

Interactive management of marine resources in the southern North Sea, a long-term perspective

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Abstract

Management of geological resources is based, ideally, on information on the quality and quantity of surface and subsurface litho-stratigraphical properties. Increasingly, these data become available for the offshore domain, though the integration into manageable and user-friendly applications is still at its infancy. Building on expertise from on-land data mining, we are now in the phase of creating 3D voxel models allowing for multi-criteria resource volume calculations. The underlying data are subdued to uncertainty modelling, a necessary step to produce data products with confidence limits. Anticipating on the dynamic nature of the marine environment, voxel models are coupled to environmental impact models that calculate resource depletion and regeneration under various scenarios, and using geological boundary conditions. In combination with foreseen impacts on fauna and flora, mining thresholds can be defined. Integration into a decision-support system allows for easy querying and on-line visualizations. Main aim is to provide long-term predictions on resource quantities to ensure future supplies for the benefit of society and next generations.

Key words: Sustainable Exploitation, Mining thresholds, 3D Geological Models, 4D Decision-Support System, Uncertainty modelling

Introduction

Mineral and geological resources can be considered to be non-renewable on time scales relevant for decision makers. Once exhausted by humans, they are not replenished rapidly enough by nature, meaning that truly sustainable resource management is not possible. Comprehensive knowledge on the distribution, composition and dynamics of geological resources therefore is critical for developing long-term strategies for resource use (e.g., Van Lancker et al., 2010). For the marine realm, resource management is often hampered by sparse data availability, though increasing exploitation demands

call for innovative approaches that include uncertainty as a primary asset. This is the scope of the TILES project (2013-2017), set-up for managing marine aggregate exploitation in the southern North Sea, but generically designed for a broader range of resources and environments.

The ambition of TILES is to:

- Develop a 4D resource decision-support system containing tools that link 3D geological models, knowledge and concepts to numerical environmental impact models. Together they quantify natural and man-made changes to define sustainable exploitation thresholds. These are needed to ensure that recovery from perturbations is rapid and secure, and that the range of natural variation is maintained, a prerequisite stated in Europe's Marine Strategy Framework Directive (MSFD), the environmental pillar of Europe's Maritime Policy.
- Provide long-term adaptive management strategies that have generic value and can be used for all non-hydrocarbon geological resources in the marine environment.
- Propose legally binding measures to optimize and maximize long-term exploitation of aggregate resources within sustainable environmental limits. These proposed measures feed into policy plans that are periodically evaluated and adapted (e.g., Marine Spatial Planning and the Marine Strategy Framework Directive, being Federal Authority's strategic priorities).

The TILES study area comprises the Belgian and southern Netherlands part of the North Sea (BPNS and NPNS, south of Rotterdam), in total ± 9700 km². Most of the resources are extracted from the offshore sandbanks (Figure 1).

