by giving the dimensions, and angle of the sandpit plus the location of the sandpit in a GIS environment (Van der Veen, 2008). For this reason the Roos and Hulscher (2004) sand extraction model adjusted by van der Veen (2008) will be used to extent MapTable with a sandpit tool. A short description of this model is given in the second part of this paragraph.

Sand extraction Model (van der Veen, 2008)

Van der Veen's model is based on the model of Roos and Hulscher (2004) that describes the depth averaged tidal flow and the interaction with the seabed. The model describes the evolution of sandpits in a tide-dominated offshore environment such as the North Sea. The pits are assumed both wide and shallow, such that linearization in the ratio of pit depth and water depth is allowed. This results in a short model calculation time. The model is built up in MATLAB. A more detailed description of the model can be found in appendix E.

When using this sandpit model it is critical to take the following limitations into account:

1. The model is only applicable for offshore conditions, boundaries of the model are infinitely far away. The model cannot predict possible effects of sandpits on the coast and of sandpits in the vicinity of the coast. The error will increase when the sandpit is closer to the coast, due to the fact that coastal processes are not taken in to account.
2. The model is working with symmetric tides. Therefore there is no migration of the emerging bed patterns possible and so migration of the sandpit.
3. Wave influence and suspended sediment are not taking into account in the model. Therefore the model error will increase when the sandpit is in shallow water (< 20 meter).
4. Depth of the sandpit needs to be small compared to the water depth. Roos et al. (2004) showed that the linear approximation works for amplitudes (pit depth + changes in seabed) up to 20 % of the water depth. If the pits are deeper the uncertainty will grow. This is an important aspect that we have to keep in mind when we want look for deeper sandpit.

5. The model assumed a flat bed in initial situation; this means that large-scale bed forms that are present on the seabed (sand banks, sand waves and shore-face connected ridges) are not explicitly taken into account. (The bottom of the North Sea is of course not flat but if we do not make this assumption the calculation time will be very complex).
6. The model can only handle sandpits with a rectangle shape.

A complete list of all limitations of the model can be found in appendix E.

5.3 Preparation of MapTable case 'Holland Coast'

To create a MapTable case for the Dutch North Sea a WAQUA schematisation is needed. The WAQUA schematisation 'SIMONA-kuststrook-fijn-1999-v4' (Deltares, 2009) is suitable for this area.

Unfortunately a small shortcoming to The WAQUA schematisation 'SIMONA-kuststrook-fijn-1999-v4' is that this schematisation or grid does not cover the complete study area. For this reason the study area for MapTable case 'Holland Coast' is reduced to the grid of the 'SIMONA-kuststrook-fijn-1999-v4' model, this is also mentioned in paragraph 1.2 (figure 1) and called the MapTable study area.

Furthermore the development of this new MapTable case is restricted to the use of the basic MapTable environment; this means that change in the MapTable DELPHI source code are not possible.

The new MapTable case is prepared by the following steps:

- Convert the bathymetry from WAQUA to ASCII format. To do this a WAQUA2ASCII MATLAB file is created. Before this conversion tool is used it is needed to modify the bathymetry file and change all ';' to ',' and change ',' to ', ' (add an extra space). Now the bathymetry file is ready to convert to ASCII with WAQUA2ASCII MATLAB file. The output file can be placed in the folder "invoer".
- Furthermore rrb.gen and rrb.asc files are needed, these files can be created manually. The files define the boundaries that MapTable will use. The rrb files need to be placed in the folder "invoer".
- MapTable tree needs to built up in the folder "referentie" with the WAQUA 'kuststrook fijn' model tree as a basis; some folders need to be stored in another place, because otherwise MapTable will not copy these folders to the new folder "variant". An overview of these new MapTable tree is shown in figure 12.
- The final step is generating the input file for WAQUA/MapTable, in this case the siminp.ingr1 file. The easiest way to create this file is to use a simpinp.ingr1 file from a previous MapTable case and rewrite this with the help of the original input file for the WAQUA case 'kuststrook fijn'.

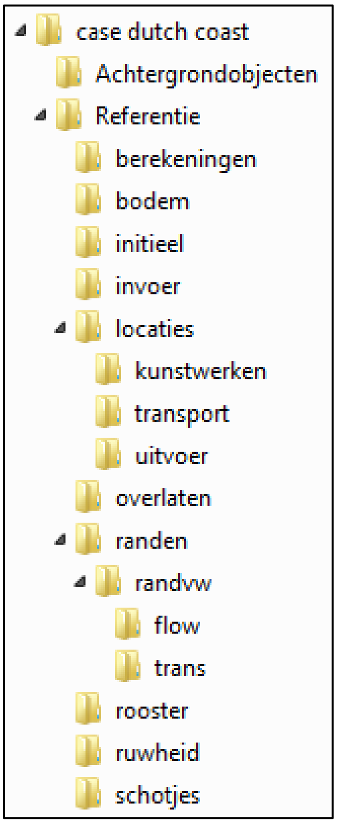


Figure 12: Folder structure MapTable

5.4 Implementation of the sandpit extraction tool in MapTable

When the new MapTable case 'Holland Coast' is created (paragraph 5.3). The creation of the interactive design tool for sand extraction can start by the implementation of the sandpit model in MapTable. This is executed by the following actions:

First of all it must be possible to draw a sandpit, this is possible by creating a new variant and draw an area for the sandpit with the option (button) <*"verander de maaiveldhoogte"*>. After drawing the sandpit, the project needs to be saved; by saving the project the shape and depth of the sandpit are stored in the files **maaiveldhoogte.gen** and **maaiveldhoogte.asc**.

When the location of the sandpit is saved the calculations for this variant can be started by clicking on the lamp symbol. This action will start the following actions:

> The folders (***berekeningen*** (not all the files in this folder), ***bodem***, ***initieel***, ***invoer***, ***locaties***, ***overlaten***, ***randen***, ***rooster***, ***ruwheid***) from the folder "***referentie***" are copied to the folder "***variant***" (***varianten\variant_name***).
>
> Then Baswaq starts and converts Baseline data in the folder "***invoer***" (with bottom changes due to the sandpit) to WAQUA format and saves this WAQUA format into the WAQUA tree. More details are described in appendix F.

When the Baswaq simulation is finished, MapTable starts **start.bat**, in this batch file all actions that are needed to use the sand extraction design tool are defined. An overview of these steps is shown in figure 13. These steps are described in appendix G including a detailed description of **parameter.exe** and **sandpit_code.exe**.

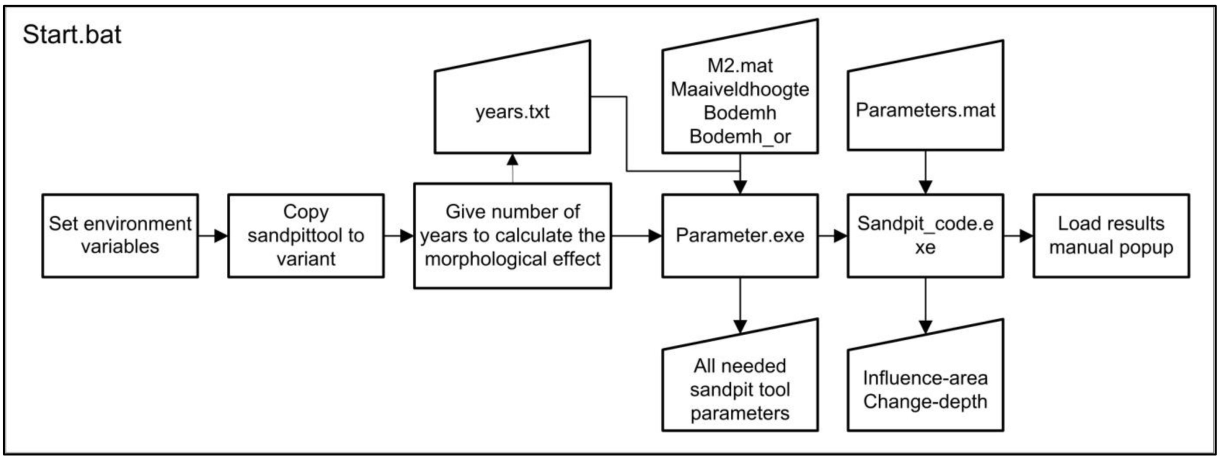


Figure 13: Steps in start.bat

5.5 Installation and user manuals for the sand extraction design tool (MapTable)

To be able to work with the developed interactive design tool for sand extraction, the MapTable, MapTable case 'Holland Coast' and the plug-in sandpit needs to be installed. How to install this, is explained in the 'install user manual MapTable with sandpit tool' that can be found in appendix H.

There is also a user manual written on how to use MapTable in combination with the sand extraction design tool, this one can be found as well in appendix H.

5.6 Result calculations with the design tool

This design tool can be used to check if the morphological influence area will affect user functions as offshore platforms, wind farms, cables and pipes. A sandpit with random dimensions and orientations can be placed in any location seawards of the modified -20 meter depth contour line. The Map with the priority zones and exclusion zones for sand extraction can be used to choose a good location for the sandpit. After drawing the calculation on the sandpit can start, when the calculation starts a first popup will come up where the morphological time scale need for the calculation needs to be entered. In paragraph 4.3 the assumption was made that for extreme conditions this morphological time scale is set to 10 years and allowed negative depth change to 10 cm. This means that the morphological depth change contour line (-10 cm) of the sandpit may not overlay with the user function (offshore platforms, wind farms, cables and pipes) after a morphological calculation time of 10 years. Calculations for other morphological time periods are also possible.

To show the possibilities of the sandpit design tool in the new MapTable for the Dutch coast four example cases are simulated. Three small sandpits –North, Middle and South– based on planned sandpits (Noordzee loket, 2010) and one larger sandpit are used as examples. This larger sandpit is located in the area that is used for sand extraction for the second Maasvlakte. In figure 14 the locations of these example sandpits are shown and table 15 shows the location bounded characteristics of each sandpit.

	North	Middle	South	large
M2 velocity (m/s)	0.53	0.64	0.76	0.67
M2 direction (degree)	71.5	44.8	31.8	41.3
Water depth (m)	21.2	21.6	17.3	24.1
Length (m)	1782	4561	2194	15215
Width (m)	5048	1726	3071	9355
Pit rotation (degree)	70	50	55	45

Table 15: Characteristics bounded to the location of each example sandpit.

The example sandpits are simulated for an excavation depth of 2 and 6 meters for morphological time scale of 10 years. In addition the sandpits are also simulated with an excavation depth of 2 meters and a morphological time scale of 50 years.

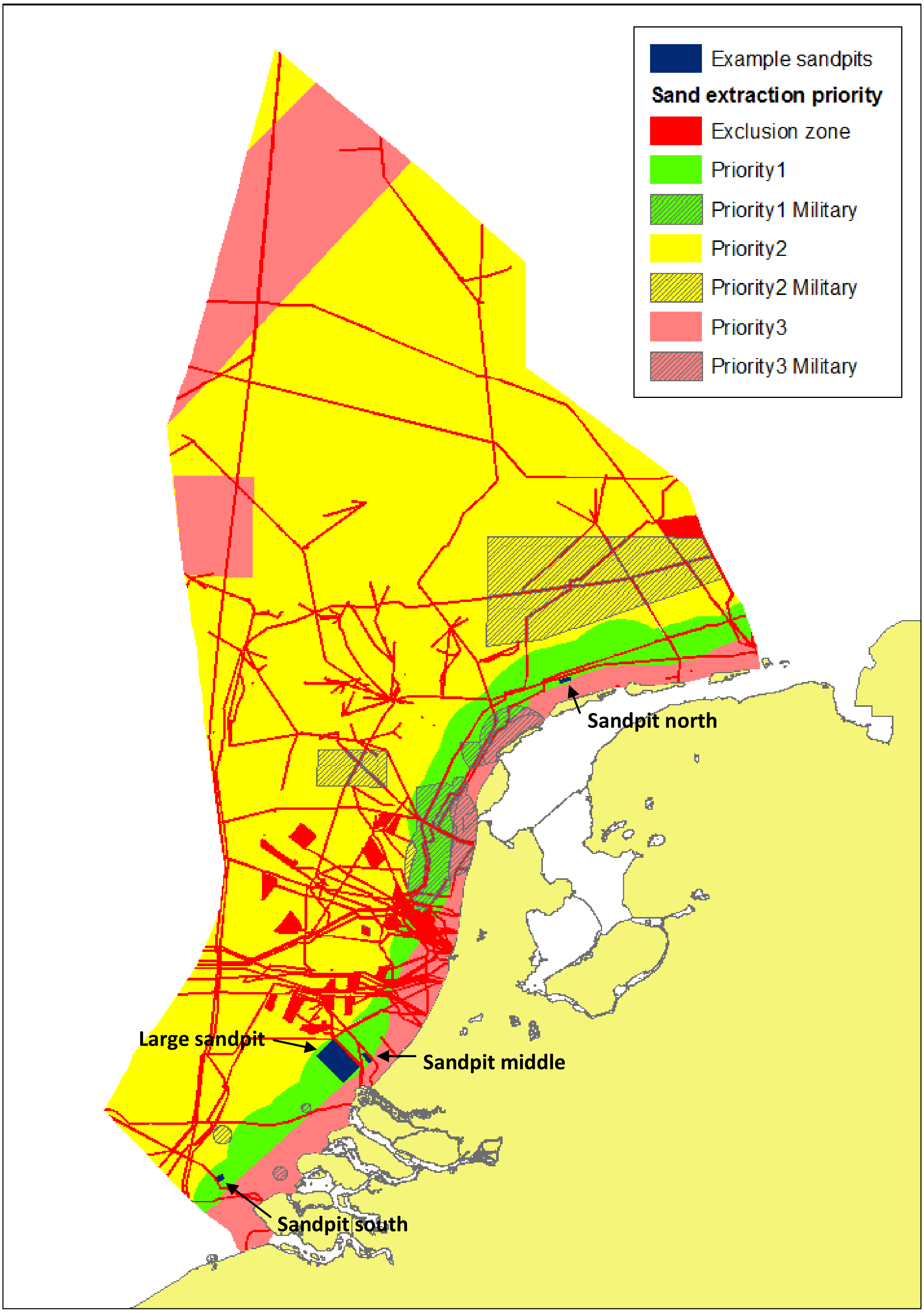


Figure 14: Locations of example sandpits; sandpit north, sandpit middle, sandpit south, sandpit large.

The results of a sandpit with an excavation depth of 2 meters and a morphological time scale of 2 meters are shown in figure 15 and table 16. These results show that morphological influence in the south is much higher than in the east. This is due to the fact that the current velocity is much higher in the south (figure 11). Furthermore it can be concluded that there is no overlay of the negative depth change contour line with user functions.

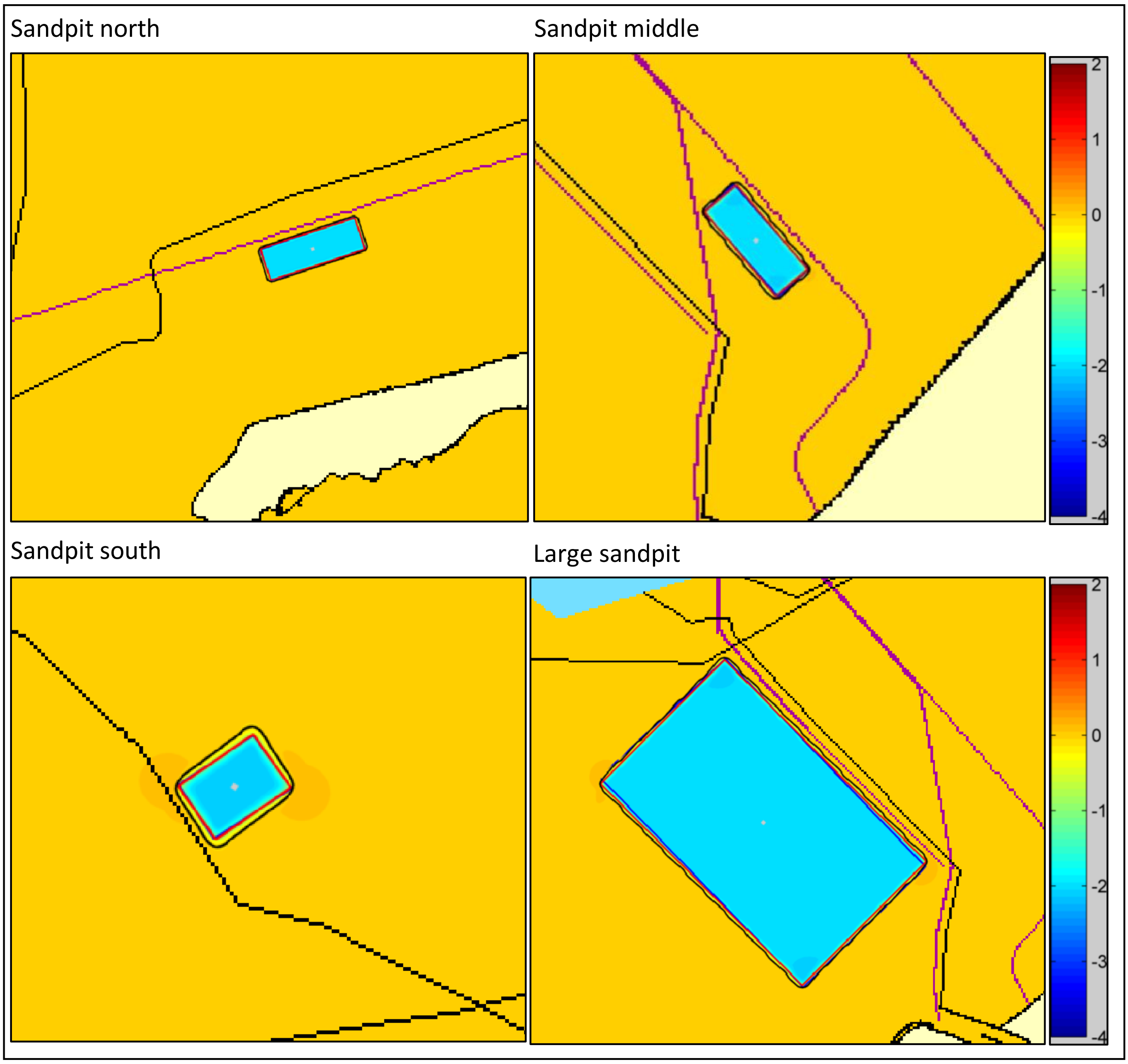


Figure 15: Results for sandpit North, Middle, South and large (for 10 years and 2 meters deep). The black line around the sandpit is the -10cm depth change contour line. The black lines are Electric cables and the purple lines are pipelines

	North	Middle	South	large
Influence area (<-0.1)(km^2)	1.38	1.50	2.58	8.50
Influence ratio	0.15	0.19	0.38	0.06
Max distance pit-contour (m)	162	190	320	230
Morphological time scale (year)	10	10	10	10
Depth(m)	2	2	2	2
Volume (km^3)	18.2	15.8	13.4	284.5

Table 16: Characteristics of the example sandpits for a morphological time scale of 10 years and an excavation depth of 2 meters. The last grey characteristics are fixed.

