E-proceedings of the 36th IAHR World Congress
28 June – 3 July, 2015, The Hague, the Netherlands

HISTORICAL EVOLOTION OF MUD DEPOSITION AND EROSION IN INTERTIDAL AREAS OF THE SCHELDT ESTUARY (BELGIUM AND SW NETHERLANDS)

CHEN WANG[1, 2], JORIS VANLEDE[3], WOUTER VANDENBRUWAENE[3], YVES PLANCKE[3] & STIJN TEMMERMAN[2]

[1] Satellite Environment Center, Ministry of Environmental Protection of P. R. China, Beijing, P.R. China, wangchen_ch@163.com

[2] University of Antwerp, Ecosystem Management Research Group, Antwerp, Belgium, stijn.temmerman@uantwerpen.be

[3] Flanders Hydraulics Research, Flemish Government, Antwerp, Belgium, joris.vanlede@mow.vlaanderen.be

ABSTRACT

The mud dynamics in an estuary are recognized as an important element of estuarine functioning, because increasing suspended sediment concentrations may be both harmful for ecological functions (e.g., biomass production by phytoplankton) and deteriorative for human functions (e.g., by siltation of shipping channels). Considering the potential risk of increase in suspended sediment concentration in the Schelde estuary, this study aims to quantify the mud deposition/erosion in different time periods since 1930 to present, different intertidal ecotope types, and different zones along the Schelde estuary, including the Westerschelde and Zeeschelde. We analyzed the height change, volume change, eroded or deposited mud mass, and the overall mud balance. Our results suggested that net mud deposition occurred in intertidal areas in both the Westerschelde and Zeeschelde in almost all time periods. The mud deposition in stable marshes plays an important role. A large amount of mud deposition is also observed in stable intertidal flats and areas that shifted from intertidal flat to marshes or from subtidal zone to intertidal flat. Over 90% of mud erosion is observed in areas that shifted from intertidal flat to subtidal zone. Mud erosion is also observed in areas that shifted from marsh to intertidal flat.

Keywords: mud deposition, mud erosion, intertidal areas, Scheldt estuary, GIS

1. INTRODUCTION

The mud dynamics in an estuary are known to be a key element of estuarine functioning, as increasing suspended sediment concentrations may be both harmful for human functions such as by siltation of shipping channels, as well as a hindrance for ecological functions such as biomass production by phytoplankton. In terms of the potential risk of increase in suspended sediment concentration in the Schelde estuary (Belgium and SW Netherlands, Figure 1), it is relevant to know the historical evolution of the mud deposition/erosion in intertidal areas within the estuary. The aim of this project is to calculate the mud deposition/erosion in different time periods since 1930 to present, for different intertidal ecotope types, and in different zones along the Schelde estuary, including the Westerschelde (Netherlands) and Zeeschelde (Belgium).

2. DATA AND METHODS

We analyzed the height change, volume change, eroded or deposited mud mass, and the overall mud balance in between time steps of around 1930, 1960, 1990, 2000 and 2010. Ecotope maps of different years were compared to get the difference maps of ecotope changes between the different time steps. Elevation data were compared between different years to get the elevation change between the different time steps. Height change in the different ecotope change classes were extracted based on the combination of elevation change maps and ecotope change maps. Volume change in the different ecotope change classes were calculated by multiplying the height change in the different ecotope change classes with the area of different ecotope change classes. Mud volume change was calculated by multiplying the volume change in the different ecotope change classes with mud content data. In the end, mud mass change was calculated by multiplying mud volume change with dry bulk density data.

The Digital Terrain Models (DTMs) in the Westerschelde and Zeeschelde of different time steps were interpolated from the bathymetric data, topographic data and LIDAR data provided by Rijkswaterstaat, aMT (afdeling Maritieme Toegang) and INBO (Instituut voor Natuur- en Bosonderzoek) (Van der Pluijm et al., 1998; Van Heerd et al., 1999; Alkemade, 2004; Temmerman et al., 2004; Rijkswaterstaat, 2011; Van Braeckel et al., 2012; Van Ryckegem et al., 2014). The ecotope maps of marsh, intertidal flat and subtidal zone were generated based on vegetation maps of Westerschelde from Rijkswaterstaat and detailed ecotope maps from INBO, which were extracted from aerial photographs and hydrograhic maps (Huijs, 1995; Van der Pluijm et al., 1998; Reitsma, 2006; Rijkswaterstaat, 2011; Van Braeckel, 2013). Sediment grain size data were collected from different sources, including the data from MOVE project (Plancke et al., 2011), from INBO (Speybroeck et al., 2014) and UA-ECOBE (Temmerman et al., 2003, 2004; Teuchies et al., 2013; Jongepier et al., 2015) during several projects. The dry bulk density is estimated based on measurements on sediment samples from the Scheldt estuary with high mud content, in particular marsh samples (Temmerman et al., 2003; Teuchies et al., 2013). Since no spatial trend in bulk density was observed along the estuary, an average dry bulk density of 500 ± 100 kg/m^3 was used for all zones.