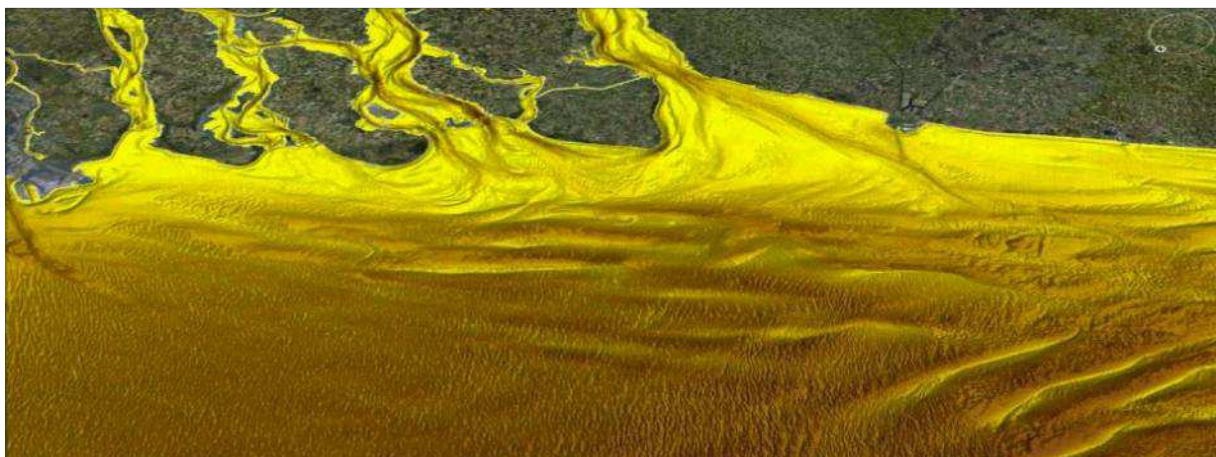


Figure 1: The Belgian-Dutch offshore area considered in the TILES project: significant volumes of sand are stored in the ebb delta of the estuaries and in sandbanks located farther seaward. North is to the West of the figure; bright to darker yellow represents shallow to deeper depths. Bathymetry data: Flanders Hydrography and Dutch Hydrographic Service & Deltares.

Material and methods

The project objectives are achieved through interdisciplinary and transnational research on the nature and dynamics of geological resources and on the environmental impact of extraction. State-of-the-art 3D geological models are being developed by transforming layer models, defining stratigraphic unit boundaries, into so-called voxel models (consisting of 'tiles' or volume blocks) and assigning to each voxel lithological or other characteristics (e.g., Stafleu et al., 2011). The primary voxel information is based on a combination of point and line data, respectively from coring and seismic investigations. These data, and additional environmental datasets, that are added to the voxels, are subjected to uncertainty analyses, a necessary step to produce data products with confidence limits. Uncertainties

relate to data and interpolation issues (van Heteren & Van Lancker, in press); their propagation is assessed throughout the data products. The geological models feed into 4D numerical impact models quantifying the environmental impact of extraction (e.g., Van den Eynde et al., 2010). Geological boundary conditions (e.g., base of extractable layers) will be used. Regeneration potential and depletion rates will be calculated per main sediment type, based on monitoring, extraction data and a 10-yr time series of sediment transport modelling (Francken et al., this volume). Per vertical series of voxels, a sustainable extraction threshold will be proposed, taking into account the geological resource available, regeneration potential and depletion rate that will limit the resource potential to what is environmentally acceptable (Figure 2). Further constraints relate to the compatibility with other human activities, protected and exclusion zones, as well as socio-economic and other environmental factors (Figure 2).

