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Impact of dredging and dumping on the stability of ebb–flood channel systems

M.C.J.L. Jeuken [a,*], Z.B. Wang [a,b]

[a] Deltares, Marine and Coastal Systems, P.O. Box 177, 2600 MH Delft, The Netherlands
[b] Delft University of Technology, Faculty of Civil Engineering and Geosciences, The Netherlands

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ABSTRACT

The impact of dredging and dumping on the morphologic stability of the tidal channels is investigated using morphologic field observations for the Westerschelde estuary dating back to 1955. The results are used to verify the theoretical concept presented by Wang and Winterwerp (2001). This concept states that a critical threshold for the amount of sediment dumping exists above which a channel system in equilibrium may become unstable and degenerate. The value of this threshold amounts to 5–10% of the total sediment transport capacity. Verification of this concept using field observations is not straightforward as the morphology of tidal channel often changes as a result of both natural processes and human interferences, i.e. the channels are not in equilibrium. In addition, the morphological timescales associated with channel degeneration are large (decades to centuries). Verification of the theory thus requires a careful analysis of abundant morphological data and numerical modeling of sediment transports. The results of such analyses presented in this study confirm the existence and the approximate magnitude of the critical level for dumping that follows from theory. Refined guidelines are derived to use the theoretical concept as an engineering tool for the evaluation and design of strategies for dumping in estuarine multi-channel systems. In the absence of the required morphological data the indicative theoretical level of 5–10% can be used to obtain a first estimate of the dump capacity in two-channel systems.

1. Introduction

The Schelde is a tide-dominated estuary that is situated in the southwest of the Netherlands and Belgium. It includes the entire gradient from fresh to salt water areas providing various habitats for marine flora and fauna. In addition to these ecological values, the estuary is of large economic importance as it provides navigation routes to the ports of Antwerpen, Gent, Terneuzen and Vlissingen. The frequently conflicting economic and environmental interests make the management of the estuary a complex task. Collaboration of the Dutch and Belgium government has resulted in the formulation of a Long-Term Vision, hereafter referred to as LTV, for the Schelde estuary. Accordingly, a primary management objective for the estuary is a dynamic preservation of the physical characteristics and dynamics of the system of channels and shoals in the marine part of the estuary between Vlissingen and the border between The Netherlands and Belgium, referred to as the Westerschelde, Fig. 1.

The morphology of the Westerschelde displays a regular repetitive pattern that consists of mutually evasive meandering ebb channels and straight flood channels. These main channels are separated by sub and intertidal shoals and linked by connecting channels. (e.g., Van Veen et al., 2005; Van den Berg et al., 1996; Jeuken, 2000; Toffolon and Crosato, 2007).This morphology is also referred to as a 'multi-channel system'. Winterwerp et al. (2001) schematized this system into a chain of so-called macro-cells and meso-cells (Fig. 1), based on morphological characteristics and numerically computed patterns of tide averaged sand transports. Each macro-cell consists of a main ebb channel and a main flood channel, displaying a characteristic morphologic behavior that is associated with net sediment exchanges between the macro-cells. Smaller-scale connecting channels link the large ebb and flood channels in macro-cells, forming meso-cells. These smaller channels often display a quasi-cyclic morphologic behavior, characterized by processes of channel origination, migration and degeneration at a timescale of years to decades (e.g., Van Veen et al., 2005; Jeuken, 2000).

Both natural processes and human interferences have influenced the morphological evolution of the estuary over the past two centuries (e.g., Van den Berg et al., 1996; Van der Spek, 1997). Initially the human interference mainly consisted of reclaiming land that largely silted up by natural processes. This reclamation resulted in a permanent loss of intertidal areas, a rather erratic pattern of embankments and a fixation of the large-scale alignment of the estuary. Since the beginning of the twentieth century the human interference shifted from land reclamation to sand extraction (since 1955 about 2 million $m^3\ yr^{-1}$) and dredging and dumping to deepen and maintain the navigation route to the port of Antwerpen. During the first deepening in the seventies the depth of the shallow sills in the navigation route was increased with 2 to 3 m from 12 to 14.5 m.

* Corresponding author. Tel.: +31 152858893; fax: +31 152858710.
E-mail addresses: Claire.Jeuken@deltares.nl (M.C.J.L. Jeuken), Zheng.Wang@deltares.nl (Z.B. Wang).