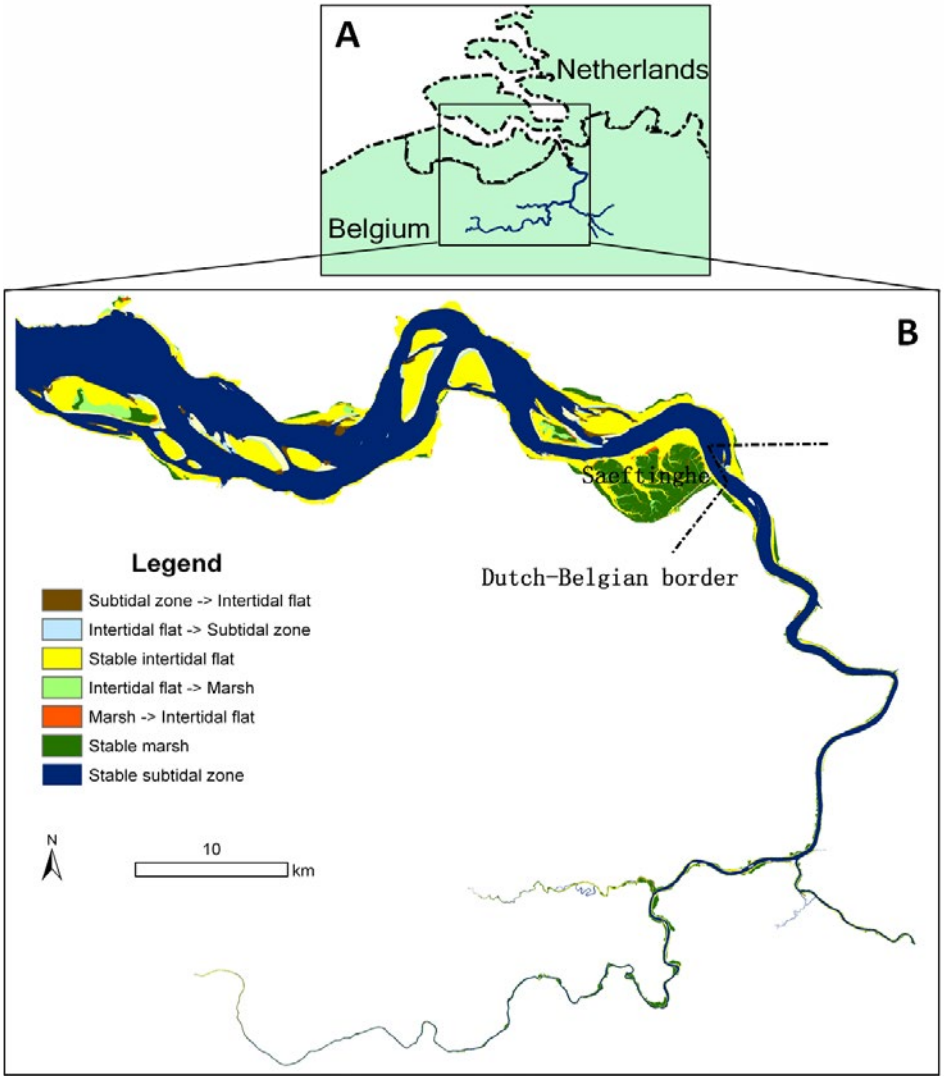

Figure 1. Study area. (A) Location within NW Europe. (B) Location of the Westerschelde (west of the Dutch-Belgian border) and Zeeschelde (southeast of the Dutch-Belgian border). Ecotope changes are mapped for the Westerschelde (2004-2010) and Zeeschelde (2001-2010).

