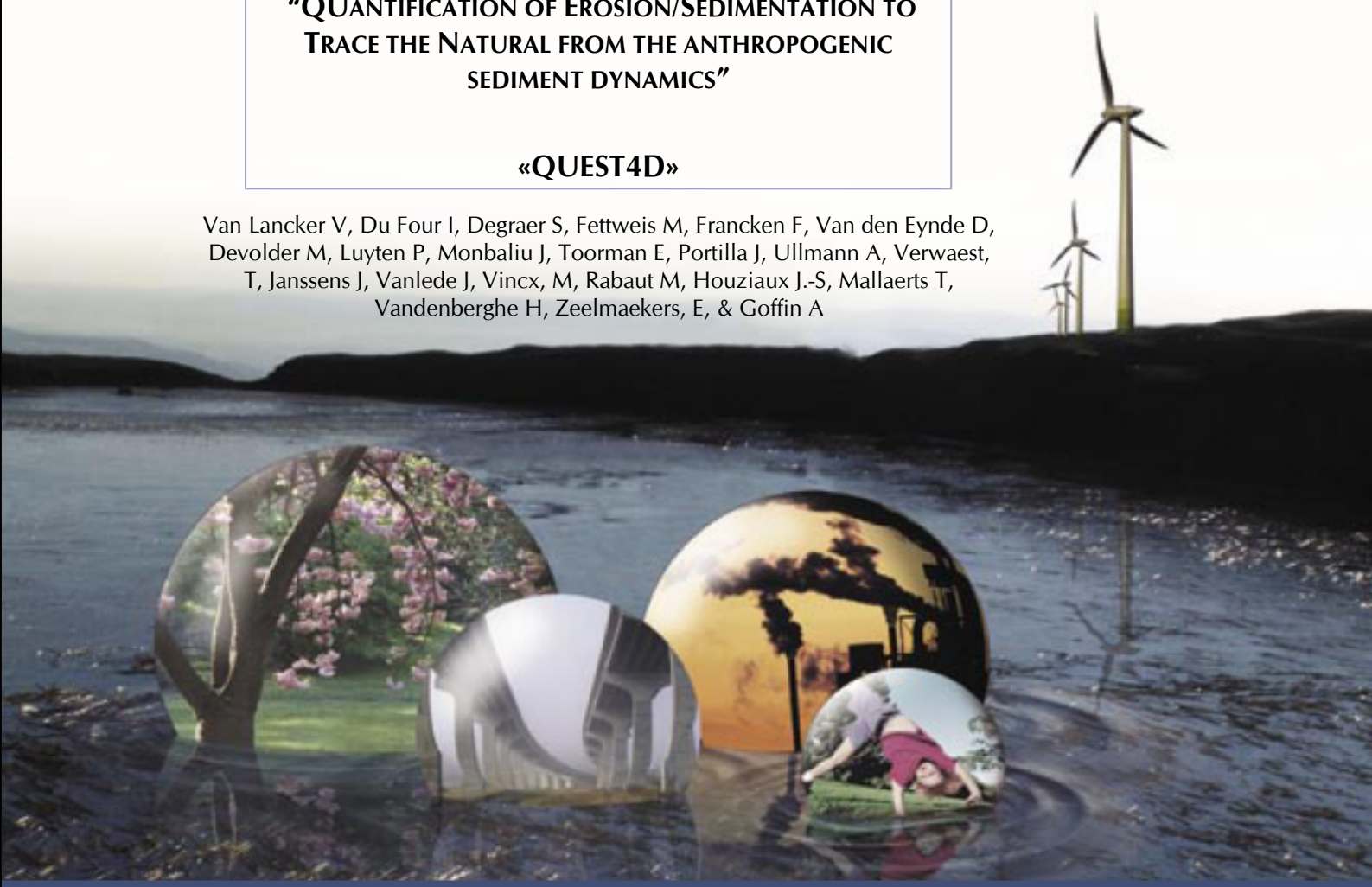
SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT

"QUANTIFICATION OF EROSION/SEDIMENTATION TO TRACE THE NATURAL FROM THE ANTHROPOGENIC SEDIMENT DYNAMICS"

«QUEST4D»