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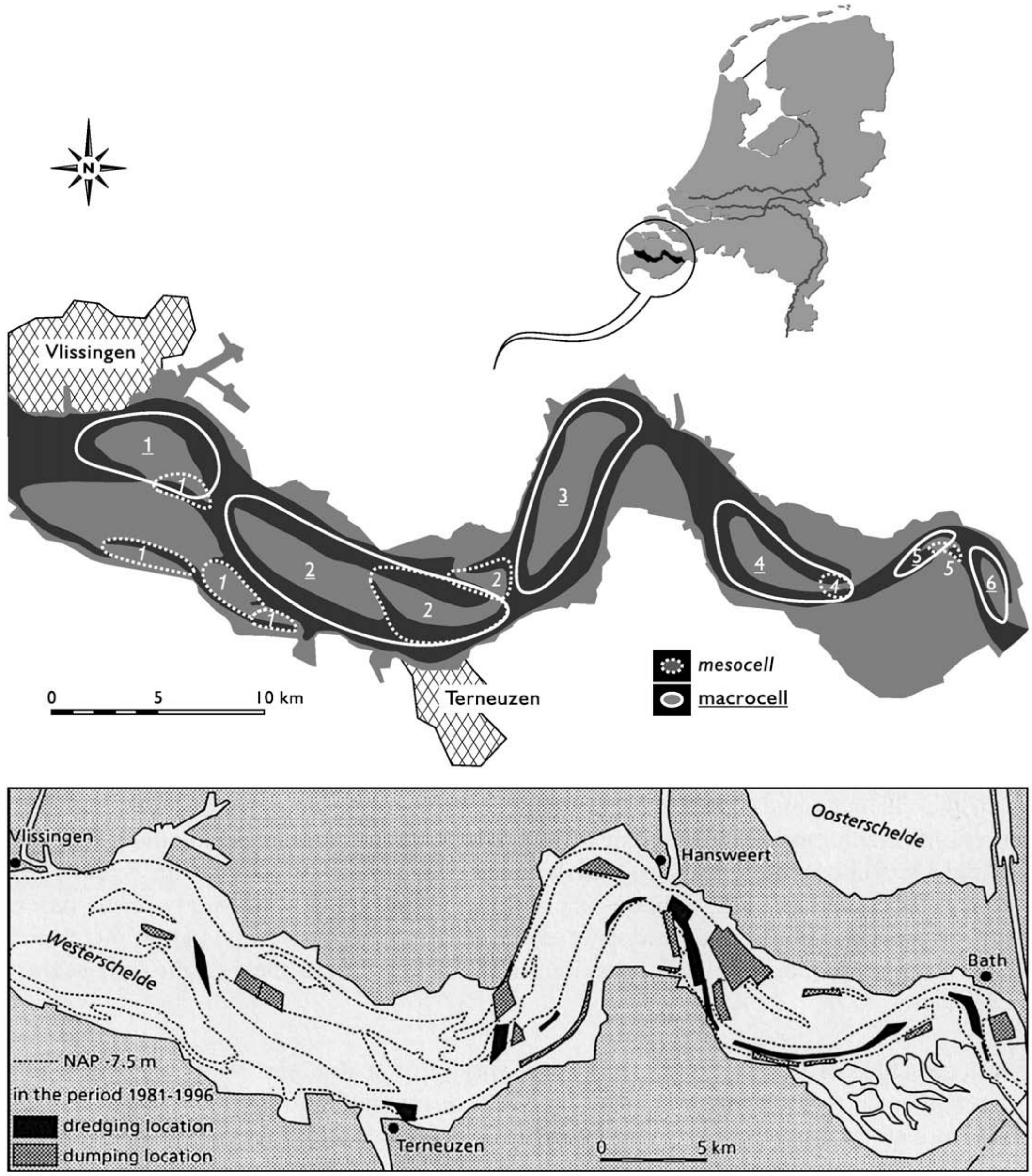

Fig. 1. The schematization of the multi-channel system of the Westerschelde into macro-cells and meso-cells. Lower picture shows locations where dredging and dumping activities are carried out.

During the last deepening, carried out in 1997/1998, these depths were increased with another 1 to 1.5 m. As a result of the enlarged navigation depth the maintenance dredging increased from less than 0.5 million $m^3 yr^{-1}$ before 1950 to about 7–10 million $m^3 yr^{-1}$ at present. The dredging and dumping operations at least enhanced the long-term deepening of the channels, the large ebb channels in particular, the loss of shallow water areas, the raise of intertidal shoals and the partial disappearance of connecting channels (Swinkels et al., 2009). From the LTV perspective these are undesirable developments. Further deterioration of the multi-channel system should be prevented and requires a well considered strategy for future dredging and dumping operations.

The model concept presented by Wang and Winterwerp (2001) may be used to design a sustainable strategy for dumping in multi-channel systems with an erodible, non-cohesive sediment bed. Appendix A summarizes the theory and the results of a numerical verification. Accordingly, for a stable channel system in equilibrium a critical level for the amount of sediment dumping exists that amounts to 5% to 10% of the gross sand transport capacity. Long-term sediment dumping exceeding this level may result in a degeneration of the multi-channel system towards a single channel system. Dumping of sediment at or just below the critical level will cause a reduction in the depth of the channel but not a complete closure of the channel. The present study aims to verify this theoretical concept using morphological observations dating back to 1955 and discusses the application of the concept in designing a strategy for dumping in tidal channel systems. Both Sections 2.2, 3.7 and 4 discuss how to deal with an equilibrium concept in a tidal channel system that is not in equilibrium, i.e. a system that displays morphological changes induced by both natural processes and human interferences.

2. Data sets and methods

2.1. Available data sets

The first detailed bathymetric survey of the entire Westerschelde dates from 1931. Regular surveys were carried out approximately