3. RESULTS AND DISCUSSION

Our results suggested that net mud deposition occurred in intertidal areas in both the Westerschelde and Zeeschelde in almost all time periods (Figure 2 and Table 1). For the total mass of mud deposition, intertidal mud deposition is slightly larger in the Westerschelde (on average 42.6 × 10^3 ton/year averaged over all time periods) than in the Zeeschelde (on average 36.2 × 10^3 ton/year), because the intertidal areas of the Westerschelde is much larger than that of the Zeeschelde. The average mud deposition rate in all the intertidal areas is the largest in the periods of 1963-1992 in the Westerschelde (79.5 × 10^3 ton/year) and 1930-1960 in the Zeeschelde (72.0 × 10^3 ton/year). In terms of the relative role of different intertidal ecotope types, the mud deposition in stable marshes plays an important role in both the Westerschelde (on average 68.7 × 10^3 ton/year) and Zeeschelde (on average 44.3 × 10^3 ton/year). The mud deposition in stable marshes in the Westerschelde mainly takes place in Saeftinghe (with 3000 ha the biggest intertidal area in the estuary), especially in the earlier periods before 2004, with mean mud deposition rates of 62.3 × 10^3 to 77.8 × 10^3 ton/year. A large amount of mud deposition is also observed in stable intertidal flats (on average 43.0 ×10^3 ton/year) and areas that shifted from intertidal flat to marshes (on average 22.0 ×10^3 ton/year) or from subtidal zone to intertidal flat (on average 227.3 ×10^3 ton/year) in the Westerschelde. Over 90% of mud erosion is observed in areas that shifted from intertidal flat to subtidal zone in the Westerschelde (on average 307.6 ×10^3 ton/year) and in the Zeeschelde (on average 11.1 ×10^3 ton/year). Mud erosion is also observed in areas that shifted from marsh to intertidal flat in the Westerschelde (on average 10.9 × 10^3 ton/year).

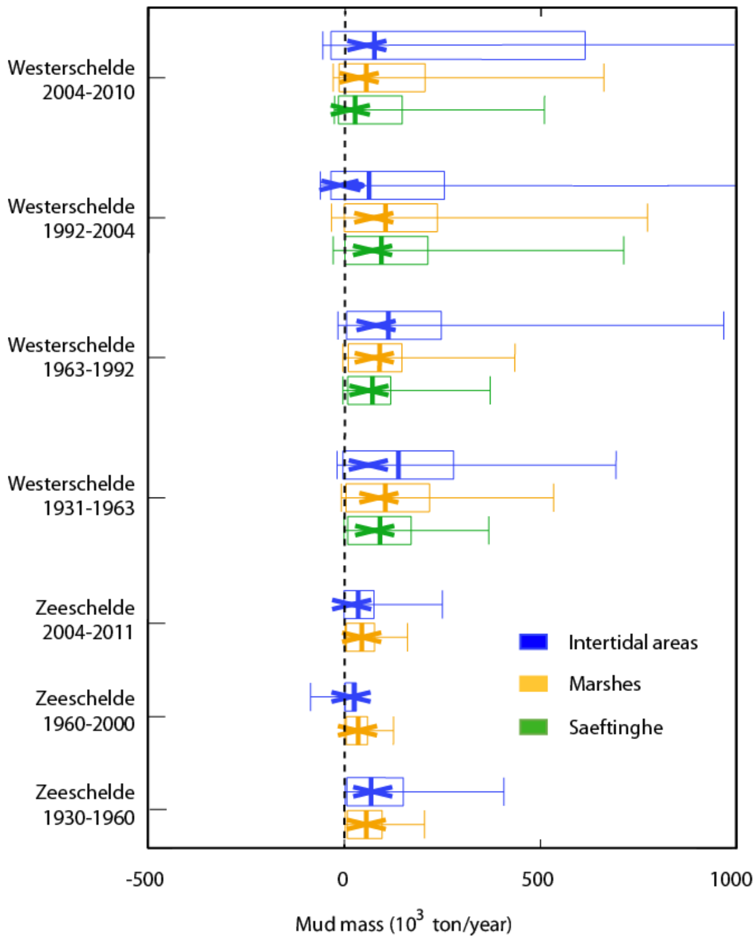

Figure 2. Boxplots of mud balance in the intertidal areas, marshes and Saeftinghe in the Westerschelde and Zeeschelde in different periods. Intertidal areas = onshore tidal flats + offshore tidal flats + tidal marshes. The upper bound and lower bound indicate the 5th percentile and 95th percentile of the values. The box indicates the 25th and 75th percentile. The thick line indicates the 50th percentile, and the cross indicates the mean value. The 95th percentile of the values in the Westerschelde in 2004-2010 and 1992-2004 are 407 × 10^4 ton/year and 249 × 10^4 ton/year, respectively, which are outside of the range of the x-axis.