Van Lancker V, Du Four I, Degraer S, Fettweis M, Francken F, Van den Eynde D, Devolder M, Luyten P, Monbaliu J, Toorman E, Portilla J, Ullmann A, Verwaest, T, Janssens J, Vanlede J, Vincx, M, Rabaut M, Houziaux J.-S, Mallaerts T, Vandenberghe H, Zeelmaekers, E, & Goffin A



ENERGY

TRANSPORT AND MOBILITY

AGRO-FOOD

HEALTH AND ENVIRONMENT

CLIMATE

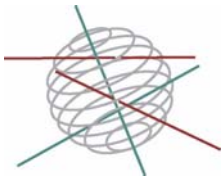
BIODIVERSITY

ATMOSPHERE AND TERRESTRIAL AND MARINE ECOSYSTEMS

TRANSVERSAL ACTIONS

.be

SCIENCE FOR A SUSTAINABLE DEVELOPMENT
(SSD)



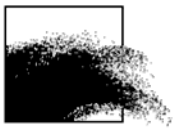
North Sea

FINAL REPORT PHASE 1
SUMMARY

QUANTIFICATION OF EROSION/SEDIMENTATION TO TRACE THE NATURAL FROM THE ANTHROPOGENIC SEDIMENT DYNAMICS "QUEST4D"

SD/NS/06A

Van Lancker V, Du Four I, Degraer S, Fettweis M, Francken F, Van den Eynde D, Devolder M, Luyten P, Monbaliu J, Toorman E, Portilla J, Ullmann A, Verwaest, T, Janssens J, Vanlede J, Vincx M, Rabaut M, Houziaux J.-S, Mallaerts T, Vandenberghe H, Zeelmaekers E, Goffin A



Rue de la Science 8
Wetenschapsstraat 8
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11 – Fax: +32 (0)2 230 59 12
http://www.belspo.be

Contact person: David Cox
+32 (0)2 238 34 03

Van Lancker V, Du Four I, Degraer S, Fettweis M, Francken F, Van den Eynde D, Devolder M, Luyten P, Monbaliu J, Toorman E, Portilla J, Ullmann A, Verwaest, T, Janssens J, Vanlede J, Vincx M, Rabaut M, Houziaux J.-S, Mallaerts T, Vandenberghe H, Zeelmaekers E, Goffin A, ***QUantification of Erosion/Sedimentation patterns to Trace the natural versus anthropogenic sediment dynamics*** "**QUEST4D**". Final Report Phase 1 Summary. Brussels : Belgian Science Policy 2009 – 7 p. (Research Programme Science for a Sustainable Development)

Introduction

Sustainable development requires the quantification of human impacts, against the seafloor's ecological value. Recent impact studies have shown only localised effects, though indications of a longer-term and broader-scale degradation of the seafloor exist. This is due possibly to cumulative anthropogenically-induced effects, but the natural evolution and the response of the seafloor due to sea-level rise are poorly known. Nonetheless, it is likely that changing wave climate and an increased storminess induce different erosion/sedimentation patterns. Such evolution needs to be disentangled against the impact of dredging, aggregate extraction, fisheries and beach replenishment on the ecosystem's physical functioning.

The Belgian part of the North Sea (BPNS) is targeted for the reconstruction of seabed ecosystem changes over the past 150 years. Spatially and temporally extensive data sets have been compiled and allow studying various ecosystem components in the space, time and depth domain. Particularly, sediments and sediment transport processes have been studied, given their central role in ecosystem studies. Long-term ecosystem changes have been investigated, starting from a historical data-set on benthos and sediments, dating back to the first decade of the 20th century (the "Gilson collection"). Together with long-term datasets in the period 1866-2008, changes in bathymetry, sediments and macrobenthos were studied. Modelling tools have been refined with the aim of using them for dedicated case studies in phase 2 of the project. Natural changes were studied, based on observations and on climate change models. Quantification of human impact has been performed at sites, where long-term datasets were available.

The research strategy consisted of extensive GIS analyses, state-of-the-art observations/sampling (RV Belgica), experiments and advanced modelling, within the space, depth and time domain (4D). A multi-sensor tripod, a.o. measuring turbidity, currents and in-situ particle size is deployed on a quasi-permanent time-scale. Parameters are measured in function of model improvement, and observations are made to test hypotheses on seabed nature and dynamics, often in a multidisciplinary context.