By increasing the excavation depth to 6 meters (figure 16 and table 17) not all locations for the sandpits are suitable any more. The lager sandpit is not suitable any more due to the fact that the depth change contour line overlays with the user functions. The south sandpit is still suitable despite the large distance between the depth change contour line and the sandpit.

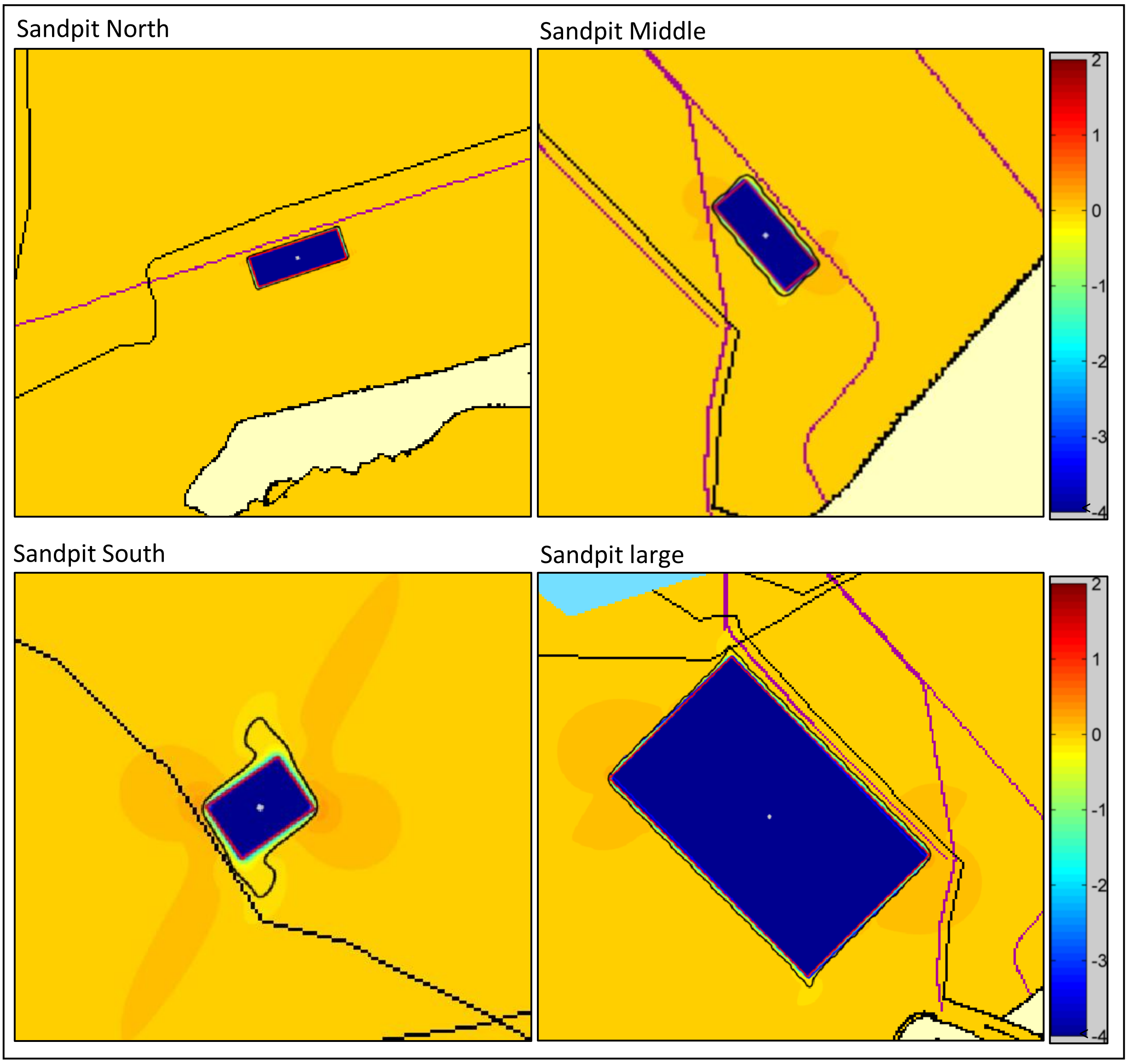


Figure 16: Results for sandpit North, Middle, South and large (for 10 years and 6 meters deep). The black line around the sandpit is the -10cm depth change contour line. The black lines are Electric cables and the purple lines are pipelines.

	North	Middle	South	large
Influence area (<-0.1)(km^2)	1.42	2.60	5.86	10.46
Influence ratio	0.16	0.33	0.82	0.073
Max distance pit-contour (m)	175	288	1483	522
Morphological time scale (year)	10	10	10	10
Depth(m)	6	6	6	6
Volume (km^3)	54.1	47.34	40.3	854.0

Table 17: Characteristics of the example sandpits for a morphological time scale of 10 years and an excavation depth of 6 meters. The last grey characteristics are fixed.

When the morphological time scale is increased to 50 years only sandpit north is suitable (figure 17 and table 18). This is also due to the fact that the M2 velocity is much lower in the north than in the south.

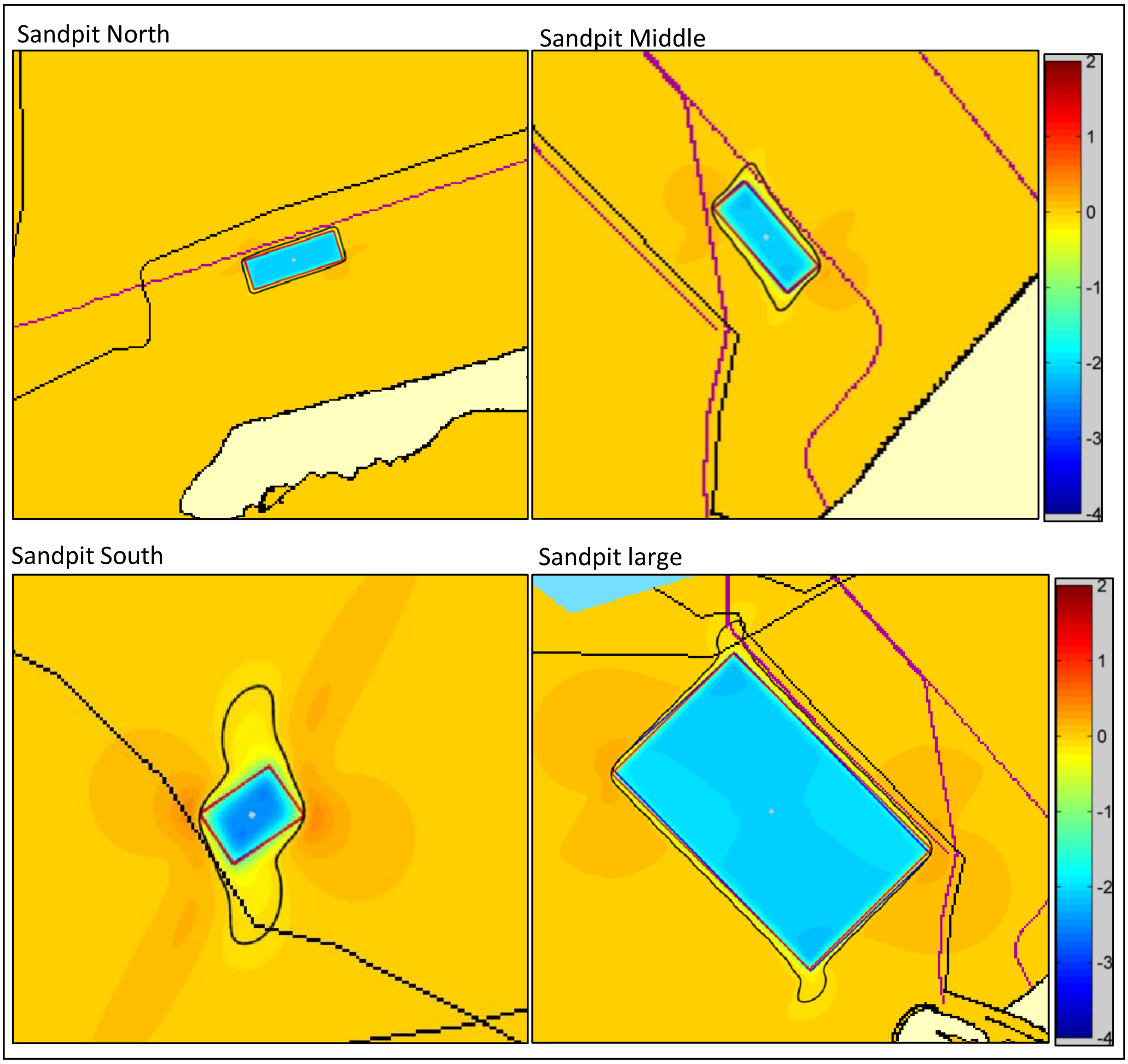


Figure 17: Results for sandpit North, Middle, South and large (for 50 years and 2 meters deep). The black line around the sandpit is the -10cm depth change contour line. The black lines are Electric cables and the purple lines are pipelines.

	North	Middle	South	large
Influence area (<-0.1)(km^2)	2.78	5.04	13.96	21.38
Influence ratio	0.31	0.64	2.08	0.15
Max distance pit-contour (m)	260	699	2727	1622
Morphological time scale (year)	50	50	50	50
Depth(m)	2	2	2	2
Volume (km^3)	18.2	15.8	13.4	284.5

Table 18: Characteristics of the example sandpits for a morphological time scale of 50 years and an excavation depth of 2 meters. The last grey characteristics are fixed.

6. Discussion

6.1 Introduction

Two tools (models) have been developed within this research. An interactive design tool, which can be used by choosing the right location and determines the necessary safety zones around sandpits. This tool has been developed by the implementation of the Twente morphological sandpit model (van der Veen, 2008) into the MapTable. A sand extraction location model has been setup within the ArcGIS model builder, which creates a map with the locations where sand extraction is allowed and the locations that have priority for sand extraction. The map is used as a background in the interactive design tool. In this chapter the sand extraction location model, the interactive design tool and the underpinning of the safety buffers for sandpits are discussed.

6.2 Sand extraction location model

This sand extraction location model is used apart from the interactive design tool (MapTable). Within the model the following principles are respected for the creation of the final map with allowed locations for sand extraction and the areas that have priority for sand extraction:

- Planned activities by RWS (Noordzeeloket, 2010) like Natura2000, wind farms, pipelines and cables are taken into account until the year 2020.
- Sand extraction locations that already have been used, are not taken into account because these locations were only extracted for an excavation depth of 2 meters. As a result these areas could be extracted further for depths of 4 and 6 meters. This is not entirely accurate for scenarios where the excavation depth is 2 meters, but is neglected due to the fact that the already used sand extraction locations are very small, compared with the amount of sand that is needed.
- In practice, it could be that in the areas of planned wind farms in the EEZ (figure 3) sand will be extracted before the wind farms are built. It is expected that this will not happen because in the coming years sand will be extracted first in the 20m_12mile_zone. Since, this is closer to the coast and in this area sand extraction has the highest priority (2.4). In general it is not expected that sand will be extracted before 2020 in the EEZ.

Changes in these principles could make a difference in the map or the area that is available for sand extraction. If for some reason other principles need to be taken into consideration, this can be easily realised because of the fact that this sand extraction location model is built within the ArcGIS model builder. In this model builder it is easy to change principles as for example shape files or regulations as a 500m safety buffer.

Uncertainties in used data

The used data is provided by Rijkswaterstaat (Noordzeeloket, 2010). Small uncertainties in measuring and digitising the data are possible. However larger uncertainties are not expected in this data. Uncertainties in the future planned activities are possible. Due to the fact that it is possible that some of the planned activities never will be realised.

6.3 Interactive design tool for sand extraction

One of the criteria for the interactive design tool was a short computation time. The average computation time of a simulation is 3 minutes, which makes this tool ideal to be used during discussion meetings. At this moment the tool is limited to the used WAQUA grid ('SIMONA-kuststrook-fijn-1999-v4'), however the model could be used in other areas if there is a WAQUA grid available.

This paragraph discusses the uncertainties in the used data, uncertainties and limitations in the morphological sand extraction model (Twente model), sensitivity of the model to input parameters and uncertainties in the design tool itself.

Uncertainties in used data

To generate the data that is needed for the design tool, the WAQUA schematisation 'SIMONA-kuststrook-fijn-1999-v4' is used. The bathymetry (for the water depth) is subtracted from this schematisation. The bathymetry is based on coastal depth files from 1999 in combination with sounding data of the Hydrographic Office for the North Sea and a terrain model for the North Sea (1990). This data is expected reliable, even though that in reality there is a small deviation, due to natural fluctuation. The M2 information used for the design tool is based on simulations with the WAQUA schematisation 'SIMONA-kuststrook-fijn-1999-v4'. The generated M2 velocity is less reliable due to the fact that there is some variation found in M2 information with other sources as van Santen (2009) and van der Veen (2008). Van Santen collected M2 information for some points in the North Sea based on harmonic analyses and van der Veen has derived the M2 information from simulations with the ZUNOWAQ model (Van Dijk and Plieger, 1998) and added this information on a grid. There is also information found about the M2 current in the North Sea atlas (2010), but this is not comparable, because the resolution of this data is much lower. Table 19 shows the different maximum M2 velocities for some locations in the North Sea (figure 18) per source.

	M2 velocity (m/s)		
Id	**Van Santen**	**Van der Veen**	**Kuststrookfijn**
110	0.45	0.48	0.45
122	0.48	0.53	0.52
123	0.60	0.57	0.56
150	0.45	0.55	0.57
163	0.58	0.59	0.67
172	0.59	0.58	0.64
180	0.57	0.57	0.67
194	0.60	0.61	0.64
201	0.64	0.64	0.66
207	0.72	0.72	0.71
217	0.68	0.69	0.68
219	0.63	0.62	0.67
222	0.73	0.72	0.74
225	0.70	0.69	0.74
235	0.72	0.69	0.72

Table 19: Maximum M2 velocity of different sources

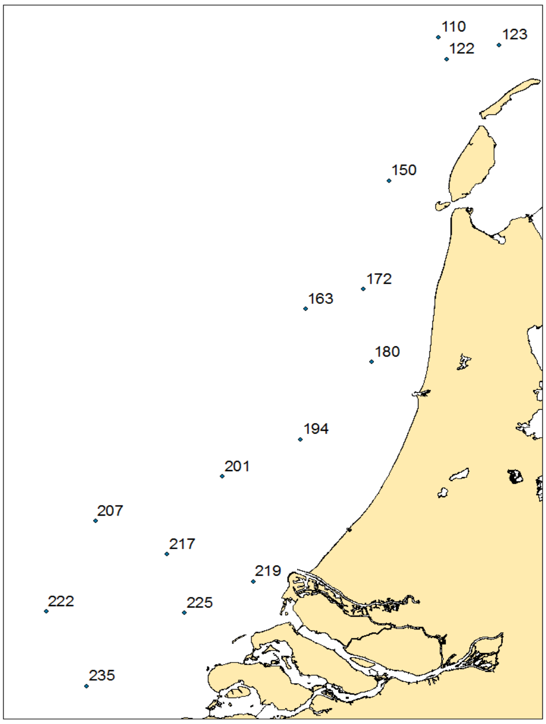


Figure 18: Id for selected locations in the North Sea

It is difficult to say which source has the best M2 velocity. Therefore it is important to keep in mind that there is an uncertainty in the used data. To know what the effect is of this uncertainty in M2 velocity, a sensitivity analysis is executed by using the different M2 velocities of table 19. Table 20 shows the used parameters of the used sandpit for the sensitivity analysis.

