The significance of biological activity for morphology and sand-mud distribution in the bed

The application of an extended sand-mud model to the Paulinapolder intertidal flat

M.Sc. Thesis

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Preface

This M.Sc. thesis forms the final project of my study Civil Engineering and Management at the University of Twente, the Netherlands. The subject of the project is biogeomorphology and the aim is to explore the significance of biological activity for morphology and the vertical sand-mud distribution in the sediment bed. The project is carried out at WL | Delft Hydraulics.

The project is financed from the research theme 'doelfinanciering Westerschelde' of WL | Delft Hydraulics. I am very thankful for this financial contribution. I would like to thank some people that supported me during this project. I thank Suzanne Hulscher (University of Twente) for bringing up the subject and for the comments that were always very directive and helpful to oversee the 'higher' objectives of the study. Further I would like to thank Michiel Knaapen (University of Twente) for more 'technical' supervision as daily supervisor. The comments were always useful.

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Further, I want to thank Linda Kusters (student Civil Engineering, TUDelft, graduated at WL), whom supplied me with a lot of data. Harriette Holzhauer (University of Twente) has provided me with a lot of knowledge and some crucial information and data.

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Summary

Biogeomorphology is the study of the interaction between (geo)morphological factors and biota. As a first step to understand the biogeomorphological interaction, the influence of biological activity on morphology and vertical sand-mud distribution in the sediment bed is analyzed. As the biogeomorphological interaction is complex, we focus on only part of these interactions (f.e. no feedback of morphology on biology).

Previous experiments have shown that biota affect the critical bed shear stress and erosion rate by several orders of magnitude. In the bed, benthos (little organisms that move through the bed) enhance sediment transport by decreasing the critical bed shear stress for erosion and increasing the erosion rate (*biodestabilization*). With high algae biomasses, algae-mats on the bed surface prevent the bed from erosion (*biostabilization*).

With a new *sand-mud-bio* model is shown that biological activity has a significant effect on morphology and the vertical sand-mud distribution in the sediment bed. To include biological activity in the model, a parameterization of the influence of biological activity on sediment strength parameters critical bed shear stress, erosion rate and vertical biological mixing coefficient, is implemented in a process-based sand-mud model. The model is applied to a part of the Paulinapolder, an intertidal flat in the Western Scheldt. It is a muddy area and biological activity is high during the year. Realistic flow and morphological conditions are set-up for the study area.

If biological activity is included in the morphological modelling it is shown that the system becomes muddy if it is stabilized and sandy if it is destabilized. This cannot be explained by means of physical processes only. The effects on bathymetry are significant as extra erosion of 10 cm and extra sedimentation of 2 cm occurs over half a year (compared to the reference situation). The destabilizing process seems to be dominant, however, no equilibrium mud contents are reached if the system is maximally stabilized.

A patchy distribution of biological activity results in even more effect on the erosion/sedimentation pattern. Significant bed level differences exist between destabilized and stabilized patches. It seems that sediment is transported in more extent to areas with lower bed shear stress than that sediment is redistributed between destabilized and stabilized patches. The mud contents in the bed generally follow temporal variations in biological activity.

The largest influence of biological activity is observed in areas with relatively low bed shear stress. Near the salt marsh, the system is in the cohesive regime initially. Biological activity triggers the switch to the non-cohesive regime, where the critical bed shear stress is lower and the erosion rate higher. The switch between the non-cohesive and cohesive regime is very important in the model. Vertical (biological) mixing in the sediment bed has an important influence on this switch as it influence the mud content in the top layer of the sediment bed. The model is less sensitive for variations in erosion rate.

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References

Baptist M.J. (1999). *Prediction of macrobenthos abundance and distribution in the Westerschelde using Habitat Suitability Evaluation.*
WL | Delft Hydraulics, project number T1542.20.

Holtmann S.E., A. Groenewold, K.H.M. Schrader, J. Asjes, J.A. Craeymeersch, C.G.A. Duineveld, A.J. van Bostelen, J. van der Meer (1996). *Atlas of the zoobenthos of the Dutch Continental Shelf.*
Ministry of Transport, Public Works and Water Management, North Sea Directorate, Rijswijk, 244pp.

Holzhauer H. (2003). *Biogeomorphology: small activities with large effects?*
Master thesis, University of Twente, Enschede.

Jeuken M.C.J.L (2000). On the morphologic behaviour of tidal channels in the Westerschelde estaury.
Doctoral thesis, University of Utrecht, Labor b.v., Utrecht.

Kusters L.E.M. (July 2003). *Paulina vegetation model: current attenuation by saltmarsh vegetation.*
WL | Delft Hydraulics, project number Z2827.85.

Ledden M. van (2001). *Modelling of sand-mud mixture. Part II: A process-based sand-mud model.*
WL | Delft Hydraulics, project number Z2840.00.

Ledden M. van (2002b). *Modelling of sand-mud mixtures: erosion behavior and application to a tidal basin.*
STW / WL | Delft Hydraulics, project number Z2840.00.