The ecosystem in the space, time and depth domain

Generally, the BPNS is a typical sandbank-swale environment; though the coastal zone comprises large mud fields, often associated with highly turbid waters. Apart from hydrodynamics, origin of water masses, waves and bed composition, it has been shown that the occurrence of mixed sediments and their variability, the effects of waves on the failure of consolidated mud beds and the erosion effects of sand on top of consolidated mud are main drivers of sediment transport in the coastal zone. The formation of high concentration mud suspensions (HCMS), during storm periods has probably a major influence on the transport of suspended particulate matter (SPM) and on the deposition of mud in (mainly) navigation channels and harbours; hitherto never investigated.

Human activities are well-spread in the coastal zone (e.g. harbour extension works, dredging and disposal of dredged material, deepening of navigation channels, aggregate extraction); as such a good understanding is needed on non-cohesive and cohesive sediment dynamics and their interaction (deposition and erosion). Flocculation is an important process and still requires field-based measurements and calibration to improve numerical modelling of sediment transport. Sediment erodibility is a major issue, since the coastal zone comprises mud with variable degrees of consolidation that is eroded and deposited according to the prevailing hydro-meteorological agents. Measurements have shown that the critical shear stress for erosion increases rapidly with depth; hence mud erosion is mostly a surface phenomenon; however under storm conditions consolidated mud layers can be eroded.

The provenance of mud in the coastal zone has always been enigmatic. A turbidity maximum area extends roughly from the Westerschelde estuary to Ostend. Especially, in this area, several mud types exist of various ages and often Holocene to older mud layers are outcropping. Mud

provenance was studied using detailed qualitative and quantitative analyses of the bulk and clay mineralogy of mud and their potential source areas. The results show that the clay mineralogy of the Holocene, modern and recent mud and SPM is identical. A very similar clay assemblage is found in the Scheldt river (Estuary and further upstream) and the Rupel river. These results indicate a close provenance relationship between the BPNS and sediments transported by the Scheldt. On the other hand, potential source areas that could be excluded as major sources of BPNS mud include the Dover Strait coasts, the Eocene and Pleistocene glacial deposits, currently exposed on the BPNS sea floor and suspension from the Atlantic Ocean. A similar to almost identical clay mineralogy was determined, respectively, for Holocene salt marsh deposits and Eemian interglacial deposits, sampled near the present-day coastline; this suggests that a provenance relationship between BPNS mud and the Scheldt river system has existed on and off since the Late Pleistocene.

Sedimentation/erosion patterns have been studied also, on the basis of time-series of very-high resolution multibeam bathymetry and sonar imagery. Especially, near the main disposal ground of dredged material, complex sediment transport processes occur. Important bedload transport rates and sand dune migration are identified, completely opposite to the residual currents and suspension transport. These observations are important in view of recirculation of dredged material, hence will allow future optimisation of dredging/disposal activities. Nearby the disposal ground, hotspots of biodiversity are found, in the troughs of sand dunes. Aggregations of the polychaet *'Owenia fusiformis'* here occur; in these areas bedforms do not migrate, whilst outside of these patchy areas, a dune migration rate of 20m is observed. It is not clear yet whether these patches are associated with the disposal ground or with higher nutrient supply from the Westerschelde estuary.

Long-term ecosystem changes

The Gilson collection (1899-1908) provided a unique opportunity to investigate how physical and biological processes have changed over the whole 20th century. Sediment and benthos data were obtained with dedicated sampling gears, operated sequentially within dense sampling grids. The dataset has been reconstructed enabling investigation of baseline relationships between benthic communities and seafloor composition. Sampling procedures and data quality issues were clearly identified, providing robust data for further analysis.

Historic sediment type maps were constructed, based on Gilson's sediment sample descriptions. Further to prior digitizations, Gilson's benthos archive was now completed with bivalves, polychaetes and amphipods. "Baseline maps" of benthos composition (species richness, total abundances) were drawn and provide a coherent picture of the former distribution of benthic biodiversity alongside the Belgian and Dutch coastal zone and in the surroundings of the Westhinder sand bank. Linking macrobenthic and sediment data will further enable to determine whether some ecological structure can be found in this century-old "new" sub-regional species assemblage.