Water depth (m)	Pit depth (m)	Length (m)	Width (m)	years	Angle (degree)	Volume (km^3)
25	2	15000	1500	10	40	45

Table 20: Parameters taken for a standard sandpit

This sensitivity analysis is shown in appendix K. The sensitivity analysis shows that there is an average uncertainty of 15% in maximum distance between the sandpit and the morphological depth change contour line. This uncertainty grows when the pit depth or morphological time scale increases. This uncertainty could be reduced by improving the data on the M2 velocity, for example by collecting real measured M2 velocity data.

For the M2 directions there is no literature found with a high resolution that can be compared with the generated directions from the used WAQUA model ('SIMONA-kuststrook-fijn-1999-v4'). M2 directions with a lower resolution are found in the North Sea atlas (2010). With these lower resolution M2 directions, the generated M2 directions show similarity in most locations. For this reason it is assumed that the used directions are correct.

Uncertainties in and limitations of the Twente morphological sand extraction model.

The limitations of the Twente model are already described in paragraph 5.2, as a result of these limitations the model is not suitable for:

- Pit depths greater than 6 meters (because the pit depth water depth ratio must remain small, otherwise a linear approximation is not suitable).
- Sandpits close to the coast; sandpits in shallow water (< 20 meters).
- Irregular shaped sandpits which are difficult to compare with rectangles.

Due to the fact that the model uses a symmetric tide, pit migration is not possible and there is an under estimation in the morphological influence of the pit. Roos et al. (2008) has already updated the Twente model, this update takes also pit migration into account. The Roos et al. (2008) model is developed in FORTRAN and it is expected that this model can be implemented in the same way in MapTable.

The model is certainly a simplification of reality therefore several processes are not taken into account. This results in variation in outcome with real measurements however as a first impression, this model will give a good idea of the morphological influence around sandpits.

Sensitivity of the model to input parameters

Van der Veen (2008) already did a Sensitivity analysis on the Twente model. This analysis shows that the M2 velocity is the most sensitive parameter of the model. When the M2 velocity increases, the area of influence increases, this means that the morphodynamic development of the pit is larger. For the water depth this is the other way around, when the water depth increases, the area of influence decreases. For the angle of the long pit axis with respect to the tidal flow, the sensitivity analysis shows that the area of influence is maximal for an angle between 30 and 50 degrees. On the dimensions of the sandpit the sensitivity analysis shows that the largest morphological influences are obtained for long and narrow pits. These findings agree with findings from Roos et al. (2008).

Uncertainties in the design tool itself

Due to the fact that it is possible to draw all kind of shapes in the MapTable and the fact that the underlying morphological model can only deal with rectangular shapes, a transformation from any shape to a rectangle shape is needed. Through this transformation the new rectangle sandpit can have a small shift in location compared with the original sandpit. This shift will not occur when the tool can handle all kind of shapes.

6.4 Other possibilities related to the sand extraction tool

During the development of the case 'Holland coast' there is also a direct link with WAQUA generated. With this link it is possible to collect all kinds of WAQUA output data from the study area; this output data can be used for the implementation of other models in MapTable. (More information about this link can be found in appendix J)

6.5 Underpinning of the safety buffers for sandpits.

There is no morphological underpinning for safety buffers around user functions. In paragraph 4.3 the assumption is made that a negative depth change of more than 10 cm after 10 years at the location of the user function is not allowed. However, this assumption could be made differently. Another allowed negative depth change or morphological time scale should have a huge effect on the outcome of the developed design tool for sand extraction. A longer morphological time scale results in a larger morphological influence area and as a consequence, fewer locations are suitable for sandpits. In contrast, a larger allowed negative depth change leads to a smaller morphological influence area. Therefore the allowed negative depth change and morphological time scale are very important factors in determining the safety area around sandpits. It is advisable to do further research on these two factors taking in mind that the maximum allowed depth change should be close to zero and the morphological time scale should be based on the lifespan of a user function.

7. Conclusion & recommendation

7.1 Conclusion

The common practice and legislation for sand extraction were studied in this research, this survey concludes that there is no morphological underpinning for the used safety buffers around user functions. Secondly this research shows that the sand demand will grow and the available area for sand extraction will become under pressure in the future. An interactive design tool for sand extraction which determines the suitability of locations for sand extraction has been successfully developed. In the next section all research questions are structurally answered.

(1) *Is there enough sand available to satisfy the future sand demand until the year 2100? Based on priority areas for sand extraction in the North Sea and future sand extraction scenarios.*

Sand demand is analysed, based on the sand demand scenarios developed by Rijkswaterstaat (Dutch department for water, infrastructure and public works). The amount of sand that is available for sand extraction is calculated with a sand extraction location model. Based on the sand demand and priority areas for sand extraction, it can be concluded that there is enough sand available to satisfy the future sand demand until the year 2100.

By this conclusion the following remarks should be taken into account:

- Developments after 2020, which are unknown at this moment, such as new wind farms or other constructions in the North Sea that will generate energy, are not taken into account in this comparison.
- Sand can be extracted cost effective by extracting it as close as possible to the coastal or on-shore location of the sand requirement. Every kilometre further away increases the costs of sand extraction by 4% (Beleidsnota 2009-2015, 2009). Due to this financial issue the pressure will be high on available areas close to the coast or areas where sand is needed.

Based on these two remarks it is interesting to look closer on how the available areas for sand extraction can be optimised.

(2) *How is the current legislation with regard to safety buffers around user functions for sand extraction regulated? Is there a better way to deal with these safety buffers, to make optimal use of the available area in the North Sea?*

In current legislation sand extraction with a maximum excavation depth of 2 meters is not permitted in a zone with a width of 500 m (safety buffer) around offshore platforms, wind farms, cables and pipes. This safety buffer guarantees that sand extraction will not have a negative effect on offshore platforms, wind farms, cables and pipes (RON2, 2004). There is no legislation found for sandpits deeper than 2 meters, but in common practice this 500 meters buffer for 2 meters depth is increased with 100 meters for every meter deeper (personal communication: Ad Stolk, RWS North Sea Directorate). There is no morphological underpinning found for these safety buffers in the literature.

A better way to deal with these safety buffers is to deal with each sandpit individually. This is due to the fact that situations differ in so many points; sandpits can have all kind of dimensions, orientations and locations. The safety buffers around sandpits depend on the morphological influences on sandpits; this depends on pit size, shape, orientation (with current direction), current velocity and water depth. In the North Sea there is a large variation in current velocity and water depth, this is an extra reason to use a site specific and individual approach.

(3) *Is it possible to develop an interactive design tool with which we can see where sand extraction is allowed and that shows the morphological effect of a sandpit with random dimensions and orientations in any location in the North Sea after a certain number of years? This will enable the option to determine the necessary safety areas around sandpits*

During this research, such an interactive design tool has been successfully developed. With this tool it is possible to check if a sandpit will affect any user function after a certain number of years, so that the safety zone that is used is satisfied. The tool is built within the MapTable by implementing the morphological Twente model that can calculate the influence area of a sandpit after a certain number of years. In addition a map with the locations where sand extraction is allowed and which locations have priority for sand extraction is used as background in the design tool. This map is generated with the sand extraction location model developed in ArcGIS. The model is based on the current common practice and legislation for sand extraction. It is easy to make adjustments in this model if there are changes in legislation.

The general conclusion of this research is that with this design tool the available area for sand extraction in the Dutch North Sea can be optimised. It determines the safety zone for each sandpit individually and site specific. In this way, the necessary safety buffer can, in many cases, be much smaller than the currently used fixed safety buffer of 500m, increasing the available space for sand extraction.

7.2 Recommendation

This research results into one main recommendation:

Evaluate the advantages of a new site specific approach relative to the existing general and fixed safety buffer approach for sand extraction in current legislation. The design tool can be used for this individual site specific approach.

Beside this main recommendation there are also recommendations about the MapTable software itself and the developed design tool for sandpits. This research was restricted to the existing MapTable developed for the river environment (this means that change in MapTable interface or DELPHI codes were not possible). To improve the functionality of MapTable for the marine environment and the implemented sandpit model the following adaptation's on MapTable are recommended, this needs to be realised in the DELPHI source codes:

- Adapt MapTable so that it will load the results from the sandpit model automatically.
- Make it easy to make small adaptation on the drawn sandpit as pick the sandpit up and move it to other locations or rotate the sandpit.
- The option to load shape files (vector files) into MapTable, the benefit of using shape files instead of raster images (like .tif files) is that vector-based images can be scaled indefinitely without degrading quality instead of raster images that are based on pixels who will loss clarity in the scaling process (ESRI ,2006).

This last mentioned point is a very important step in making the MapTable a common used software package.

For the developed design tool there are recommendations for improvements of the morphological model and the design tool itself. The morphological model could be improved by the following points:

- Improve the model so that it can work with all kinds of shapes and not only with rectangles.
- Improve the model so that it can work with asymmetry of the currents. In this way the sandpit migration in time is taking into account, this is already done in Roos et al. (2008).
- Implementation of upcoming errors when the used conditions are not valid for the model. This can be done in MATLAB or by using a Visual Basic popup.

A recommendation on the developed design tool for sand extraction itself is:

- Improve the tool so that the tool can give the optimal location for sand extraction by a given volume sand and the location where this sand is needed. With the volume and location this optimal location is calculated on the hand of the shortest distance to the location where sand is needed and the areas that are available for sand extraction.

There is also a recommendation on the used input data; the M2 velocity. Due to the fact that there is a lot of variation is found in values of the M2 velocity in different sources, there is an uncertainty in this data. It is recommended to reduce this uncertainty by improving the data on the M2 velocity, for example by collecting real measured M2 velocity data.

Due to the fact that the developed design tool is not suitable for sandpits with a large excavation depth than 6 meters, it is recommended to improve the design tool so that the tool is also suitable for deeper sandpits than 6 meters. Because there are plans to create sandpits with a depth of 20 meters.

Finally, it is recommended to do further research on the needed safety area around sandpits which depends on the allowed negative depth change and morphological time scale. To make a good estimation on these allowed negative depth changes and morphological time scale further research is needed.

When all these recommendations are followed, a future in the use of MapTable is seen by connecting the MapTable also with other models. The implementation of models into the MapTable makes the model user friendlier.

Acknowledgements

This research is made to a success by using the following software and schematisations:

- SIMONA, this software is provided by Rijkswaterstaat
- MapTable 2.0, this software is provided by Deltares, contact Otto Levelt
- WAQUA schematisation 'SIMONA-kuststrook-fijn-1999-v4', the schematisations is provided by Rijkswaterstaat and is operated by Deltares, contact Remco Plieger
- ArcGIS 9.3, ESRI software, University of Twente licences
- MATLAB 2010a, Student license University of Twente

This research is initiated within the 'Building with Nature' Innovation programme, within the case called 'Sustainable development Holland coast'.

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List of abbreviations

BritNed cable	= The interconnector cable between the Netherlands and the UK
DNV	= Det Norske Veritas
EC	= European Council
EEZ	= Exclusive Economic Zone
EIA	= Environmental impact assessment (= MER)
GIS	= Geo Information System
GNP	= Gross National Product
GVB	= Gemeenschappelijk visserijbeleid
IBN	= Integraal Beheerplan Noordzee
LNG	= Liquid Natural gas
MER	= Milieueffectrapportage (= EIA)
MSC	= Marine Stewardship Council,
MW	= Megawatt
NAP	= Normaal Amsterdams peil
NCP or NCS	= Netherlands Continental Shelf or Plat
NorNed cable	= The interconnector cable between the Nederlands and Norway
RWS	= Rijkswaterstaat = Dutch department for water, infrastructure and public works
SAC	= Special Area of Conservation
SPA	= Special Protection Area
UNCLOS	= United Nations Convention on the Law of the Sea

Notations

The following conventions in type and style are used throughout this report:

<u>Type style</u>	<u>Used for</u>
Bold	File names
Bold italics	folders
<Buttons>	Buttons (on the screen or on the keyboard) that perform the indicated action.
Italics	Script or functions
(“Nederlands”)	Dutch translation
<u>underline</u>	Parameters

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Appendices

Appendix A WAQUA model Kuststrook fijn Dutch coast.

The WAQUA schematisation 'SIMONA-kuststrook-fijn-1999-v4' is provided by Rijkswaterstaat and is operated by Deltares.

This 'Kuststrook fijn' model (figure 19) is a model in Paris curvilinear coordinate system. It covers the entire Dutch coast, bounded on the south by the Belgian-French border and 50 km east of continuous east of the Dutch- German border. Grid extends in seaward direction is approximately 60 to 70 km offshore.

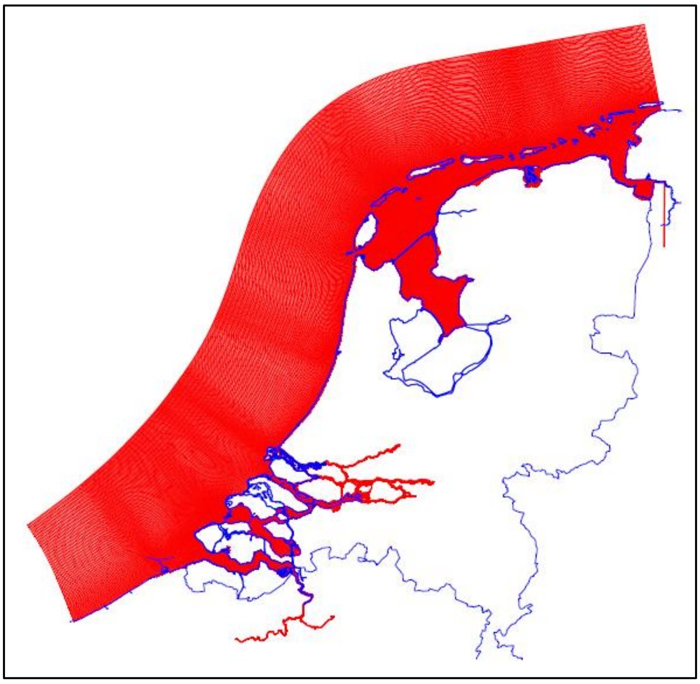


Figure 19: WAQUA schematisation SIMONA-kuststrook-fijn-1999-v4

The grid contains 941 by 401 grid points, of which 36 % of the grid cells are active (approximately 134,000 grid cells). The resolution varies widely. Offshore the cells are 300-800 m by 2.5 km and in coastal areas the cells are more squares with length en width around 300-400 m.

The 'Kuststrook-fijn' model is used for the creation of conditions for smaller detailed models like Zeedelta, NDB, IJmond and South Coast. The model is also part of the Nautlus-boom, the operational model - train (for the production of forecasts).

Extra information about WAQUA schematisation 'SIMONA-kuststrook-fijn-1999-v4' can be found in the model description document (Deltares, 2009)

Appendix B Description of other user functions in the Dutch North Sea

Shipping

Current use

The North Sea is important for marine traffic and its shipping lanes are among the busiest in the world. The main routes are just seaward of the 12-mile line, there are special routes to the major seaports and around those routes are anchor areas. The total route system in the Dutch part of the North Sea covers an area of approximately 3,600 km^2; this is 6 percent of the total Dutch North Sea. Around these route system there are clearways defined, these are barrier-free zones, which are intended to guarantee the connection between the internationally established traffic routes (IBN 2005). Every year there are approximately 260.000 ship movements in the Dutch North Sea (the territorial sea and Exclusive Economic Zone). Transport to and from Dutch sea harbours are involved in 42% of these shipping movements. The economic value of shipping including transhipment is high for the Netherlands and amounted to €25 billion in 2004 (Beleidsnota Noordzee 2009-2015, 2009).

Shipping on the North Sea can be separated in route bound shipping and non-route bound shipping. Route bound shipping takes account of slightly more than 50% of the total shipping movements. Route bound shipping includes ferries, cargo shipping, tankers, bulk transportation, and container shipping. Non-route bound shipping includes particularly fisheries, offshore supply vessels, and recreational shipping. (Noordzeeloket, 2010)

Analysis of vessel traffic data on the North Sea shows that the average number of ships has slightly decreased over the last decades (DNV, 2008). Most likely this is a result of the expansion in size per ship. Some routes are less intensive used but busier deep water routes are another consequence. This accounts for the route bound shipping activities.

Future developments

Shipping activity and distribution is likely to change, due to changes in our future like shifts in global economic patterns - i.e. emerging markets in India and China- may result in increased shipping of goods. Or new opportunities caused by climate change, for example in case that the polar ice sheets in the Arctic recede sufficiently to allow ships passage then this will be attractive for transport between Europe and the far East and the western USA.

The expectation is that fisheries and oil shipping may decrease whereas liquid Natural gas (LNG), bio fuel and container shipping will probably increase in the future (Beleidsnota Noordzee 2009-2015, 2009). Present studies (Planco, 2007 & The British Ports Association, 2009) clearly indicate the economic importance of the ports around the North Sea and the expectation of continued growth of cargo handling into the future. At this moment growth of cargo handling is not resulting in a growth of ship movements due to the fact that the average ship size still grows, so that the combined cargo handling capacity has increased. In the future it is expected that ship sizes will increase further, this growth is however likely to decrease. After all there is a limit to the size to which shipping channels and other port infrastructure can grow.

Military area

Current use

More than 7% of the Dutch North Sea (4,200 km^2) is used for military purposes. The main usage categories that can be distinguished within the group of military uses of shore are the following:

- Shooting ranges;
- Flying zones;
- Mine testing areas;
- Submarine exercise areas;
- Ammo dumping sites.