Table 1 – Average mud erosion/deposition rates in mass and muss per unit in different ecotope types of all sub-division zones in the Westerschelde and Zeeschelde.

	Location	Stable marsh	Stable intertidal flat	Marsh -> Intertidal flat	Intertidal flat -> Marsh	Intertidal flat -> Subtidal zone	Subtidal zone -> Intertidal flat	All intertidal areas
Mass (ton/year)	Westerschelde	68,742	43,081	-10,916	21,964	-307,587	227,345	42,629
	Zeeschelde	44,332	-5,228	1,241	20	-11,135	6,988	36,219
Mass per unit area (ton/ha/year)	Westerschelde	33	4	-59	27	-199	143	4
	Zeeschelde	68	-4	-11	50	-75	3	20

The mud deposition rate per unit area (Table 1) is much larger upstream in the Zeeschelde (with an average of 20 ton/ha/year) than downstream in the Westerschelde (4 ton/ha/year). The same as the total mass of mud deposition, the mass per unit area is also the largest in the periods of 1963-1992 in the Westerschelde (7 ton/ha/year) and 1930-1960 in the Zeeschelde (36 ton/ha/year). The mud deposition per unit area is the highest in stable marshes in both the Westerschelde (33 ton/ha/year) and Zeeschelde (68 ton/ha/year). High deposition rate per unit area is also observed in areas that shifted from subtidal zone to intertidal flat in the Westerschelde (143 ton/ha/year) and areas that shifted from intertidal flat to marshes in the Zeeschelde (50 ton/ha/year). The highest mud erosion rate per unit area is observed in both the Westerschelde (199 ton/ha/year) and the Zeeschelde (75 ton/ha/year) in areas that shifted from intertidal flat to subtidal zone. High erosion rate per unit area is also observed in areas that shifted from marsh to intertidal flat, especially in the Westerschelde (59 ton/ha/year). A positive correlation is expected between the suspended sediment concentration and the deposition rate, because of higher sediment availability for deposition (Temmerman et al., 2003; Vandenbruwaene et al., 2011).

4. CONCLUSIONS

In conclusion, there is a net mud deposition in intertidal areas in both the Westerschelde and Zeeschelde in all time periods from 1930 to 2010. The total mud deposition is slightly larger in the Westerschelde than in the Zeeschelde because of the much larger intertidal area in the Westerschelde, although the mud deposition rate per unit area is the opposite. Both the highest total mass and the highest mass per unit area of the mud deposition are observed in the periods of 1963-1992 in the Westerschelde and 1930-1960 in the Zeeschelde. Stable marshes play an important role in mud deposition, especially in Saeftinghe. Large amount of mud deposition is observed in areas that shifted from subtidal zone to intertidal flat and areas that shifted from intertidal flat to marshes. Large amount of mud erosion is observed in areas that shifted from intertidal flat to subtidal zone and areas that shifted from marshes to intertidal flat. A positive correlation is expected between the deposition rate and the suspended sediment concentration.

ACKNOWLEDGMENTS

The calculations presented in this report would not have been possible without the kind permissions from several institutes to use existing datasets on the intertidal areas in the Schelde estuary. We would like to thank Rijkswaterstaat (Dick De Jong) for providing the elevation, tide data, vegetation maps and sediment data of the Westerschelde. We would like to thank INBO (Alexander Van Braeckel) and aMT (Frederik Roose) for providing the elevation data, ecotope map, and sediment data of the Zeeschelde. We also would like to thank UA-ECOBE (Johannes Teuchies, Lotte Oosterlee, Lindsay Geerts, Alexandra Silinski and Iason Jongepier) for the sediment data from tidal marshes.

REFERENCES

Alkemade I. S. W. (2004). Kwaliteitsdocument laseraltimetrie, Projectgebied Westerschelde. Delft, Netherlands, Ministerie van Verkeeren Waterstaat, Rijkswaterstaat.

Huijs S. W. E. (1995). Geomorfologische ontwikkelingen van het intergetijdegebied in de Westerschelde 1935-1989 Utrecht, Universiteit Utrecht.

Jongepier I., Wang C., Missiaen T., Soens T. and Temmerman S. (2015). Intertidal landscape response time to dike breaching and stepwise re-embankment: A combined historical and geomorphological study. *Geomorphology*, **236**: 64-78.