The distribution of bivalves was further explored and compared to the present-day distribution (1994-2008, UG-ILVO database). Changes were attributed to long-term patterns in the North Atlantic Oscillation (NAO), since the bulk of both data-set had indeed been collected under opposite winter NAO conditions. All observed species distribution shifts match the expectations of altered physiographic conditions, due to NAO. On the BPNS, processes related to turbidity and sedimentation/re-suspension are important, and the very coastal waters to the West experience contrasting patterns of salinity, under prolonged episodes of positive or negative NAO conditions. The latter effect, clearly tracked in euryhaline benthos data, reflects increased river runoffs (due to NAO-induced increased precipitations over NW Europe). Both effects are imposed by highly positive NAO values, especially since the regime shift of 1988. The very different pattern displayed by the historic data, prior to 1903, seems to mirror 30 years of sustained negative NAO conditions. Results urge for a re-examination of variations in datasets,

due to NAO cyclicity and their shifts. Especially, the overall turbidity and siltation increase of Belgian coastal waters needs verification against varying river discharges, resulting from NAO cyclicity.

Long-term analyses were performed on bathymetry datasets in the period 1866-2007. No significant movement of the sandbanks could be demonstrated, though some banks had variable patterns of erosion and deposition, with the Flemish Banks showing accretion along their SW extremity, and erosion along their NE part. The troughs in-between banks experienced erosion mainly, resulting in steeper slopes of the banks. In the coastal zone, a sedimentation trend seems to dominate, with particular accretion of sediments in the Grote Rede swale, landward of the Wenduine Bank. From the analyses of long-term sediment changes, this would correspond with mud deposition. Apart from human-induced, localised, sediment changes (e.g. disposal grounds of dredged material), no wide-spread changes in median grain-size could be deduced. However, a major change is seen in the sorting of the sandy sediments over the past 100 yrs. All of the Gilson samples that were re-analysed, were well-sorted, whilst recent samples are predominantly moderate to poorly-sorted. The cause of this worsening in sorting is associated with enrichment of fine sandy sediments, as shown by the skewness value of the recent sediments. Their spatial occurrence is mostly linked to harbour areas, disposal grounds, and aggregate extraction sites; though the trend is also observed in the so-called 'natural systems'. A possible link with NAO or other cyclicity should be investigated.

Modelling of processes

For predictions and more integral impact assessments, modelling is a prerequisite. However, the complexity of the BPNS seabed nature and dynamics requires refined modelling, ideally calibrated and validated with observations and measurements. Improved bed models are being designed to account for erosion of old sediments (Holocene and outcropping Tertiary clays) distinguishing between active layers and more passive buffer or parent layers. It has been shown that classical flocculation models, based on an empirical approach, are not able to satisfactorilly reproduce measurement data and required a better understanding of SPM dynamics. To study its implications in coastal morphodynamics, both the mineral, as well as the microbial fraction needs consideration. Since, these are strongly site-specific, this information should be acquired at the same moment.

A major issue remains the influence of the Westerschelde estuary on the sediment- and morphodynamics of the BPNS and vice versa. Especially, cross-border mud transport is highly sensitive internationally and has led to numerous studies. Mud balances, computed by modelling, result in a yearly net export of 2 Mton from the Scheldt estuary, being still one order of magnitude larger than the net import, following from mud balances, based on observations. Exact numbers from observations remain associated with large uncertainties and are not well known; estimates range from 0.05 to 0.35 Mton yearly net import. Since it appears that the model's concentration gradient between the inner and outer estuary of the Scheldt is realistic, the computed export might be due to an underestimation of the estuarine circulation and the observed phase error of the M4 tidal component. The latter influences the tidal asymmetry and thus also the residual sediment transport. Further verifications are needed.

Finally, wave turbulence and wave energy dissipation, and their importance in the turbulence part of hydrodynamic models are being modelled. Therefore a coupled wave-current model has been implemented and tested on High Performance Computer facilities. This will enable a more sound modelling and interpretation of current field (including turbulence) measurements and its consequences for SPM modelling. The model suite will later be used for specific case studies.