The last category is the most problematic, although it is nowadays not allowed to use the dumpsites any more, there is still a lot of munitions stored from the First and Second World Wars. These materials are hazardous and removal is therefore dangerous. Sand mining in those areas is very dangerous and is therefore not allowed. The training areas are shown in figure 3, the frequency of use varies from daily to several times a year. Shared use (like fishing, sand extraction, and navigation) of the military training areas is permitted when this is compatible with military training taking place there. In periods of increased importance of fishing or recreation no military trainings are taking place. (Ministerie van Defensie, 2005)

Future developments

The use of military areas in the Dutch North Sea will most probably not change much in upcoming years. In 2004, the defence grounds were laid down for a period of ten years in the Second National Structure Plan for Military Areas. But due to the increasing pressure for space on the North Sea, combined use of military exercise areas is getting more attention, for example by temporary opening of military fields for sand extraction.

Military areas that will be closed and are located next to ecological main structure, the birds and habitat directive areas or protected nature get priority to become protected nature (Beleidsnota Noordzee 2009-2015, 2009).

Oil and gas extraction

Current use

There are approximately 130 production platforms in use in the Dutch part of the North Sea, from which the majority serves for gas extraction. Some platforms are in the coast sea, but the bulk is concentrated in the centre part of the NCS. (Noordzeeloket, 2010)

Extracted gas and oil is usually transported to shore via pipelines, sometimes via shuttle tankers (oil). Around the platforms a safety zone of 500m is defined in which no shipping or other activities are allowed (excluding standby vessels and supply ships). This safety zone is defined in accordance with the United Nations Convention on the Law of the Sea (UNCLOS), and is effective globally. The area taken up by the 500 m shipping safety zones is less than 0.1 % of the Dutch Continental Shelf. (Van der Wal et. al., 2009a)

Offshore production of oil and gas is not subject to seasonal variation.

Future developments

The number of active platforms is expected to decrease as the production of many fields is in decline. The large companies are leaving the area, leaving fields which are not entirely exhausted. This gives opportunities for companies which can obtain the best from these still producing fields in an innovative manner and on a smaller scale. The Dutch government tries to promote this innovative smaller scale mining. To stimulate this, the government wants to help new players with effective legislation, efficient license procedures, a good infrastructure and simple access to data. Whether smaller fields will become economical interesting for exploitation depends on prospective fuel prices, and investment climate. (IBN 2015, 2009)

Long term safety against flooding from sea

Current situation

To guarantee the long term safety against flooding from sea sand replenishment is needed to prevent structural erosion and preserve the functionality in the coastal system, and since 2001, to maintain the volume of sand in the coastal foundation zone. Furthermore the primary flood defences – including what are known as priority weak links – need to maintained, and if needed improved. (Nationaal water plan, 2009)

Future developments

In the future the current volume of sand replenishments will be insufficient to keep pace with rising sea levels. In addition, there will be effects of soil subsidence and the loss of sand from the coastal foundation zone, which, until now, has not been taken into consideration in sufficient measure, one key factor being sand demand in the Wadden Sea. The volume of replenishments will have to be increased significantly to keep up with rising sea levels and the necessary sand stocks will have to be secured. (Nationaal water plan, 2009)

Cables and pipelines

Current use

On the Dutch part of the Continental Shelf is about 3700 km pipeline and 4000 km cable, primarily in the southern part. Of these, about 2100 km cable and 200 km pipeline is no longer in use. First the cables are described and next the pipes. (Noordzeeloket, 2010)

Cables in the North Sea are either power cables (electricity) or telecommunications cables. Power cables have been laid to connect countries with each other for purposes of supplying cheaper electricity as well as achieving a reliable power supply. Furthermore there are power cables between wind farms and the coast. Telecommunication cables typically carry phone conversations and are part of the Internet infrastructure. Similar to cables are pipelines, they transport manly oil, gas and water. Most pipelines are connecting offshore gas and oil production facilities with the coast (van der Wal et. al., 2009a).

Safety zone

On either side of the cables and pipes is a safety zone of 500 meters defined by the United Nations Convention on the Law of the Sea (UNCLOS). The reason to designate a safety or maintenance zone is to avoid disruption of service by e.g. fishing vessels or anchoring ships breaking a cable and to ensure access to the cable for maintenance vessels. In the case of pipelines transporting oil or similar products, this protection is also of great importance for protecting the environment. There is an exception possible to allowed activities within this zone if the owner of the cables or pipes gives permission (van der Wal et. al., 2009a).

Future developments cables and pipes

A few years ago it was expected that the rise of Internet would lead to a sharp increase in the number of telecommunications cables, in particular between the Netherlands and Great Britain and the United States. This expectation has been revised, mainly due to the use of new technologies. Probably the number of expansions will be limited. (Noordzeeloket, 2010)

The amount of power cables is likely to increase, due opening up of the European electricity market there is a demand for an international power supply link (interconnectors). The interconnector cable between the Netherlands and Norway (NorNed cable) is already present and another interconnector is currently under construction between the Netherlands and the UK (BritNed cable). Other reasons for the growth of power cables are the growth of wind farms at the North Sea, the construction of wind farms will generate an additional need for power cables between the wind farms and the Dutch coast. The government is exploring possibilities for so called ‘sockets at sea’ for the benefit of large-scale wind farms. (Beleidsnota Noordzee 2009-2015, 2009)

Pipelines, are most likely to increase, as companies are focusing on smaller platforms (= producing oil and gas from smaller, previously unprofitable). Small fields will only be developed and taken into production when connecting to existing infrastructure nearby is possible. In locations where no such infrastructure is available tankers will be used to transport the product to a receiving port (van der Wal et. al., 2009a).

Policy

The central policy aim is to facilitate infrastructure that meets the expected demand for communications links and the transport of gas, oil and electricity. Policy is to use space as efficiently as possible by developing routes where cables and lines will be bundled. Furthermore, a removal obligation for both cables and lines has been introduced in the National Spatial Strategy unless it can be proven in individual cases that the social benefits of leaving them outweigh the cost of removal. This means that, in practice, pipes remain in place and cables are removed. (Beleidsnota Noordzee 2009-2015, 2009)

Fishing

Current use

In 2006, the Dutch offshore fishing sector had 440 vessels and a crew over 2.000 persons. Fishery intensities in the North Sea vary by area and season, the Dutch fishing fleet operates mainly in southern and eastern parts of the North Sea. Fishermen choose to fish with different fishing gears and vessel sizes, resulting in different fish species being targeted and different preferences on where to fish.

The Dutch fishing fleet consists mostly of beam trawlers and freezer trawlers. The main target species for the larger beam trawlers are sole, plaice and other flatfish, while small vessels target shrimp. Within the EEZ and in the 'Plaice Box' north of the Frisian Islands and in the German Bight fishing is only allowed for the smaller vessels (with engines of less than 300 hp) and a licence is needed. (Noordzeeloket, 2010)

In 2006, sector turnover totalled approx. €440 million (0.1% of GNP; not including the processing industry). In addition to its economic significance, the Dutch fishing industry has an important social and cultural significance due to its traditional alliance with the country. (Beleidsnota Noordzee 2009-2015, 2009)

Process of enlargement and increase of productivity in a number of cases have conducted to overfishing. As a result of the common fishery policy (GVB) of the EU, the capture rights of Dutch fishery sector decreased with 50% in the period 1997-2002. These circumstances caused a decreasing of the Dutch fleet with 26 % between 1997 and 2008 (van der Wal et. al 2009a).

Future developments

In the coming years, several changes are expected in the fisheries on the North Sea. Factors that can influence the fisheries are: European Council (EC) policy, sustainability labels, energy prices, fish prices, fish availability, climate changes, etc. (van der Wal et. al 2009a).

The Dutch fishing sector at the moment suffers under an increasing pressure, due to the following developments (Beleidsnota Noordzee 2009-2015, 2009):

- Fishing methods used (beam trawling) are very energy-intensive;
- The sector has an economic overcapacity and catch yields are restricted by the Common Fishery Policy;
- Social pressure on the sector to produce in a more eco- and animal-friendly way is growing;
- The space in the North Sea available for fishing is coming under increasing pressure.

It is expected -that as a result of the above trends- there will be an 8% to 50% decrease in the economical value of fishing on the Dutch continental shelf in the period 2005-2015. There are also opportunities for the fleet to distinguish them self by responsible fishing using ecolabels for consumers (Marine Stewardship Council, MSC). The Dutch government and the EU are bringing pressure but also stimulating the sector to produce sustainably (Beleidsnota Noordzee 2009-2015, 2009).

Climate change could affect the fishing sector but consequences are still unknown. Some fish species may move north and hence become less attractive in economical terms, and perhaps new and economically interesting species may arrive in the area (Beleidsnota Noordzee 2009-2015, 2009).

Recreation

Current use

The Dutch coast is a national and international tourist attraction, primarily because of its 250 km of wide sandy beaches backed by dunes and interspersed with seaside resorts and harbours which often have a unique identity. The coast region is good for approximately 7 million overnight stays per year, 25% of the total overnights in the Netherlands. The North Sea and the coast area are also important for the sport fishing (Noordzeeloket, 2010).

Beside the economic importance tourism and recreation have also an important social function in the form of rest and entertainment. With that tourism and recreation have a positive impact on the public health (Noordzeeloket, 2010).

Future developments

The international competitive position of the Dutch coast as a tourist attraction is under pressure and is decreasing in the last ten years. But the water sport sector is growing; there is need for new marinas along the coast, increasing demand for recreation boat trips along the coast and an increasing demand for cruises to Great Britain. (IBN 2015, 2009)

Despite that the international competitive position of the coast is declining. It is expected that the coast and the coastal belt will be more intensively used for a wide range of leisure pursuits. Climate change and an increase in leisure economy open up opportunities for developing the tourist sector, so that the sector can grow. (Beleidsnota Noordzee 2009-2015, 2009)

Wind farms

Current use

The Netherlands wants to supply more sustainable energy so that it will be less dependent on politically unstable regions. Besides various activities on land wind energy offshore is a new sustainable technology, which is in full development. Two wind farms have been built close to the North-Holland coast, with a total capacity of 228 MW: ‘The Egmond aan Zee offshore Windpark’ and ‘The Princess Amalia Windpark’ (Beleidsnota Noordzee 2009-2015, 2009).

Shipping is not allowed in the wind parks: both to protect the plants and also for the safety of navigation. The construction of wind farms will generate also a need for power cables between the wind farms and the Dutch coast to deliver the energy. The current practice to keep a safety zone of minimal 500 meters around the cables could result in an undesirable big spatial reservation and cause conflicts around the landing points. To reduce this, a narrower service area could be used or cables can also be grouped. (IBN2015, 2009)

Future developments

In 2005, the North Sea is released for further development of wind farms. Ever since, many new initiatives are developed and in 2011 the wind energy will grow with 950 MW. At the same time the government, companies and civil society organisations are working on a strategy for developing more wind parks for the period 2010-2020. With the intention that, for the longer term, offshore wind energy will provide a substantial share of sustainable energy in the Netherlands.

The target of the government programme ‘Clean and Efficient’ is to generate 20% sustainable energy by 2020, with the target to increase to 40% by 2050. In addition, a target figure of an installed power capacity of 6,000 MW of wind energy in the North Sea in 2020 has been formulated; a total area of 400 up to 1000 km ^{2} is needed to achieve this (figure 3 shows planned wind farms until the year 2020). Achieving this object is of national importance (Beleidsnota Noordzee 2009-2015, 2009).

Protected nature

Current use

The North Sea is a highly complex and open marine ecosystem, shallow and rich in nutrients. The area is a breeding ground for fish, living area sea mammals for and important as a migratory route and wintering place for several species of bird. There is a growing concern about the effect of increased human activity on the marine ecosystem. Therefore the valuable areas are protected by legislation (van der Wal et. al 2009a).

The two most important pieces of European legislation relating to nature conservation are the Habitats Directive and the Birds Directive. Member States are required to implement these directives in national legislation. A Special Area of Conservation (SAC) is an area designated for reasons outlined in the Habitats Directive. A Special Protection Area (SPA) is based on the Birds Directive. These SAC and SPA may overlap and together underpin a European network of protected areas known as Natura2000. Countries can also protect additional areas by national laws (van der Wal et. al 2009a).

The Dutch Cabinet has registered with European Birds and Habitats Directives the following ecologically valuable areas as Natura2000 on the NCP (Beleidsnota Noordzee 2009-2015, 2009):

- Dogger Bank
- Klaver Bank
- Friese Front
- The Westerschelde estuary/Vlakte van de Raan
- The coastal sea to the north of Bergen/ Wadden Sea

Future developments

Worldwide climate change and the resulting rise in sea levels will impact the marine ecosystem. There is uncertainty regarding the exact consequences for habitats and biodiversity. Otherwise there is a growing concern nationally and internationally about the effect of intensification of human activity on the marine ecosystem. Marine biodiversity is under increasing pressure, and natural resources are being depleted. It is needed that in the future additional attention is being paid to these growing spatial pressures on Nature. The Delta commission suggests this also by advising to provide more space than is currently given to coastal functions especially nature and recreation and to give special attention to nature values and sustainability (Nationaal water plan 2009-2015, 2009).

Altogether it is expect that the Natura2000 network will undergo future adaptation e.g. to include more marine species or habitats in the future.

Mari culture

Current use

At the moment mari culture is limited available in the North Sea, particularly the Wadden Sea and Oosterschelde (IBN2015, 2009)

Future developments

The cultivation of shellfish at sea is a new possible development. Due to the fact that license for traditional farming areas (particularly the Wadden Sea and Oosterschelde) are tightened, it is expected that shell fishing at the North Sea will increase. One possible innovation is the realisation of sea parks where mari culture and Nature can be combined. Practical interest is at the moment only for mussel cultivation. Especially the shallow coastal sea (up to 8 to 10 meters deep) is eligible for mussels. It seems also that mussels could be combined with fixed objects like wind parks. (IBN2015, 2009)

Fish farming in the North Sea in the coming years seems unlikely. Open systems are too onerous in terms of environment, closed systems at sea are too expensive and offer more opportunities on land (IBN2015, 2009).

Appendix C Interaction between sand extraction and other user functions

Shipping

Shipping and sand extraction interact mainly positive with each other, for example extracting sand from dredging navigational routes, keeps the navigational routes open. Shipping might be hindered during the extraction of sand, but this effect will be minimal.

Concluding: shipping and sand extraction could be easily combined.

Military area

Due to the increasing pressure for space on the North Sea, shared use with other use functions of the military training areas is permitted where this is compatible with military training taking place there. Sand extraction and military areas can interact in a positive way to open military areas for sand extraction when there are no military trainings in those areas.

Concluding: sand extraction is limited possible in military areas.

Oil and gas extraction

Sand extraction is not possible on locations were oil or gas platforms are, around the platforms a safety zone of 500m is defined in which no shipping or other activities are allowed (excluding standby vessels and supply ships).

Concluding: Oil and gas extraction interact negative with sand extraction. Sand extraction is not allowed within a circle with a radius of 500 m around the platforms.

Long term Safety against flooding from sea

There is of course a strong interaction between long term safety against flooding from sea and sand extraction. Around fifty percent of the total sand that is extracted from the sea is used to guarantee the long term safety against flooding.

To maintain the sand balance in the coastal area and prevent erosion on large scale, sand extraction inland of the modified -20 meter depth contour line is not allowed. There are some exceptions possible.

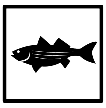
Concluding: Sand extraction is not allowed inland of the modified -20 meter depth contour line (with some exceptions).

Cables and pipes

Sand extraction close to cables and pipes could be dangerous, cables and pipes could be exposed. To protect the cables and pipes no sand may extracted within an area of 500 metres on either side of cables and pipes. In the case of pipelines transporting oil or similar products, this protection is also of great importance for protecting the environment.

If sand extraction projects for coastal replenishment are unfeasible or difficult to realise as a result, studies will be conducted to determine whether the active bundling of existing cables and pipes is possible and feasible.

Concluding: Cables and pipes could not be combined with sand extraction.



Fishing

Fishing and sand extraction are allowed in the same areas at this moment, on the long term there are no direct negative effects expected. At the moment of sand extraction there is a short direct negative effect for fishing, because sand extraction obtains the floor in a mess, in a way that the fish is temporarily driven off.

In order to limit the possible effects of sand extraction on the benthos and fishing, the central government focuses on sand extraction at larger depths than the current 2 metres.

Concluding: Sand extraction and fishing interact on a short period only negative with each other. Fishing and extracting sand could be combined in the same area but not on the same moment.

Recreation

Recreation takes place landward of the modified -20 m depth contour line, in this area sand extraction is very limited. For this reason recreation and sand extraction do not interact often with each other. If sand extraction is needed in a recreation area this could take place when the area is not in use by recreation like the winter time.

Concluding: Sand extraction is temporally allowed / possible in recreation areas. We do not expect problems between recreation and sand extraction.

Wind farms

Extracting sand in wind farms is not allowed due to the fact that sand extraction could damage the wind farm construction. To keep the wind farms safe, a safety zone of 500 meters around the wind farms is used.

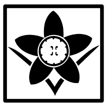
Most of the wind energy areas are designated seaward of the 12-mile line if possible, because in that case sand extraction is most cost-efficient and has priority in the area between the 12 mile line and established NAP -20 meter depth contour line.

Concluding: Sand extraction had priority between the 12-mile line and established NAP -20 meter depth contour line. Around wind farms sand extraction is not allowed in a zone of 500 meters.