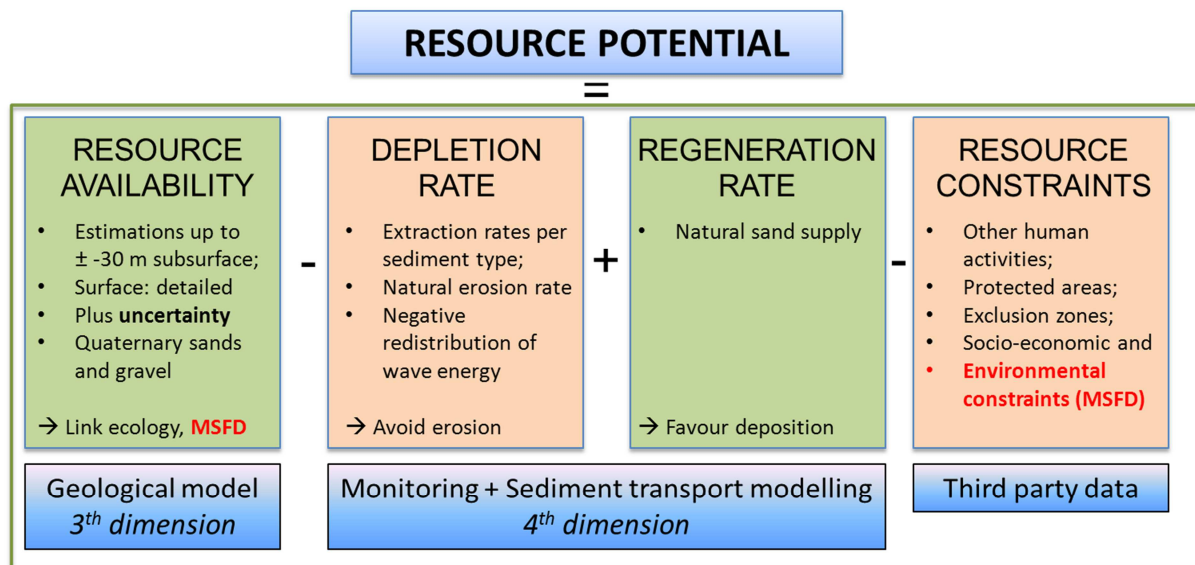


Figure 2: Definition of the resource potential within TILES. Combination of the datasets into impact modelling will yield a sustainable extraction threshold per vertical series of voxels. This will allow assessing the resource potential within sustainability limits, a MSFD prerequisite.

Finally, scenario analyses and prediction forecasts will be performed to estimate the resource potential on the long term. A newly developed multi-criteria decision-support system (DSS) will be used to run the scenarios. Advanced criteria-evaluation techniques, incorporating expert knowledge, will support the construction of suitability maps (e.g., De Tré et al., 2010). Geological boundaries, distributions of particular resource qualities, and the resource estimation at various cut-off grades will be calculated in a time-efficient manner. Sediment transport model results will be used as input and will reflect, amongst others, how the extraction scenarios lead to changes in wave energy and direction. Additionally, the DSS will allow weighing other functions on the BPNS, and take into account environmental and socio-economical parameters. Using a dedicated subsurface viewer, a suite of data products will be viewable online. They can be extracted on demand from the underlying voxel model. The flexible 3D interaction and querying is invaluable for professionals, but also for the public at large and for students in particular.

The TILES workflow is presented in Figure 3; in its entirety leading to a geological knowledge base that will function as a critical platform for the exchange of data, information and knowledge.

Simple Lithology	Udden-Wentworth classes	Adjusted Folk classes	Shell content (%)
Clay	Boulder (>256 mm)	mud	little (1-10%)
Diamicton	Cobble (64-256 mm)	slightly sandy mud	much (10-30%)
Gravel	Very coarse gravel (pebble) (32-64 mm)	sandy mud	numerical range (every range within 0-100%)
Gyttja	Coarse gravel (pebble) (16-32 mm)	muddy sand	
Mud	Medium gravel (pebble) (8-16 mm)	slightly muddy sand	
Ooze	Fine gravel (pebble) (4-8 mm)	sand	
Peat	Very fine gravel (granule) (2-4 mm)	slightly gravelly mud	
Sand	Very coarse sand (1-2 mm)	slightly gravelly sandy mud	
Shell hash	Coarse sand (0.5-1 mm)	slightly gravelly muddy sand	
Silt	Medium sand (0.25-0.5 mm)	slightly gravelly sand	
	Fine sand (0.125-0.25 mm)	gravelly mud	
	Very fine sand (0.0625-0.125 mm)	gravelly muddy sand	
	Silt (mud) (0.0039-0.0625 mm)	gravelly sand	
	Clay (mud) (0.001-0.0039 mm)	muddy gravel	
		muddy sandy gravel	
		sandy gravel	
		gravel	
			Mud content (%)
			little (1-2%)
			moderate (2-10%)
			much (>10%)
			numerical range (every range within 0-100%)
			Median grain-size (d50)
			numerical range (any user-defined range)

Figure 4: Selected attributes for resource characterization, available for both the Belgian and Netherlands part of the North Sea. European standards for the description of geological data are adhered to. The first attributes are derived primarily from lithological databases. Shell and mud content, as well as median grain-size can originate both from lithological and grain-size databases.