Natural evolution and climate change

To interpret changes in the marine environment or to assess human impacts adequately, knowledge on the natural variability of seabed processes is needed. Especially sandbank areas are prone to variation and storms can have major impacts on sediment volume changes. This was investigated for a sandbank area, without human impact, where a series of bathymetric data were available. From a correlation of sediment volume changes with the directionality and strength of winds, waves and currents, it was shown that prolonged northeastern conditions are associated with the lowest sediment budgets, whilst those from the southwest are clearly associated with a sediment input. The spatial validity of these findings needs further investigation, though useful repetitive bathymetric time series are generally very scarce.

The influence of storms on SPM concentration has been studied also. Here, the direction of wind, wave height and availability of erodible cohesive sediments are crucial. It is argued that local mud sources, such as mud in sandy beds or consolidated mud layers, have to exist, besides the well-known and generally accepted English Channel, as major source of SPM.

For the study of the influence of climate change on seabed processes, a dedicated investigation was set-up. It has been shown that high sea surges along the Belgian coast occur when a low pressure system remains stationary over the Baltic Sea and is associated with a reinforced Azores high. This sea-level pressure (SLP) pattern shows a strong Southwest-Northeast pressure gradient leading to onshore winds along the Belgian coast. Wintertime highest sea surges (99th percentile) at Ostend have increased at a rate of + 1 mm/yr from 1925 to 2000. This increase is associated with the SLP rise over the Azores leading to an increase of the frequency of strong surge-related pressure gradient. A statistical downscaling method is used to set-up a model to relate SLP to sea surge at Ostend. A multiple linear regression is designed to relate the daily surge height at Ostend with (i) the daily SLP over the Baltic Sea; and (ii) the daily value of the pressure gradient between the Baltic Sea and the Azores. This regression robustly reproduces the interannual to long-term variability of high surges at Ostend. The regression is then used with SLP time series simulated until 2100 under climate change scenarios. High surges are expected to stay stationary during the 21st century, associated with no significant changes in SLP conditions over the Baltic Sea and over the Azores. It is not expected that climate change for the 21st century would significantly modify surge and wave-related atmospheric circulation. Nevertheless, the mean sea-level rise, associated thermal dilatation and ice melting, will ineluctably increase the amplitude of sea level peaks during storm events. Possible links between hydro-meteorological parameters (storm-surges, waves) and beach and foreshore sediment volumes for the Belgian coast will be investigated.

Impact of human activities

Finally, case studies were selected where the impact of human activities is known, however now attempting to quantify changes on the long-term.

A good example is the long-term effect of the harbour extension works of Zeebrugge, which has impacted the area just east of it, the 'Bay of Heist'. A strong sedimentation trend (in the form of a sandbank) was revealed in the bay itself, but also in a zone parallel to and some 100m away from the eastern groyne of the harbour. The former results from low flow velocities, due to the sheltering effect of the eastern groyne; whilst the latter sedimentation pattern is due possibly to the wave attenuation effect of the eastern groyne. Sedimentation trends are predicted aiding future management of the area.

Natural from anthropogenically-induced sedimentation was studied on the main disposal ground of dredged material (Vlakte van de Raan, B&W S1). A clear difference is observed in sedimentation patterns between the old and present disposal site of dredged material, respectively on a sand shoal and in a gully. This shows the importance of morphological setting

for the final estimation of impacts; however, also the type of disposed material will determine recovery rates after cessation of activities. Sediment transport processes in this area are complex, and need further investigation to get a better insight in the consequences of the long-term disposal of dredged material in near coastal areas.

On a larger scale, long-term changes in the cohesive sediment distribution of the Belgian–Dutch nearshore zone have been correlated with the increase of maritime access works. Conclusions were made on the basis of changes in the distribution of fresh mud and increase of suspended sediment during the last 100 years. The possible fingerprint of NAO cyclicity needs further investigation.

Finally, the need emerged to quantify the extent of beam trawling activities on the BPNS. Fisheries activities remain the most frequent disturbers of the seafloor, yet hitherto their spatial extent is never investigated. Generally, fishing activities occur in the swales of sandbanks mainly, with highest concentration towards the foot of the steep slope of the sandbanks. For the first time, this disturbance is quantified and demonstrated along two sandbank areas. A methodology is now in place to evaluate the impact of beam trawling on a large-scale; this can be applied whenever new high-resolution and good quality multibeam backscatter data are available. These data are crucial in the evaluation of long-term changes in soft-substrata habitats.