Mari culture

Mari culture is expected landward of the established NAP -20 meter depth contour line, where sand extraction is limited. There are no interaction problems to expect between mari culture and sand extraction for this moment. In the future conflicts between sand extraction and Mari culture could occur, because more sand will be extracted landward of the established NAP -20 meter depth contour line. In this case sand extraction is not allowed in Mari culture areas because sand extraction will destroy the mari culture.

Concluding: Sand extraction cannot be combined with Mari culture.



Protected nature

At the moment there is limited interaction between protected nature and sand extraction. There is planned Natura2000 between the established NAP -20 meter depth contour line and the 12-mile line, the Zeeland Banks. Natura2000 has in general priority above sand extraction, so sand extraction is not allowed in Natura2000 there are some exceptions possible.

Concluding: In general sand extraction is not allowed in Natura2000 areas, but there are some exceptions possible.

Appendix D model builder diagrams

First part of model builder creating the exclusion zone and priority zones for sand extraction (figure 20).

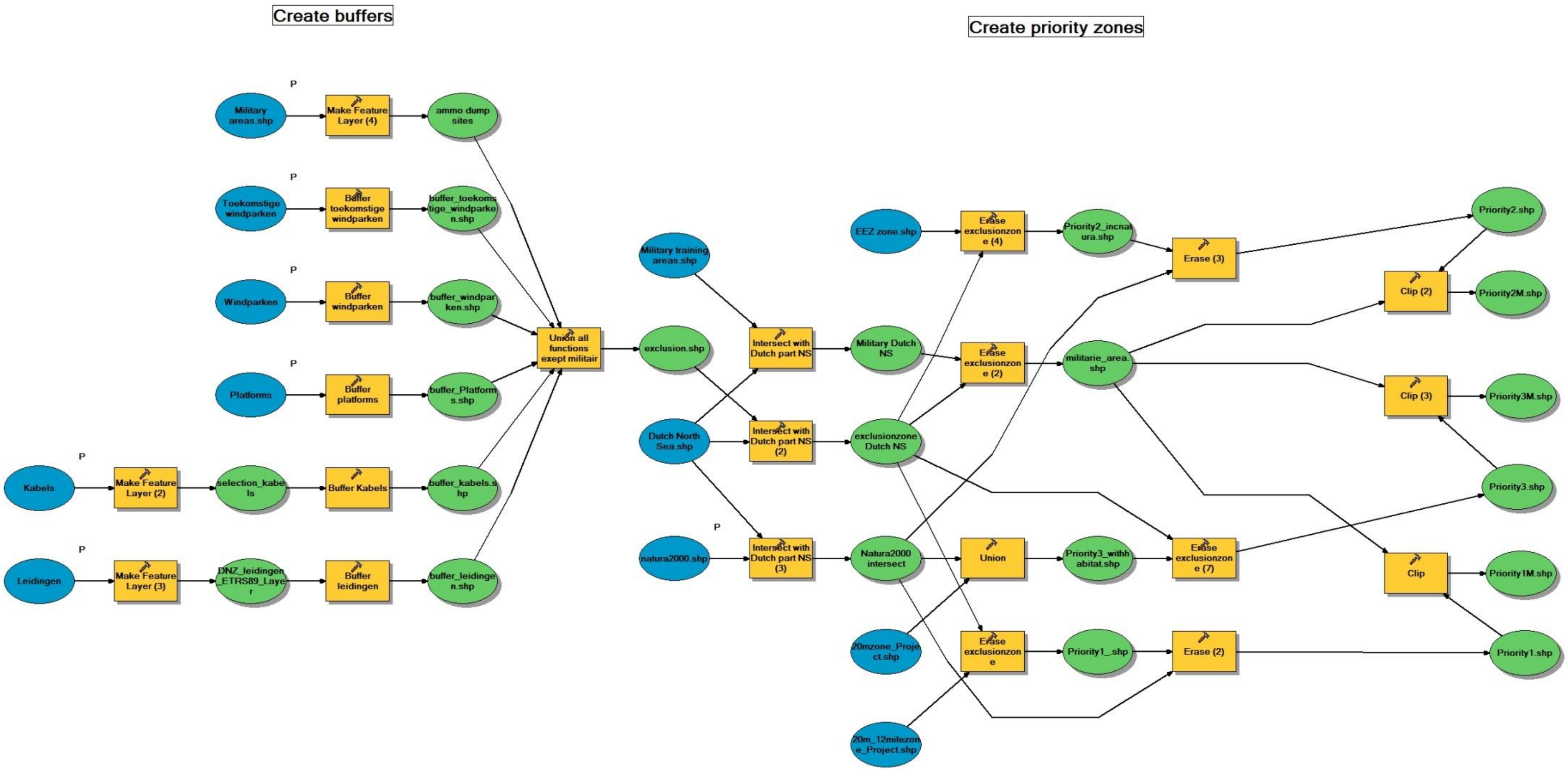


Figure 20: Overview of the first part of model builder: Creating the exclusion zone and priority zones for sand extraction.

Second part of the model builder calculating the area of each priority zone and exclusion zone for sand extraction (figure 21).

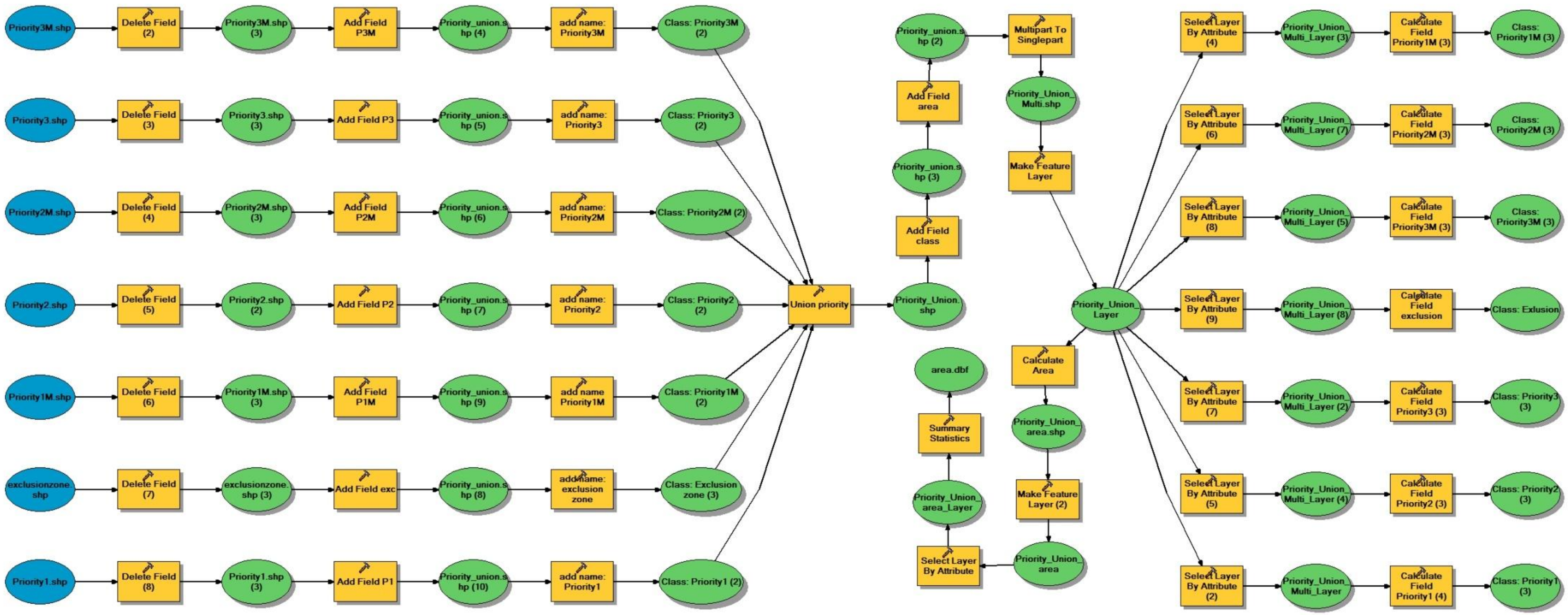


Figure 21: Overview of the second part of the model builder calculating the area of each priority zone and exclusion zone for sand extraction.

Appendix E Description Van der Veen's sandpit model.

The van der Veen's model is built up in MATLAB and exists of 3 parts. In the first part the equations 1.1, 1.2 and 1.3 describe the fluid motion: these are shallow water equations, which are derived from the Navier-Stokes equations. In the second part, equation 1.4 describes the sediment motion, only bed load is considered (as the velocities are low it is assumed that this will be the dominant mode of transport). The bed load transport is parameterised by an empirical relationship by Van Rijn (1993), where increasing velocity causes increasing in sediment transport and sediment transported more easily downhill then uphill. The last part of the model contains a sediment mass balance to describe the behaviour of the seabed.

$$g\frac{\partial \zeta}{\partial x} + \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fv + \frac{ru}{H + \zeta - h} = 0 \quad (1.1)$$

$$g\frac{\partial \zeta}{\partial y} + \frac{\partial v}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fu + \frac{rv}{H + \zeta - h} = 0 \quad (1.2)$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial h}{\partial t} + \frac{\partial}{\partial x}[(H + \zeta - h)u] + \frac{\partial}{\partial y}[(H + \zeta - h)v] = 0 \quad (1.3)$$

$$\vec{S} = \alpha|\vec{u}|^b\left(\frac{\vec{u}}{|\vec{u}|} - \lambda\vec{\nabla}h\right) \quad (1.4)$$

$$\frac{\partial h}{\partial t} + \vec{\nabla} * \vec{S} = 0 \quad (1.5)$$

Symbol	Description
g	Acceleration of gravity
u, v	X and y components of depth-averaged flow velocity
f	Coriolis parameter (51˚N
r	Friction parameter
σ	Angular frequency M2
a	Bed load proportionality parameter
b	Power of sediment transport
λ	Bed slope coefficient
ρ	Density seawater
E_p	Bed porosity
v	Kinematic viscosity of water
Sandpit parameters (MapTable)	
L	Length sandpit
B	Width sandpit
$h_{(pit)}$	Bed level position relative to the undisturbed seabed (Height sandpit)
GIS input / WAQUA	
U	Max. flow velocity M2
H	Undisturbed water depth
φ	Angle of pit with respect to direction of M2

Table 21 used symbols in the sandpit model from Van der Veen.

The equations are made non-dimensional; this means that they are scaled using typical North Sea values. From scaling follows that the seabed evolves only on a slow time (τ) while the flow and sediment transport evolve in the fast time (t) and slow time (τ). As the morphological development depends on local parameters, T_{long} is defined as the time in years that have passed when τ is 1.

Furthermore we assume that the depth of the pit is small compared to the water depth, a new parameter μ is introduced.

$$\mu = \frac{h_{pit}}{H} \quad (1.6)$$

Now we can write the solution of system ($\emptyset(u, v, \zeta, h)$ as $\emptyset = \emptyset_0 + \mu\emptyset_1$, where $\emptyset_0(u_0, v_0, \zeta_0, h_0)$ is the basic state of the model with a flat bed when there is no influence of the sandpit and $\emptyset_1$ represents the disturbance of the system due to the sandpit. Further the model is simplified with an alternating uniform flow; the basic flow (u_0) is represented by a simple symmetric block flow. This symmetric block flow gives qualitatively similar results compared to a sinusoidal M2 tide. The symmetric tide implies that there is no migration of emerging bed patterns.

To solve the problem the equations are transformed to the Fourier domain. This is done by recognising that the pit is actually a superposition of wavy bed patterns, which we also expect to find in the flow. And then the solution of change in seabed ($\widehat{H}_{m,n}$) is transformed back to physical space and shows how the seabed has changed in time. The solution for the change in seabed is shown by:

$$h_1(x, y, \tau) = \sum\nolimits_{m,n} \widehat{H}_{m,n} e^{i(k_m x + l_n y)} \quad (1.7)$$

For a more detailed overview of the solution see Van der Veen (2008).

The results of the model are the area of influence of the sandpit. This makes it straightforward to compare the effects of different pits which each other. There is a threshold value for the area of influence this is when the vertical change in seabed level is higher than the threshold value for example: $|h_1| \geq 0.1$

It is also possible to show a map with the height changes around the sandpit in MATLAB. Van der Veen made also a connection with ArcGIS; with the help of Dynamic Link Library (DLL) technique the MATLAB code is converted to a COM object. This is an object that can be used by many coding languages. This object is imported in the Visual Basic script that is imbedded in the GIS to allow the inclusion of a sandpit. Now the user is able to draw a pit or any other construction with specified dimensions at any chosen location in the North Sea. The model then calculates the morphological effects of the new sandpit. The model uses site specific parameters like water depth and flow velocity from the databases stored in GIS. The result is an area of influence displayed as a number in ArcGIS.

This model has the following limitations:

1. The model is only applicable for offshore conditions, boundaries of the model are infinitely far away. The model cannot predict possible effects of sandpits on the coast and of sandpits in the vicinity of the coast. The error will increase when the sandpit is closer to the coast, due to the fact that coastal processes are not taken in to account.

2. There is no migration of the emerging bed patterns possible due to the use of symmetric tides.
3. Wave influence is not included in the model (waves can increase the sediment transport), so the model assumes that the sandpit is located in deeper waters, so waves will have less influence. In general sand mining is only allowed seaward from the 20 m NAP line, where we will deal with deep water.
4. Suspended sediment is not taken into account (the model assumes that the sandpit is located in deeper offshore water (this is for our study area also the case) where the bed load transport is the dominant mode of sediment transport)
5. Depth of the sandpit needs to be small compared to the water depth. Roos et al. (2004) showed that the linear approximation works for amplitudes (pit depth + changes in seabed) up to 20 % of the water depth. If the pits are deeper the uncertainty will grow. This is an important aspect that we have to keep in mind when we want look for deeper sandpit.
6. The model assumed a flat bed in initial situation; this means that large-scale bed forms that are present on the seabed (sand banks, sand waves and shore-face connected ridges) are not explicitly taken into account. (The bottom of the North Sea is of course not flat but if we don't make this assumption the calculation time will be very large.
7. Morphological changes due to benthic organisms are not taken into account. In the North Sea there are of course benthic organisms, but taking this effect into account is too much time consuming and there is at the moment not enough information to describe this effect fully.
8. For sand extraction it is very likely that sediment with a different size comes on the top which may affect sediment transport. This effect is not taken into account.

With all those limitations it is difficult to simulate the complex morphological system in the North Sea, but we think that this model with a short calculation gives a good approximation on the morphological effects of sand mining.

Appendix F MapTable

In this appendix a short description of the MapTable is given followed by the steps that are taken when MapTable simulates a variant.

Short description of the MapTable

MapTable is a software package developed by Meander/ Arcadis (Van der Werff ten Bosch, 2009) financed by Rijkswaterstaat and is used for interactive support of planning in the water management. With the software it is possible to calculate the impact of an intervention in the river on the water level. MapTable is mainly used for Space for the River projects at this moment.

With MapTable we can design in an interactive way. The software can used on a pc but also on a computer screen embedded in a table (digital design table using a touch screen). The advantage of MapTable is that different parties can be involved in the design phase. Each party can stand around MapTable and can draw its proposal on the screen. All parties see the effects of their proposals directly which improves the dialogue.

At this moment MapTable is only applicable for the river environment and not applicable for the marine environment. Within the framework of ‘Building with Nature’ the functionality of MapTable will be extended. In this research program the focus is not only on the impact of water levels, but also on the impact of an intervention on topics, such as water safety, nature and recreation. ‘Building with Nature’ is developing a marine environment MapTable within the case ‘Sustainable development Holland coast’. As a first start of this project Witteveen + Bos has made a connection in MapTable with the wave model SWAN during a project on the IJsselmeer. With this connection it is possible to calculate the wave heights using MapTable (Zuijderwijk, 2010).

In MapTable the location and dimensions of a measure can be drawn. All information that is drawn on the screen is stored in the underlying spatial database and the impact is calculated by using a two dimensional hydrodynamic model WAQUA (Van der Werff ten Bosch 2009). Besides WAQUA other software or models can be started by MapTable by calling the software or models with commands in the start.bat file. More information about MapTable can be found in MapTable 2.0 help file (Van der Werff ten Bosch, 2009) and a more technical description of what MapTable exactly does when a variant is simulated (by clicking on the lamp symbol) is given in appendix F.

For MapTable it is important that the models who work behind MapTable are fast so that they have a short calculation time. This is because MapTable will be used in interactive group sessions; so it is important to have the results in a short time. MapTable is open source and can be used for free, to keep this it is also important that the models that will be implemented in MapTable are also free to use.

Steps that are taken when MapTable computes a variant

The steps that are taken when we compute an active variant are shown in figure 22. Before a variant can be simulated (or computed), a new variant needs to be created and some changes in groundlevel (“maaiveldhoogte”), changes in barriers (“drempels”) or changes in land use (“landgebruik”) can be made. This new variant needs to be saved. Now we can press the <compute the active variant> (<“reken de active variant door”>) button to compute the active variant the steps included this computation are described now:

First of all the folders (***berekeningen***, ***bodem***, ***initieel***, ***invoer***, ***locaties***, ***overlaten***, ***randen***, ***rooster***, ***ruwheid***) from the reference case ("***referentie***") are copied to the folder **variant** (***varianten\name_variant***).