Ledden M. van & Z.B. Wang (submitted). *Modelling sand-mud morphodynamics in the Friesche Zeegat.*
Submitted abstract for the International Cohesive Sediment Conference (INTERCOH), October 2003..

Lesser G. (2000). *Computation of Three-dimensional Suspended Sediment Transport within the Delft3D-Flow Module*.
WL | Delft Hydraulics (Z2396), IHE Delft (Thesis HE066), The Netherlands.

Mol A.C.S. (March 2003). *Wave attenuation by vegetation*.
WL | Delft Hydraulics, project number Z3040.

Nederbragt G.. (September 2001). *Seasonal variations of suspended sediment and diatoms in the Western Scheldt.*
WL | Delft Hydraulics / Delft Cluster, project number Z2837.

Ormondt M. van & D. Roelvink (2003). *Humber morphological model.*
WL | Delft Hydraulics, report Z3451.

Paarlberg (2003a). *Research Plan to the subject biogeomorphology.*
University of Twente, Enschede.

Paarlberg (2003b). *Literature study to the subject biogeomorphology.*
University of Twente, Enschede.

Rijn L.C. van (1993). *Principles of sediment transport in rivers, estuaries and coastal seas*.
Aqua Publications, Amsterdam, The Netherlands.

Stelling G.S. (1984). *On the construction of computational methods for shallow water flow problems.*
Rijkswaterstaat communications, No. 35, The Hague, Rijkswaterstaat, The Netherlands.

Sutherland T.F., C.L. Amos & J. Grant (1998). *The effect of buoyant biofilms on the erodability of sublittoral sediment of a temperate microtidal estuary.*
Limnology and Oceanography, vol. 43, pag. 225-235.

Temmerman, S. (2003). *Sedimentation on tidal marshes in the Scheldt estuary: a field and numerical modelling study.*
Unpublished PhD thesis, Catholic University of Leuven, 204 p.

Twisk (2002). *Toelichting op de ecotopenkaarten Westerschelde 1996 en 2001.*
Projectgroup MOVE; project number RIKZ/OS/2002.843x

Uittenbogaard R. (2003). *Modelling turbulence in vegetated aquatic flows.*
Riparian Forest Vegetated Channels, Workshop Trento (Italy).

Vreugdenhil C.B. (1989). *Computational hydraulics. An Introduction.*
Springer-Verlag, Berlin, Heidelberg.

Widdows J., M. Brinsley & M. Elliott (1998b). *Use of in situ flume to quantify particle flux (biodeposition rate and sediment erosion) for and intertidal mudflat in relation to changes in current velocity and benthic macrofauna.*
Black K.S., D.M. Paterson & A. Cramp (eds.). Sedimentary processes in the Intertidal Zone. Geological Society London, Special Publications, vol. 139, pp. 85-97.

Widdows J., M.D. Brinsley, P.N. Salkeld & C.H. Lucas (2000a). *Influence of biota on spatial and temporal variation in sediment erodability and material flux on a tidal flat (Westerschelde, Netherlands).*
Marine Ecology Progress Series, vol. 194, pp. 23-37.

Widdows J., M.D. Brinsley, P.N. Salkeld & S. Brown (2000b). *Temporal changes in intertidal sediment erodability: influence of biological and climatic factors.*
Continental Shelf Research, vol. 20, pp. 1275-1289.

Widdows J, A. Blauw, P. Herman, C.H. Lucas, J.J. Middelburg, S. Schmidt, M.D. Brinsley, P.N. Salkeld & H. Verbeek (2000c). *Role of physical and biological processes in sediment dynamics (sedimentation, erosion and mixing) of a tidal flat in Westerschelde estuary, S.W. Netherlands.*

Widdows J. & M.D. Brinsley (2002b). *Impact of biotic and abiotic processes on sediment dynamics and the consequences to the structure and functioning of the intertidal zone.* Journal of Sea Research, vol. 48, pp. 143-156.

WL | Delft Hydraulics (2001). *Delft3D-FLOW, user manual, version 3.06.*

Internet sites and other references:

[1] http://hjs.geol.uib.no/diatoms/Biology/index.html-ssi (08-04-2003)

[2] http://www.marlin.ac.uk/Bio_pages/Bio_Eco_IMU.AreSyn.htm (08-04-2003)

[3] Mindert de Vries, WL | Delft Hydraulics, Delft, the Netherlands

[4] http://www.comp.leeds.ac.uk/cpde/boussinesq.html (07-07-2003)

[5] NIOO-CEME: Centre for Estuarine and Marine Ecology, Yrseke, the Netherlands. http://www.nioo.knaw.nl/CEME/

[6] Data received from Tom Ysebaert of the NIOO-CEME (see [5])

[7] Stijn Temmerman, PhD student at the University of Leuven, Leuven, Belgium

[8] http://www.waterbase.nl (16-06-2003)

[9] Michiel Knaapen, University of Twente, Enschede, the Netherlands

[10] Remark of Han Winterwerp (WL | Delft Hydraulics, Delft, the Netherlands) during a meeting about mud modelling (31-03-2003)

Appendices