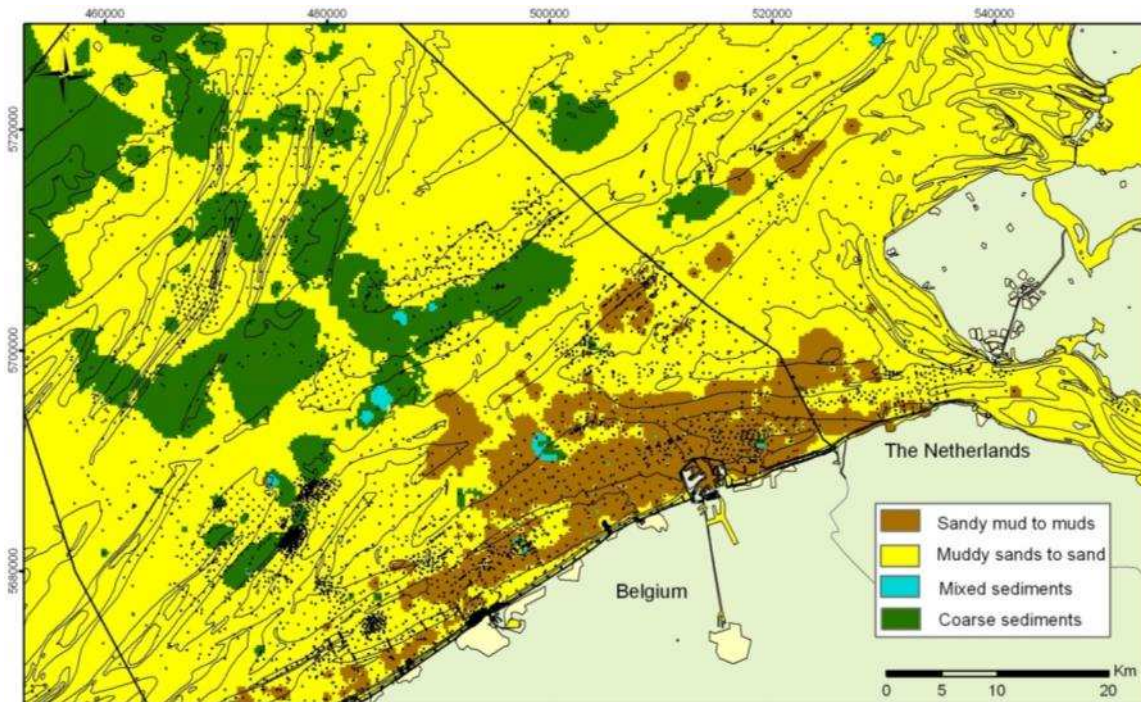


Figure 5: Grouping of adjusted Folk classes, representative of EUNIS Level 3 habitats: sandy mud to mud, muddy sands to sands, coarse sediments and mixed sediments. The distribution reflects the percentages of gravel, sand, silt and clay from sample data (black dots). Here, only sampling density is a measure of uncertainty (Van Lancker & van Heteren, 2013).

Multi-criteria Decision Support System

A DSS is being developed to answer a multitude of questions related to the voxel data. Using soft computing techniques and decision logic, a maximum of flexibility in the decision process is aimed at. A two-tiered approach is followed: (1) questions from a user need translation into requirements; (2) the system evaluates each voxel and provides a score from 0 (bad) to 1 (good) on the basis of (i) how well the voxel fulfils the requirements, (ii) how sure we are on the quality of the data; and (iii) missing data. In this process, the resource is defined following the attributes shown in Figure 4. A user can select

any of the parameters listed which will then be prioritized by the system. Quality is related to data uncertainty and, based on expert judgement, incorporates methodology (e.g., coring techniques), analytical procedures (e.g., grain-size analyses), vintage, and data density. Per voxel, an interpolation-uncertainty is also provided. In this process transparency is regarded important enabling a user to trace how a certain score is obtained.

Conclusions

To anticipate on actual and future resource supplies and needs, long-term adaptive management strategies for the exploitation of geological resources are urgent requests (e.g., marine spatial planning, EU's Marine Strategy Framework Directive). They comply ideally with EU recommendations on 'Efficient use of resources' (EC COM2011_571) and ICES Guidelines for the management of Marine Sediment Extraction (ICES, 2003).

Within TILES a transnational, harmonized geological knowledge base will be provided as a critical platform for the exchange of data, information and knowledge. The set-up, functionalities, and coupling to environmental impact models are highly innovative and will herald a new age in resource management, locally and transnationally.

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