Then Baswaq will start and will convert the Baseline data in the folder input ("***invoer***") to WAQUA format and saves this WAQUA format into the WAQUA tree. For example file **bodemh** is converted to **bodem.ingr1** (ingr1 = name of the run defined in the **siminp** file) in folder ***bodem.*** The **rbb.gen** is used as boundary. All grid cells (mn) that are outside of the boundary will have a value of-999,99. Furthermore the following files are also converted by Baswaq: **overlaat_l.asc**, **overlaat_l.gen** **overlaat_p.asc**, **overlaat_p.gen.** These files are converted to ***overlaten*\overlaat.ingr1**. **Ruwvlak-u** and **ruwvlak-v** are converted to ***ruwheid*\area-u.ingr1** and ***ruwheid*\area-v.ingr1.** Furthermore **schotarea-u.ingr1** and **schotarea-v.ingr1** are created (not clear from which files).

After running Baswaq MapTable will call **start.bat**. In this batch file all actions that you want to do can be listed as commands. In the first 4 lines reference information is given as the directory where WAQUA software (SIMONA) is installed. In the default situation MapTable will start up WAQUA from this batch file by the following commands:

echo Starting waqpre...
waqpre.pl -input siminp.%runid% -runid %runid% -back no -debug no -isddh no -isddv no -bufsize 10
echo Starting waqpro...
waqpro.pl -runid %runid% -back no -debug no -isddh no -isddv no -bufsize 10 -npart 1

After or before running WAQUA a lot of other commands can be given.

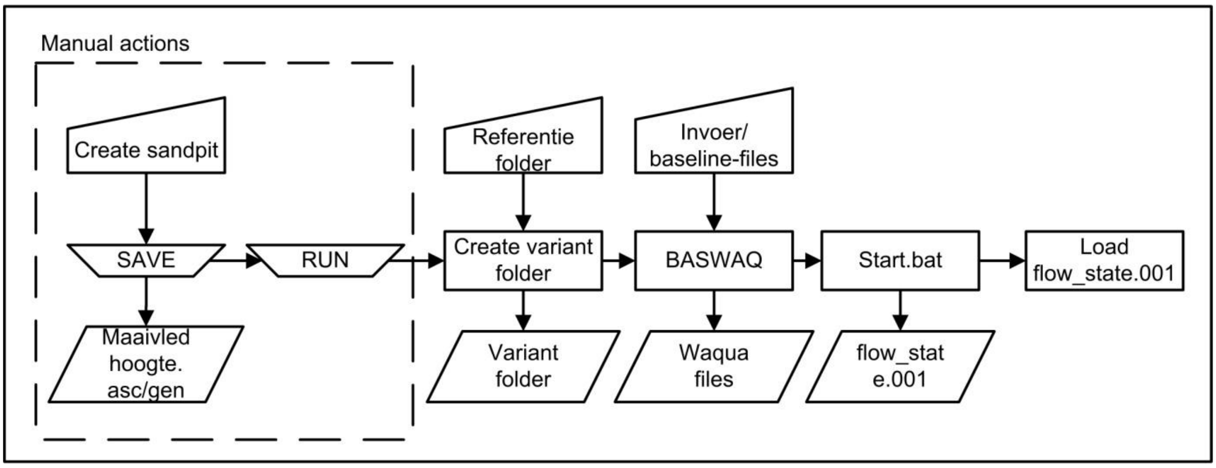


Figure 22: Steps that are taken when MapTable computes a variant

Appendix G Description start.bat including parameters.exe and sandpitcode.exe

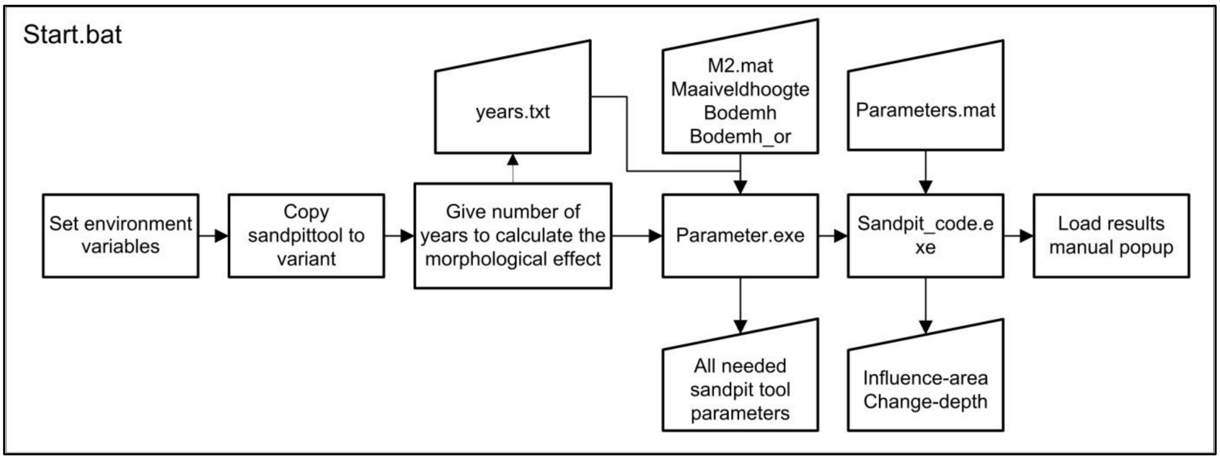


Figure 23: Steps in start.bat

An overview of the steps that are taken in start.bat is shown in figure 23 (same as figure 13).

When start.bat starts a popup will come up with the question for how many years do you want to calculate the morphological effect through? (Voor hoeveel jaar wilt u het morfologische effect door rekenen?) In this popup you can enter for how many years you want to calculate the morphological effect. Subsequently the sandpit plug-in folder is copied to the variant calculation folder (***variant\berekeningen***).

In the next step **parameters.exe** is started this is a MATLAB executable. This executable is a MATLAB script that is converted to an executable with the MATLAB function:

mcc –m scriptname.m

The advantage of an executable is that a MATLAB script can be used without the MATLAB software. In the **parameters.exe** script all necessary parameters needed for the sandpit tool are collected, these parameters are stored in **parameters.mat**. Input files of parameters.exe are: **M2.mat**, **Maaiveldhoogte.asc/gen**, **Bodemh.asc**, **Bodemh_or.asc** (stored in folder bodem). **M2.mat** is generated beforehand with simulations of WAQUA. A full explanation of the steps that are taken in **parameters.exe** is described in this appendix under sub heading **parameter.exe**.

After collecting all the parameters the sandpit tool (also MATLAB script converted to an executable) is started, this is realised by calling the executable **sandpit_code.exe**. The steps in this executable are described in this appendix under sub heading **sandpit_code.exe**.

As last action a popup will come up with the following massage:
'Het resultaat kan ingeladen worden door als achtergrond figuur het volgende figuur te laden: [INSTALLDIR]\Projecten\Holland coast\Varianten\name_variant\berekeningen\Sandpit\results.tif'

That is saying that results can be loaded by loading the results stored in [INSTALLDIR]\Projecten\Holland coast\Varianten\name_variant\berekeningen\Sandpit\results.tif

Parameter.exe

Figure 24 visualises the actions/steps that are taken in **parameters.exe**:

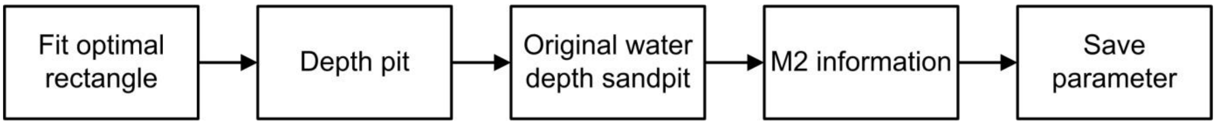


Figure 24: Steps that are taken in parameters.exe

Fit optimal rectangle around the drawn sandpit

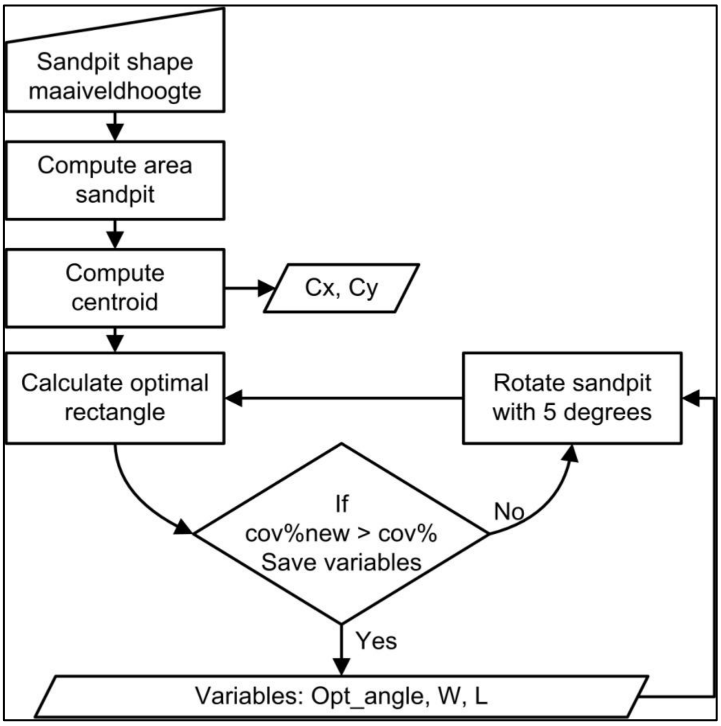


Figure 25: Visual overview of steps that are taken to fit an optimal rectangle around the sandpit

Figure 25 shows a visual overview of the important steps that are needed to determine an optimal rectangle that fits the sandpit. The following steps are taken to fit an optimal rectangle around the drawn sandpit:

1. Simulation parameters are defined. These simulation parameters determine the accuracy and speed of the simulation. The simulation parameters are:
    - <u>Angle step</u> (“<u>hoek_stap</u>”) this is the rotation steps that are used to find the optimal angle of the rectangle that simulates the sandpit.
    - <u>End angle</u> (“<u>end_hoek”</u>) gives the value when for which angle the optimisation stops.
    - <u>Number of steps</u> (“<u>aantal_stappen</u>”) is the number of times that we change the width.
    - <u>Grid points</u> are the points per side from the rectangle in total there are (grid points)^2 points. To find the optimal rectangle we will look how many points there are in the sandpit, if there are more points in the sandpit the rectangle will fit better.
2. Load the sandpit by importing **maaiveldhoogte.gen** created in MapTable and define the x and y coordinates.

3. Compute area of the polygon (sandpit), the following formula is used to calculate the area:

   $$\mathrm{A} = \frac{1}{2}\sum_{\mathrm{i}=0}^{\mathrm{n}-1}(\mathrm{x_i\, y_{i+1}} - \mathrm{x_{i+1}\, y_i})$$

   In these formulas, the vertices are assumed to be numbered in order of their occurrence along the polygon's perimeter, and the vertex (xn , yn) is assumed to be the same as (x0 , y0). Note that if the points are numbered in clockwise order the area A, computed as above, will have a negative sign.
4. Compute the centroid ("zwaartepunt") of the sandpit polygon.
   The centroid of a non-self-intersecting closed polygon defined by n vertices (x0,y0), (x1,y1), ..., (x_{n-1},y_{n-1}) is the point (C_x, C_y), where:

   $$C_x = \frac{1}{6A}\sum_{i=0}^{n-1}(\mathrm{x_i} + \mathrm{x_{i+1}})(\mathrm{x_i\, y_{i+1}} - \mathrm{x_{i+1}\, y_i})$$

   $$C_y = \frac{1}{6A}\sum_{i=0}^{n-1}(\mathrm{y_i} + \mathrm{y_{i+1}})(\mathrm{x_i\, y_{i+1}} - \mathrm{x_{i+1}\, y_i})$$

   A is the polygon's signed area (calculated in step 3).
5. Calculate the optimal rectangle for the sandpit by:
   - Starting with the boundary conditions of the rectangle like max width, max height, step size, start width rectangle (widthrect), start height_rectangle (height rect) and end height rectangle (heightrect).
   - The width is varied by the step size in a loop till that the height becomes smaller than the end height. When the width is changed the new height is calculated by heigthrect = (oppsandpit/(width)).
   - For each new rectangle the cover percentage with the sandpit is calculated with the MATLAB function *inpolygon*, this function calculates the number of points that are inside the polygonal region (the sandpit). The rectangle is divided in a number of points. For each point *inpoygon* will look if the point is inside the sandpit polygon. If this is true this point is added by totalsum; the total points that are in the polygon.
   - Now we can calculate the cover percentage by dividing the number of points that are inside the sandpit by the total number of points.
   - If this percentage is higher than the previous rectangle, the specific dimensions of the sandpit are stored (opt_angle , optpoints_x, optpoints_y)

The previous steps are also repeated for the rotated rectangle with different angles with the x-as (in this case the step size 5 degrees till 90 degrees). This rotation is realised by rotating the sandpit polygon because this is easier done and it gives the same effect as rotating the rectangle. This is described by the following steps:

- First the sandpit polygon is created around the point (0,0) by removing the centroid coordinates C_x and C_y.

- Convert Cartesian coordinates x and y to polar coordinate r by:

$$r = \sqrt{y^2 + x^2}$$

$$\theta = \begin{cases} 0 & if\ x = 0\ and\ y = 0 \\ \arcsin\left(\frac{y}{r}\right) & if\ x \geq 0 \\ \arcsin\left(\frac{y}{r}\right) + \pi & if\ x < 0 \end{cases}$$

  All these formulae assume that the pole is the Cartesian origin (0,0), that the polar axis is the Cartesian x axis, and that the direction of the Cartesian y axis has azimuth +π/2 rad = +90° (rather than −π/2).

- Than the angle (θ) is increased with the angle step (5 degrees).
- Now the polar coordinates can be convert back to Convert Cartesian coordinates x and y with the formulas:

$$\mathrm{x} = \mathrm{r}\cos\theta$$
$$y = \mathrm{r}\sin\theta$$

- Furthermore C_x and C_y are added so we have the original coordinates.
- The best <u>angle</u>, <u>width</u> and <u>height</u> of the best fit rectangle are now known.

Pit depth
The depth of the sandpit is stored in the file **maaiveldhoogtes.asc** in the fifth column. With MATLAB code the depth is imported from this file and stored as the parameter **d**.

Original water depth sandpit
The original water depth of the location of the sandpit can be determined by using the original bottom **(bodemh_or.asc**) and the new bottom with sandpit (**bodemh.asc**). With the function *setdiff* the changed cells can be determined and the m, n coordinates of the changed cells can be saved. These m, n coordinates are coordinates that are in the sandpit. So the original water depth of the sandpit can be calculated by calculating the mean of water depth of all m, n coordinates that are changed.

M2 information
M2 information is collected by running WAQUA twice; 1. collect the M2 velocity in x direction and 2. collect the M2 velocity in y direction. This M2 information is stored by using the *sdsoutput option save harmonic tides.* After running WAQUA the needed M2 tidal information is extract from the **sds** (WAQUA output) file with *sds2mat function* to a mat file. Finally the M2 current and direction is calculated for each grid cell based on the M2 velocity in x direction and in y direction, this information is saved in **M2.mat**.

Save needed parameters
Now the following parameters are saved in the file **parameters.mat**:

Parameter	Description
Opt_angle	Gives the angle of the optimal rectangle that fits the sandpit
W	Optimal Width of the sandpit rectangle
L	Optimal Length of the sandpit rectangle
d	Depth of the sandpit
ba	Mean original water depth of the location of the sandpit
Meanmaxm2	Average M2 velocity above the sandpit
Direction	Average direction of the M2 current
Mn	M, n coordinates of the sandpit
Cx Cy	Centroid coordinates of the sandpit
data	Original shape of the sandpit
xrect	X coordinates of optimal rectangle but not rotated
yrect	Y coordinates of optimal rectangle but not rotated
xrechthoek	X coordinates of optimal rectangle (in the correct position)
yrechthoek	Y coordinates of optimal rectangle (in the correct position)
coefficient	Cover percentage of draw sandpit and rectangle

Table 22: Parameters that are stored in parameters.mat

Sandpit_code.exe

In this code first parameters.mat is loaded so that all parameters can be used, furthermore **jaren.txt** is imported. In this file the number of years that needs to be calculated is stored. Now the sandpit tool will start and calculate the morphological changes of the sandpit for the number of years that is stored in **jaren.txt**.

The results need to be saved so that the sandpit will have the same location as this is drawn in MapTable. To do this some extra steps are needed, these extra steps are shown in figure 26 and are described here:

The used sandpit model does not take real coordinates into account; the model draws the sandpit with as centroid the point (0,0). To get the results (morphological changes of the sandpit after a number of years), the centroid coordinates of the sandpit needs to be added to the coordinates of outcome of the sandpit model. Furthermore the sandpit needs to be rotated so that the direction of the M2 current is parallel to the x-axis. In this way the output of the sandpit model can be placed in the same location as where the sandpit is drawn. To make this possible the output needs to be saved as a .tif-file (results.tif) and with a .tfw-file (results.tfw) to georeference the .tif file, so that MapTable knows where to place the .tif-file.