Plancke Y., Vos G., Vanlede J., Taverniers E. and Mostaert F. (2011). TIDE - WP3 task 4: Interestuarine comparison: Report 1 - Hydro- and morphodynamics of the Scheldt-estuary. Version 2_0. WL Rapporten, 770/62. Antwerp, Belgium, Flanders Hydraulics Research.

Reitsma J. M. (2006). Toelichting bij de vegetatiekartering Westerschelde 2004 op basis vanfalse colour-luchtfoto's 1:5000/1:10000 Den Haag - Delft, Ministerie van verkeer en Waterstaat, Rijksinstituut, Adviesdienst Geo-Informatie & ICT

Rijkswaterstaat (2011). Kwaliteitsdocument laseraltimetrie Projectgebied Westerschelde 2011 Delft, Ministerie van Verkeer en Waterstaat Rijkswaterstaat.

Speybroeck J., De Regge N., Soors J., Terrie T., Van Ryckegem G., Van Braeckel A. and Van den Bergh E. (2014). Monitoring van het macrobenthos van de Zeeschelde en haar getij-onderhevige zijrivieren (1999-2010): Beschrijvend overzicht van historische gegevens (1999, 2002, 2005) en eerste cyclus van nieuwe strategie (2008, 2009, 2010). Rapport INBO.R.2014.1717661. Brussel, Belgium, Instituut voor Natuur-en Bosonderzoek.

Temmerman S., Govers G., Meire P. and Wartel S. (2003). Modelling long-term tidal marsh growth under changing tidal conditions and suspended sediment concentrations, Scheldt estuary, Belgium. *Marine Geology*, **193** (1-2): 151-169.

Temmerman S., Govers G., Wartel S. and Meire P. (2003). Spatial and temporal factors controlling short-term sedimentation in a salt and freshwater tidal marsh, Scheldt estuary, Belgium, SW Netherlands. *Earth Surface Processes and Landforms*, **28** (7): 739-755.

Temmerman S., Govers G., Wartel S. and Meire P. (2004). Modelling estuarine variations in tidal marsh sedimentation: response to changing sea level and suspended sediment concentrations. *Marine Geology*, **212** (1-4): 1-19.

Teuchies J., Vandenbruwaene W., Carpentier R., Bervoets L., Temmerman S., Wang C., Maris T., Cox T. J. S., Braeckel A. V. and Meire P. (2013). Estuaries as filters: the role of tidal marshes in trace metal removal. *Plos One*, **8**: e70381.

Van Braeckel A. (2013). Geomorfologie – fysiotopen - ecotopen. p. 89-102 In Van Ryckegem, G. (red.). MONEOS – Geïntegreerd datarapport Toestand Zeeschelde INBO 2012. Monitoringsoverzicht en 1ste lijnsrapportage Geomorfologie, diverstiteit Habitats en diversiteit Soorten. Rapport INBO.R.2013.26. Brussel, Belgium, Instituut voor Natuur-en Bosonderzoek.

Van Braeckel A., Coen L., Peeters P., Plancke Y., Mikkelsen J. and Van den Bergh E. (2012). Historische evolutie van zeescheldehabitats: kwantitatieve en kwalitatieve analyse van invloedsfactoren. Rapporten INBO.R.2012.59. Brussel, Belgium, Instituut voor Natuur- en Bosonderzoek.

Van der Pluijm A. M. and De Jong D. J. (1998). Historisch overzicht schorareaal in Zuid-West Nederland Middelburg, Utrecht, Netherlands, Rijkswaterstaat - Rijksinstituut voor Kust en Zee.

Van Heerd R. M. and Van 't Zand R. J. (1999). Productspecificatie Actueel Hoogtebestand Nederland Delft.

Van Ryckegem G., Van Braeckel A., Elsen R., Speybroeck J., Vandevoorde B., Mertens W., Breine J., De Regge N., Soors J., Dhaluin P., Terrie T., Van Lierop F., Hessel K. and Van den Bergh E. (2014). MONEOS - Geïntegreerd datarapport INBO: toestand Zeeschelde 2013: monitoringsoverzicht en 1ste lijnsrapportage Geomorfologie, diversiteit Habitats en diversiteit Soorten. Rapport INBO.R.2014.2646963. Brussel, Belgium, Instituut voor Natuur-en Bosonderzoek.

Vandenbruwaene W., Maris T., Cox T. J. S., Cahoon D. R., Meire P. and Temmerman S. (2011). Sedimentation and response to sea-level rise of a restored marsh with reduced tidal exchange: Comparison with a natural tidal marsh. *Geomorphology*, **130**: 115-126.