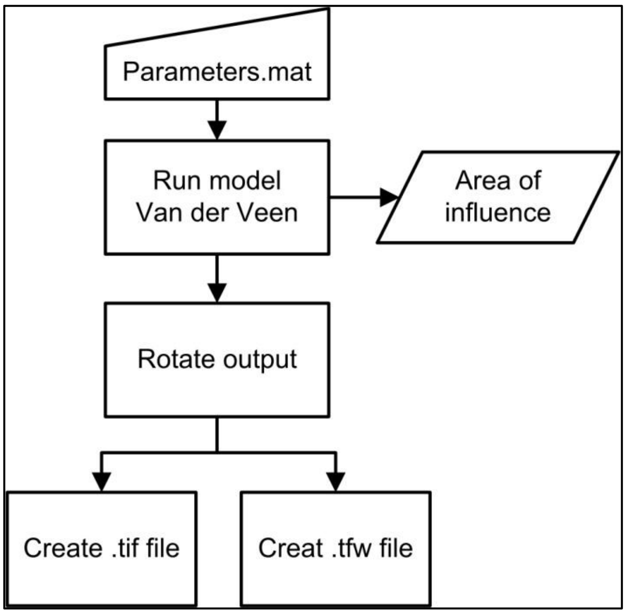


Figure 26: Steps that are taken in sandpit_code.exe

These extra steps added to the original sandpit code, the new MATLAB code can be found in appendix I.

Appendix H User manuals

Install user manual MapTable with sandpit tool

1) Install MapTable (normal way see: Release Notes MapTable 2.0.0.0.txt)
    - run **setup.exe**
    - Install MPICH2: go to directory ***[INSTALLDIR]\Install\win32\MPICH2*** run the **msi-file**. If they ask for a dotnet installation: Run the **dotnet** executable in the same directory. Follow for both the instructions from the wizards.
    - Install ActivePerl: go to directory ***[INSTALLDIR]\Install\win32\Perl*** run the **msi-file**. Follow the wizard instructions.
2) Change **MapTable.exe** with **MapTable.exe** in the zipfile **MapTable 2.0.0.39.zip**
3) Create a plugins directory in ***[INSTALLDIR]\MapTable 2.0\Bin*** and Copy sandpit folder to this plugins in directory (***[INSTALLDIR]\Bin\plugins***)
4) Copy and replace the ***baswaq*** folder (in this install folder) to ***[INSTALLDIR]\MapTable 2.0\Bin***
5) Install MCRinstaller: run **MCRInstaller.exe** in the folder MCRInstaller.
6) Important is that you install Mpich2 for running WAQUA (this is already done in step 1).

    On the University of Twente you need to registrate your account with the following command:

    C:\Program Files\MPICH2\bin\mpiexec –register in cmd.exe

    Write here your password.
7) Copy the case **Holland coast** (folder) to ***[INSTALLDIR]\Projecten***
8) Change path SIMONAdir and plugin_dir in the start.bat file in the directory ***[INSTALLDIR]\projecten\case dutch coast\berekeningen***

    (You need to change ***C:\Program Files (x86)\Meander\MapTable 2.0*** with the location of your install directory (**[INSTALLDIR]**))

    In my case this is:

    set SIMONADIR=C:\Program Files (x86)\Meander\MapTable 2.0\Bin\SIMONA
    set PATH=%SIMONADIR%\bin;%PATH%
    set runid=ingr1
    set plugin_dir=C:\Program Files (x86)\Meander\MapTable 2.0\Bin\plugins\Sandpit

How to use MapTable sandpit tool

First of all we need to start MapTable:

- Double click **MapTable 2.0.exe**, MapTable software will start now.
- Open a project and browse to ***[INSTALLDIR]\MapTable 2.0\Projecten\Holland coast*** and open **final.mtp**
- Create a new variant and give it a name (for example variant1)
- Draw sandpit, give it a name and depth (depth is positive)
- Save the project
  (A new folder is created in variant (***varianten*\variant1**) in this folder the following files are stored: **maaiveldhoogte.asc** (information stored about the depth of the sandpit) and **maaiveldhoogte.gen** (coordinates of the sandpit polygon).)
- Now you can run the variant (by clicking on the lamp symbol)

After running a popup will come up with the question:

'For how many years do you want to calculate the morphological effect through?' ("Voor hoeveel jaar wilt u het morfologische effect door rekenen?") In this popup you can enter for how many years you want to calculate the morphological effect.

After entering a number of years a very short WAQUA calculation starts. This is only done because MapTable does this automatically (we will not use this calculation). Than program **parameter.exe** will start. **Parameters.exe** will collect and calculate all parameters that are needed to run the sandpit tool and write these parameters in the MATLAB file **parameters.mat**.

After running **parameters.exe**, **sandpit_code.exe** will start this tool and calculates the morphological changes of the sandpit over 100 years and will save the results as a .tif file (**results.tif**) with a .tfw file (**results.tfw**) to georeference the .tif file.

Finally a popup is shown with the information: 'The result figures can be loaded by opening **results.tif** as a new background. **Results.tif** can be found in the ***[INSTALLDIR]\Projecten\Holland coast\Varianten\name_variant\berekeningen\Sandpit***'

(*"Het resultaat kan ingeladen worden door als achtergrond figuur het volgende figuur te laden:* ***[INSTALLDIR]\Projecten\Holland coast\Varianten\name_variant\berekeningen\Sandpit*\results.tif***')*

Appendix I MATLAB codes

Important MATLAB codes that are used in this research are shown in this appendix starting with the codes of parameter.exe (parameters.m MATLAB script) followed by sandpit_code.exe (sandpit_code.m MATLAB script).

Parameters.m

```
%% calculate optimal rectangle

% Define simulation parameters
hoek_step = 5; % begin en stepwaarde van rotatie.
end_hoek = 90; % eindwaarde rotatie
aantal_stappen = 50; % staphoogte van de simulatie. Groot getal --> nauwkeurig maar traag
gridpoints = 40; % aantal punten per zijde vd rechthoek waarop je gaat kijken in hoeverre de
rechthoek
                 % over de polygoon past. In totaal zijn er dus gridpoints^2
                 % punten. Hoe groter dit getal hoe nauwkeuriger de
                 % schatting en hoe trager de simulatie.

%Load shape maaiveldhoogte:
data = importdata('..\..\maaiveldhoogte.gen', ' ', 1);
x = data.data(:,1);
y = data.data(:,2);

% Compute area of polygon.
oppplus = polyarea(x,y); %positive area (anti clockwise of clockwise doesn't matter)
sumopp = 0;
for a = 1:length(x)-1
    newopp = ((x(a)*y(a+1) - x(a+1)*y(a)));
    sumopp = sumopp + newopp;
end
opp = sumopp/2; % positive for anti clockwise and negatieve for clockwise

% Compute the centroid (zwaartepunt) the polygon.
sumx = 0; sumy = 0;
for a = 1:length(x)-1
    new = (x(a)+x(a+1))*(x(a)*y(a+1) - x(a+1)*y(a));
    sumx = sumx+new;
    new = (y(a)+y(a+1))*(x(a)*y(a+1) - x(a+1)*y(a));
    sumy = sumy+new;
end
Cx = sumx/(6*opp); % x-coordinaat zwaartepunt
Cy = sumy/(6*opp); % y-coordinaat zwaartepunt

% definieren andere variabelen
angle_step = (hoek_step*pi)/180; % hoeveel radialen je per keer draait
coefficient = 0; % gebruiken we om te bepalen hoeveel procent van de polygoon bedekt is door
de rechthoek

%calculate optimale rectangle for the sandpit
for graden = 0:hoek_step:end_hoek
    %determine the start conditions:
    maxwidth = max(x) - min(x); % maximale breedte vd polygoon
    maxheigth = max(y)- min(y); % maximale hoogte vd polygoon
    stepsize = maxwidth/aantal_stappen;
    widthrect = max(max(x)-Cx,Cx-min(x)); % beginwaarde breedte rechthoek
    heigth_rect = min(max(y)-Cy,Cy-min(y)); % eindwaarde hoogte rechthoek
    heigthrect = maxheigth; % beginwaarde hoogte rechthoek

    while heigthrect > heigth_rect % Repeatedly execute statements while condition is true.
(herhaalt tot heightrect kleiner is als heigth_rect.)
        totalsum = 0;
        xmax = Cx+widthrect; xmin = Cx-widthrect;
        xdelta = gridpoints;
        xstep = (xmax-xmin)/xdelta;
        width = xmax - xmin;
        heigthrect = (oppplus/(width)); % nieuwe hoogte wordt berekent die afhankelijk is van
de breedte
        ymax = Cy+heigthrect/2; ymin = Cy-heigthrect/2;
        ydelta = gridpoints;
        ystep = (ymax-ymin)/ydelta;
        for xloop = xmin:xstep:xmax
```

```
            for yloop = ymin:ystep:ymax
                totalsum = totalsum+inpolygon(xloop,yloop,x,y);
            end
        end
        coefficient_new = totalsum/((xdelta+1)*(1+ydelta));% kijk of coeffiecient is het
precentage van de rechthoek dat overlap heeft met de sandpit
        if coefficient_new>coefficient % wanneer de nieuwe coeffiecient groter is (dus de
recht hoek beter overlapt) schrijf de parameters weg die nu volgen:
            coefficient = coefficient_new;
            opt_angle = graden;
            opt_points_x = [xmin,xmax];
            opt_points_y = [ymin,ymax];
            optimale_polygoon_x = x;
            optimale_polygoon_y = y;
        end
        widthrect = widthrect-stepsize; % breedte wordt met stepsize verkleint
    end

    %rotatie
    %eerst naar poolcoordinaten
    x = x-Cx; y = y-Cy;
    for a = 1:max(size(x))
        absolute(a) = sqrt(x(a)*x(a)+y(a)*y(a));   %bepaal M
        if x(a) > 0                                    %bepaal hoek
            angle(a) = atan(y(a)/x(a));
        elseif x(a) < 0 && y(a) >= 0
            angle(a) = atan(y(a)/x(a))+pi;
        elseif x(a) < 0 && y(a) < 0
            angle(a) = atan(y(a)/x(a))-pi;
        elseif x(a) == 0 && y(a) > 0
            angle(a) = (1/2)*pi;
        else
            angle(a) = -(1/2)*pi;
        end
    end

    %nu de rotatie zelf
    angle = angle + angle_step;
    %en weer terug naar carthesische coordinaten
    for a = 1:max(size(x))
        x(a) = absolute(a)*cos(angle(a));
        y(a) = absolute(a)*sin(angle(a));
    end
    x = x+Cx; y = y+Cy;
    graden % dit is om te zien hoe ver het programmatje is
end

%optimale rechthoek om shape is (maar niet in juste positie):
xrect = [opt_points_x(1), opt_points_x(1), opt_points_x(2), opt_points_x(2), opt_points_x(1)];
yrect = [opt_points_y(1), opt_points_y(2), opt_points_y(2), opt_points_y(1), opt_points_y(1)];

%%nieuwe rechthoek sandpit, rechthoek op de juiste plaats over de shapefile
%eerst naar poolcoordinaten
    xrechthoek = xrect-Cx; yrechthoek = yrect-Cy;

    for a = 1:max(size(xrechthoek))
        absolute1(a) = sqrt(xrechthoek(a)*xrechthoek(a)+yrechthoek(a)*yrechthoek(a));
%bepaal M
        if xrechthoek(a) > 0                                    %bepaal hoek
            angle1(a) = atan(yrechthoek(a)/xrechthoek(a));
        elseif xrechthoek(a) < 0 && yrechthoek(a) >= 0
            angle1(a) = atan(yrechthoek(a)/xrechthoek(a))+pi;
        elseif xrechthoek(a) < 0 && yrechthoek(a) < 0
            angle1(a) = atan(yrechthoek(a)/xrechthoek(a))-pi;
        elseif xrechthoek(a) == 0 && yrechthoek(a) > 0
            angle1(a) = (1/2)*pi;
        else
            angle1(a) = -(1/2)*pi;
        end
    end
    %nu de rotatie zelf
    angle11 = angle1 + ((-opt_angle)*pi)/180;
    %en weer terug naar carthesische coordinaten
    for a = 1:max(size(xrechthoek))
        xrechthoek(a) = absolute1(a)*cos(angle11(a));
        yrechthoek(a) = absolute1(a)*sin(angle11(a));
    end
```

```
    xrechthoek = xrechthoek+Cx; yrechthoek = yrechthoek+Cy;

%% OUTPUT
opt_angle; %geeft de optimale draahoek in graden weer
xrechthoek; %x coordinates rectangle juiste positie
yrechthoek; %y coordinates rectangle juiste positie
coefficient; % welk deel van de polygoon bedekt is (schatting)
L = opt_points_x(2) - opt_points_x(1); % breedte
W = opt_points_y(2) - opt_points_y(1); % lengte

%% Depth pit

fid= fopen('..\..\maaiveldhoogte.asc','r');

readline = fgets(fid);
c = textscan(readline, '%n %s %n %n %f %s', 'delimiter', ',');
db = c(1,5);
d = db{1,1}; %depth
fclose(fid);

%% Original water depth sandpit
 % Bodem + m, n coordinaten van de zandpit

% Import the bodem
bodemh = importdata('..\..\invoer\bodemh.asc');
bodemh_or =importdata('..\..\bodem\bodemh_or.asc');

%bepaal welke cels veranderd zijn
a = bodemh;
b = bodemh_or;

g = setdiff(bodemh, bodemh_or, 'rows'); % Hoogtes die veranderd zijn ten opzichte van
originele bodem met m, n coordinaten (m = x as en maximaal 942, n = y as en maxmimaal 402)
g2 = setdiff(bodemh_or, bodemh, 'rows'); % originele hoogtes van de zandpit plus m, n
coordinaten

mn = g(:,1:2); %nm coordinaten die verandert zijn (van g2 of g is het zelfde)
bh = g2(:,3); %onverstoorde bodem hoogte zandpit
ba = mean(bh); %gemiddelde originele bodem zandpit ofwel original waterdepth

%% load M2 information from WAQUA

load currentM2.mat %generated by exporting wit sds2mat the M2 velocity in x and y direction
comming from the harmonic analyze
% the direction and current are already calculated per grid cell (by running generateM2info.m)
% hoek and currentM2 will be loaded for each grid cell.

%% M2 current direction for sandpit cells

leng = length(mn); %bepaal aantal coordinaten die de sandpit beslaat

for i = 1:leng
hoektot(i) = hoek(mn(i,2),mn(i,1));
end
Direction = mean(hoektot);

%% M2 current for sanpit cells
for i = 1:leng
M2max(i) = currentM2(mn(i,2),mn(i,1));
end
meanmaxm2 = mean(M2max);

%% needed
opt_angle %geeft de optimale draahoek in graden weer
W % Breedte
L % Lengte
d % diepte pit
ba %gemiddelde originele bodem zandpit ofwel original waterdepth
meanmaxm2 % gemiddelde maximale M2 snelheid
Direction % richiting bij gemiddelde max M2
mn; % coordinaten die veranderd zijn
coefficient

%% wegschrijven
save('parameters.mat', 'opt_angle', 'W', 'L', 'd', 'ba', 'meanmaxm2', 'Direction', 'mn', 'Cx',
'Cy', 'data', 'xrechthoek', 'yrechthoek', 'xrect', 'yrect','coefficient');
```

Sandpit_code.m

```
%MATLAB script of the analytical model to predict effects of sand pits on
%the seabed.

%input parameters:
    %theta = angle between length-axis of the pit and x-axis of the domain.
    %Li = length pit.
    %Bi = width pit.
    %di = pit depth.
    %u_0 = flow velocity in the basic state.
    %Hi = local waterdepth
    %c = flow velocity (max M2)
%output parameters:
    %area of influence, area where the bed change is more than 10 cm
    %ratio of influence, ratio between area of influence and area of the
    %park

clear all
close all
%%load parameters needed for the sandpit plus number of years
load parameters.mat
jaren = importdata('jaren.txt');

sigma = 1.4e-4;          %rad/s
fi = 1.15e-4;            %value of coriolis parameter
theta =  -opt_angle-(270-Direction);
%270 is direction of current on the x-axis
Li = L;
Bi = W;
di = d;
c = meanmaxm2;
Hi = ba;

%plot size
Lplot = 25000;

%model parameters (input)
    ri = 2.0e-3;            %linearised friction coefficient
    lambdai = 2;            %bedload parameter
    b = 3;                  %sediment transport parameter

%scaling parameters

    Hster = Hi;             %m (local depth used to scale!)
    Uster = c;              %m/s (local velocity used to scale!)

%declaration of morphological time
    time = jaren ;          %define time after which you want to see the bed developemen (yr)
    alpha = 5.5e-5;
    ep = 0.4;
    yr = 3.15e+7;           %(s) seconds in a year

    Tlong = (Hi .* (1 - ep))./(alpha .* (c.^2) .*sigma);
    Tlong_yr = Tlong ./yr ;

    t = time./Tlong_yr;

%scaling procedure
    f = fi ./ sigma;
    r = (ri ./ (sigma .* Hster));
    lambda = ((Hster .* sigma) ./ Uster) .* lambdai;
    L = Li .* (sigma ./ Uster);
    B = Bi .* (sigma ./ Uster);
    de = di ./Hster;

%script parameters
    Lxi = 100000;           % size of the grid in x-direction (in m)
    Lyi = 100000;           % size of the grid in y-direction (in m)
    NN = 1000;              % Number of cells (pick an even number)

    %scaling
    Lx = Lxi .* (sigma ./ Uster);
    Ly = Lyi .* (sigma ./ Uster);

    dx = Lx/NN;
    dy = Ly/NN;
```

```
    X1 = -(NN/2-1)*dx : dx : (NN/2)*dx;
    Y1 = -(NN/2-1)*dy : dy : (NN/2)*dy;
    [x,y] = meshgrid (X1,Y1);

    dk = 2*pi ./ Lx;
    dl = 2*pi ./ Ly;

    K1 = -(NN/2-1)*dk : dk : (NN/2)*dk;
    L1 = -(NN/2-1)*dl : dl : (NN/2)*dl;

    [k,l] = meshgrid(K1,L1);

  % Definition of the pit (without sloping sides).
    for i = 1 : size(x,1),
        for j = 1 :size(x,2),
            %verdraaiing van het assenstelsel
            ksi(i,j) = (x(i,j) .* (cos(theta .* (pi/180)))) + (y(i,j) .*...
                (sin(theta .* (pi/180))));
            eta(i,j) = -x(i,j) .* sin(theta .* (pi/180)) + y(i,j) .*...
                cos(theta .* (pi/180));

            if (abs(ksi(i,j))) <= (L/2) %position on the bottom of the pit
                HL(i,j) = 1;
            else
                HL(i,j) = 0; %position outside the pit
            end

             if (abs(eta(i,j))) <= (B/2) %position on the bottom of the pit
                HB(i,j) = 1;
            else
                HB(i,j) = 0; %position outside the pit
             end
          h_pit(i,j) = (HL(i,j) .* HB(i,j));

          %dimensionless depth times the actual depth of the pit
        end
    end;

    h_put = h_pit .* -de;

%Fourier analysis
    h_init = fft2(h_put);

%definition of omega (real part)

teller1 = ((k.^2) .*l .*c .* (b-1) .* (l .*r - k .* f));
noemer1 = (((r.^2) + ((k.^2) .*c .^2)) .* (k.^2 + l.^2));
rest1 = (lambda .* (k.^2 + l.^2));
omega  = (c.^b) .* ((teller1 ./ noemer1) - rest1);
omega(round(size(omega,1)/2),round(size(omega,2)/2)) = 0;
% Repair divide by zero
Omega1 = fftshift(omega);

%calculation of the seabed in Fourier space
    Hf = h_init .* exp(Omega1 .* t);

%transform back to physical space
Hs = ifft2(Hf);

%output
  X1_ongesch = X1.* (Uster ./ sigma);
  Y1_ongesch = Y1.* (Uster ./ sigma);
  Hs_ongesch = Hs .* Hster;
%area of influence
    dxi = Lxi/ NN;
    dyi = Lyi / NN;

    %area of influence total area
    check = (abs(Hs_ongesch) >= (0.1));
    cellcount = sum(sum(check));

    %area inside pit
    check_pit = check .* h_pit;
    area_infl_pit = sum(sum(check_pit));
    cellcount_pit = sum(sum(h_pit));
```

```
    %area of influence outside sandpit
    area = cellcount - cellcount_pit;
   %area where the bottomchange is larger than 0.1 (m) outside the sandpit:
    oppvierkant = (dxi .* dyi .* area);
    oppkm = oppvierkant/1.0e6

    % only negative influence area.
    checkmin = (Hs_ongesch <= -0.1);
    cellcountmin = sum(sum(checkmin));

    %area of influence outside wind farm negative (-0,1)
    areamin = cellcountmin - cellcount_pit;

    oppmin = (dxi .* dyi .* areamin); %area where the bottomchange is larger than 0.1 (m)
outside the windfarm
    oppkmmin = oppmin/1.0e6;

%ratio of influence
    ratio_of_influence = oppvierkant/ (Li .*Bi) .*100;

%volume is:
volume = (dxi .* dyi .* cellcount_pit .* d)/1.0e6;

%% Rotate the figure back so that the current direction is correct.

 for i =1:length(X1_ongesch)
    for j = 1:length(Y1_ongesch)
        dm(i,j,1)= Hs_ongesch(i,j);
        dm(i,j,2)= X1_ongesch(i);
        dm(i,j,3)= Y1_ongesch(j);
    end
end
%first to poolcoordinates
for i = 1:max(length(X1_ongesch))
    for j = 1:max(length(Y1_ongesch))
        absolute(i,j) = sqrt((X1_ongesch(i)^2)+Y1_ongesch(j)^2);
        if X1_ongesch(i) > 0
            angle(i,j) = asin(Y1_ongesch(j)/absolute(i,j));
        else
            angle(i,j) = -1*asin(Y1_ongesch(j)/absolute(i,j))+pi;
        end
    end
end
%Rotation it self
angle_hoek = -(270-Direction); %angle that need to be used for the
angle= angle + ((angle_hoek*pi)/180);
%and back to carthesische coordinaten:
for i =1:length(X1_ongesch)
    for j = 1:length(Y1_ongesch)
        ddm(i,j,1)= Hs_ongesch(i,j);
        ddm(i,j,2) = absolute(i,j)*sin(angle(i,j))+Cx;
        ddm(i,j,3) = absolute(i,j)*cos(angle(i,j))+Cy;
    end
end

%% create output figure (tif)
figure(4);
surfc(ddm(:,:,2),ddm(:,:,3),real(ddm(:,:,1)),'EdgeColor','none'), shading interp;
colorbar('location','EastOutside');
axis([-Lplot+Cx Lplot+Cx -Lplot+Cy Lplot+Cy])
axis off

hold on
    plot((data.data(:,1)),(data.data(:,2)),'Color','blue');%original figure
hold on
    plot(xrechthoek,yrechthoek,'Color','red') %rectangle
grid off
hold on
% contourlijn
[C,leve] = contour(ddm(:,:,2),ddm(:,:,3),real(ddm(:,:,1)),[-0.1],'-k');

%prepare color bar
colorbarmin = min(real(ddm(:,:,1)));
Cmin = -4; %min(colorbarmin);
colorbarmax = max(real(ddm(:,:,1)));
Cmax = 2; %max(colorbarmax);
 caxis([Cmin,Cmax])
```

```
        h=colorbar;
        set(get(h,'child'),'YData',caxis)
        set(h,'YLim',caxis)
colorbar('hide')
%save figure
set(gcf, 'Units', 'pixels', 'Position', [0, 0, 500, 476]); %476 is adjust
                                    % so that the length and width are equal
set(gcf, 'paperunits', 'centimeters', 'paperposition', [0 0 10 10])
export_fig result.tif '-r254' -native

%colorbar tif
figure(5)
axis off
grid off
caxis([Cmin,Cmax])
        h=colorbar;
        set(get(h,'child'),'YData',caxis)
        set(h,'YLim',caxis)

set(gcf, 'paperunits', 'centimeters', 'paperposition', [0 0 10 10])
export_fig colorbar.tif '-r254' -native

%% create tfw (location of the figure)
MyImage = imread('result.tif');

[rows,columns,planes] = size(MyImage);

PMx=50000/columns;  %Line 1:   x-scale. This is the horizontal distance in meters represented
by each pixel. So in the above example each pixel is .6 meters wide.
Ry=0;               %Line 2:   Rotation about y axis.
Rx=0;               %Line 3:   Rotation about x axis.
PMy=-50000/rows;    %Line 4:   y-scale This is the vertical distance in meters represented by
each pixel. So in the above example each pixel is .6 meters tall. Normally negative, because
whilst an image has its origin in the top left corner, for Northings and Eastings the origin
is normally considered to be the bottom left corner - hence why the scale is normally
negative.

LBx = Cx - Lplot;   %Line 5:   x-reference point. This is the horizontal coordinate (or
Easting) of the center of the top left pixel.
LBy = Lplot + Cy;   %Line 6:   y-reference point. This is the vertical coordinate (or
Northing) of the center of the top left pixel.

tfwgoed = [PMx Ry Rx PMy LBx LBy];

fid = fopen('result.tfw', 'wt');
fprintf(fid, '%6.8f\n', tfwgoed);

%tfw colorbar
CMyImage = imread('colorbar.tif');

[Crows,Ccolumns,Cplanes] = size(CMyImage);

CPMx=60;             %Line 1:   x-scale. This is the horizontal distance in meters represented
by each pixel. So in the above example each pixel is .6 meters wide.
CRy=0;               %Line 2:   Rotation about y axis.
CRx=0;               %Line 3:   Rotation about x axis.
CPMy=-50000/Crows;   %Line 4:   y-scale This is the vertical distance in meters represented by
each pixel. So in the above example each pixel is .6 meters tall. Normally negative, because
whilst an image has its origin in the top left corner, for Northings and Eastings the origin
is normally considered to be the bottom left corner - hence why the scale is normally
negative.

CLBx = Cx - Lplot -20000;   %Line 5:   x-reference point. This is the horizontal coordinate
(or Easting) of the center of the top left pixel.
CLBy = Lplot + Cy;   %Line 6:   y-reference point. This is the vertical coordinate (or
Northing) of the center of the top left pixel.

Ctfwgoed = [CPMx CRy CRx CPMy CLBx CLBy];

fid = fopen('colorbar.tfw', 'wt');
fprintf(fid, '%6.8f\n', Ctfwgoed);

fclose(fid);

%% back rotation of countour (C) so we can calculate the needed buffer,
% determine the max distance between contuour en sandpit
```

```
%rectangle normal no rotation
xrect = [-(Li/2), -(Li/2), (Li/2), (Li/2), -(Li/2)]; %xy coordinaten vd de optimale rechthoek
yrect = [-(Bi/2), (Bi/2), (Bi/2), -(Bi/2), -(Bi/2)];

%contour back rotated so it fits a rectangle with no rotation
%contourline around 0,0
contourlengte1 = C(2,1)+1;
xC = C(1,2:contourlengte1);              %contour x coordinaat
yC = C(2,2:contourlengte1);              %contour y coordinaat
xC = xC-Cx;
yC = yC-Cy;

%Rotation of contourline
for i =1:length(X1_ongesch)
    for a = 1:max(size(xC))
        absolute1(a) = sqrt(xC(a)*xC(a)+yC(a)*yC(a));   %bepaal M
        if xC(a) > 0                                      %bepaal hoek
            angle1(a) = atan(yC(a)/xC(a));
        elseif xC(a) < 0 && yC(a) >= 0                                   %bepaal hoek
            angle1(a) = atan(yC(a)/xC(a))+pi;
        elseif xC(a) < 0 && yC(a) < 0
            angle1(a) = atan(yC(a)/xC(a))-pi;
        elseif xC(a) == 0 && yC(a) > 0
            angle1(a) = (1/2)*pi;
        else
            angle1(a) = -(1/2)*pi;
        end
    end
    %Rotation it self
    angle11 = angle1 + ((opt_angle)*pi)/180;%(-opt_angle-(270-Direction))/180;
    %and back to carthesische coordinaten:
    for a = 1:max(size(xC))
        xCRB(a) = absolute1(a)*cos(angle11(a));
        yCRB(a) = absolute1(a)*sin(angle11(a));
    end
end

%determine max distance between contour and sandpit.
[Cxmin, pCmin] = min(xCRB);
[Cxmax, pCmax] = max(xCRB);
[xrectmin, pxrectmin] = min(xrect);
[xrectmax, pxrectmax] = max(xrect);
%minafstandx = Cxmin - xrectmin
maxafstandx = Cxmax - xrectmax;

[Cymin, pyCmin] = min(yCRB);
[Cymax, pyCmax] = max(yCRB);
[yrectmin, pyrectmin] = min(yrect);
[yrectmax, pyrectmax] = max(yrect);
%minafstandy = Cymin - yrectmin
maxafstandy = Cymax - yrectmax;
%needed buffer or max distance between contourline and sandpit
Maxdistance_Contourline_rectangle = abs(max(maxafstandy,maxafstandx))

%%save results
save('results.mat', 'ratio_of_influence', 'oppkm','ba', 'meanmaxm2', 'Direction', 'mn', 'Cx',
'Cy', 'volume', 'C');

%write results to txt file.
results = [c, Hi, oppkm, oppkmmin, Maxdistance_Contourline_rectangle, volume, Direction, Li,
Bi, di, time];
% open a file for writing
fid = fopen('results.txt', 'w');

% print a title, followed by a blank line
fprintf(fid, 'M2velocity(m/s), Waterdepth(m), Influence area(km2), Influence area only
negative(km2), Maxdistance_buf(m), Volume(km3), direction(degree), length(m), width(m),
depth(m), years \r\n');

% print values in column order
% two values appear on each row of the file
fprintf(fid, '%1.2f, %2.2f, %5.2f, %5.2f, %4.2f, %5.2f, %3.2f, %7.2f, %7.2f, %2.2f, %4.2f
\r\n', results);

fclose(fid);

close all
```

Appendix J MapTable connected with WAQUA for 'Holland coast' case

During this research a working interaction between MapTable and the WAQUA schematisations 'SIMONA-kuststrook-fijn-1999-v4' is generated. This interaction is very useful to generate output information from WAQUA, which can be used as input for other models. Unfortunately this interaction has became unnecessary during this research, due to that the used sandpit model uses initial conditions. Due to the use of these initial conditions WAQUA calculations became unnecessary.

For further research with other models this interaction could be helpful, there for a short description of this interaction is given in this appendix.

The case 'Holland coast' is already prepared for the use of WAQUA, as matter of fact it is using WAQUA already, but it is set for a very short calculation time. If we want to use variables calculated with WAQUA we need to change the siminp file. In this file the time period can be set even as the desired output. For example we can calculate the new current velocity above a sandpit after 30 days.

But there are a few points that we need to keep in mind, these are:

- It takes a lot of calculation time if we want to calculate effect after a long period, the calculation time for 1 day is approximately 8 minutes for every day more this will increase with 7 minutes.
- It is difficult to generate average values for each gird point over a long time period.

Appendix K Sensitivity analysis on the outcome by using the different velocities.

To find out what the effect is of this uncertainty in M2 velocity, a sensitivity analysis has been done on the outcome of the different M2 velocities in the different sources (van der Veen, 2008 and van Santen, 2008). A sandpit with the following parameters is used for this sensitivity analysis:

Water depth (m)	Pit depth (m)	Length (m)	Width (m)	years	Angle (degree)	Volume (km^3)
25	2	15000	1500	10	40	45

Table 23: Parameters taken for a sandpit used for the sensitivity analysis.

The locations of each point (id) are shown in figure 18. The results for each source of M2 velocity are (table 24):

Kuststrookfijn				
Id	M2velocity(m/s)	Influence area(km2)	Influence area negative(km2)	Max distance_buf(m)
110	0.45	2.44	2.44	107
122	0.52	2.54	2.54	125
123	0.56	2.54	2.54	133
150	0.57	2.58	2.58	135
163	0.67	5.16	5.16	215
172	0.64	4.68	4.68	188
180	0.67	5.16	5.16	215
194	0.64	4.68	4.68	188
201	0.66	4.76	4.76	199
207	0.71	6.78	6.78	258
217	0.68	5.22	5.22	229
219	0.67	5.16	5.16	215
222	0.74	7.34	7.34	301
225	0.75	7.42	7.40	315
235	0.72	6.94	6.94	266
Van Santen				
Id	M2velocity(m/s)	Influence area(km2)	Influence area negative(km2)	Max distance_buf(m)
110	0.45	2.44	2.44	107
122	0.48	2.54	2.54	116
123	0.60	4.62	4.62	164
150	0.45	2.44	2.44	107
163	0.58	2.70	2.70	147
172	0.59	3.60	3.58	156
180	0.57	2.58	2.58	135
194	0.60	4.62	4.62	164
201	0.64	4.68	4.68	188
207	0.72	6.94	6.94	266
217	0.68	5.22	5.22	229
219	0.63	4.64	4.64	200

222	0.74	7.34	7.34	301
225	0.70	6.32	6.32	250
235	0.72	6.94	6.94	266
Van der Veen				
Id	M2velocity(m/s)	Influence area(km2)	Influence area negative(km2)	Max distance_buf(m)
110	0.48	2.54	2.54	116
122	0.53	2.54	2.54	127
123	0.57	2.58	2.58	135
150	0.55	2.54	2.54	131
163	0.59	3.60	3.58	156
172	0.58	2.70	2.70	147
180	0.57	2.58	2.58	135
194	0.61	4.64	4.64	171
201	0.64	4.68	4.68	188
207	0.72	6.94	6.94	266
217	0.69	5.26	5.26	240
219	0.62	4.64	4.64	200
222	0.72	6.94	6.94	266
225	0.69	5.26	5.26	240
235	0.69	5.26	5.26	240

Table 24: Model outcome of different velocities per source for each id point.

The sensitivity analysis is shown in table 25.

Difference in max distance_buf				
Kuststrookfijn - van Santen		**Kuststrookfijn - van der Veen**		
absolute	percentage	absolute	percentage	max
0	0%	8.99	8%	8%
9.03	7%	2.02	2%	7%
31.61	24%	2.06	2%	24%
28.11	21%	4.08	3%	21%
68.76	32%	59.09	27%	32%
31.64	17%	41.31	22%	22%
80.59	37%	80.59	37%	37%
23.59	13%	16.7	9%	13%
10.97	6%	10.97	6%	6%
7.95	3%	7.95	3%	3%
0	0%	11.21	5%	5%
15.49	7%	15.49	7%	7%
0	0%	34.37	11%	11%
65.19	21%	74.91	24%	24%
0	0%	26.34	10%	10%
			Average:	15%

Table 25: Result of a sensitivity analysis for different M2 velocity.

The sensitivity analysis shows that there is an average uncertainty of 15% in maximum distance between the sandpit and the morphological depth change contour line. This uncertainty grows when the pit depth or morphological time scale is increased. This uncertainty could be reduced by improving the data on the M2 velocity, for example by collecting real measured M2 velocity data.