Improved quantification of sediment transport in lowland rivers

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ABSTRACT: Quantifying sediment transport is essential for understanding large-scale morphological developments as well as for the calibration of numerical models and long-term river management. A research proposal is developed that aims to improve the quantification of sediment transport in lowland rivers by improving acoustical measurement methods and by investigating the relation between bedforms, both geometry and superimposed bedforms, and total sediment transport.

1 INTRODUCTION

The management of river sediments is of vital importance for many reasons: flood protection, navigation, infrastructure and ecology. This results in a need for research on river morphodynamics, sediment transport processes and fluxes and the use of numerical tools for prediction of morphological development of the river. Currently, river managers face the oncoming challenge of sea-level rise and climate change, which will have large, but uncharacterized, effects on lowland rivers. Recently, a Dutch national research program *Rivers2Morrow* has been initiated, which focusses on the long-term development of the Dutch delta.

To enable river management and long-term numerical prediction, continuous observations of suspended sediment load and bed load transport are essential, enabling the explanation of observed morphological trends and the calculation of multiyear budgets. However, available observations are often scarce. This holds for many delta's worldwide, including the Dutch delta (Becker, 2015). The reason for this is that measuring is usually time- and labour intensive. It is difficult to get precise and accurate measurements, for instance because sediment fluxes are highly variable in time and space and because instruments are intrusive or are based on optical or acoustical measurements that not only depend on sediment concentration, but are influenced by other variables, hindering the interpretation of such measurements (Guerrero et al., 2016; Hoitink and Hoekstra, 2004; Thorne and Hurther, 2014).

To complement observations, sediment fluxes can be estimated through sediment transport equations (*e.g.* Van Rijn, 1993; Meyer-Peter and Müller, 1948; Engelund and Hansen, 1967), whether or not implemented in numerical morphological models. However, transport equations are to a large extent based on flume data and tested for a limited range of parameters. Furthermore, dune geometry to determine bedform roughness is estimated and their form is simplified (Bradley and Venditti, 2017). Superimposed secondary bedforms are not taken into account. The added complexity in real rivers systems can limit the applicability of sediment transport modelling.

In fine-grained estuaries, well-accepted transport equations can lead to an underestimation of transport by an order of magnitude, as recently shown for the Yellow River (Ma et al. 2017). Ma et al. (2017) attributed this underestimation to a relation between bedforms and sediment transport efficiency. Schindler et al. (2015) have shown that a small fraction of cohesive sediment can have a dramatic effect on bed form dimensions, decreasing height and steepness. This is crucial in numerical modelling of sediment transport, as dune dimensions have a large effect on flow and sediment fluxes.

A recent study on the sediment budget of the Rhine-Meuse estuary further illustrated that current availability of sediment transport observations and numerical modelling tools is insufficient to get accurate information on sediment fluxes (Becker, 2015). This emphasizes the need for reliable transport modelling and continuous measurements to calibrate and validate morphological models.

2 RESEARCH AIM

This project aims to improve the quantification of sediment transport in lowland rivers, with a focus on acoustical measuring methods, bedforms and sediment dynamics in the Rhine-Meuse estuary and with that, the applicability of sediment transport equations and sediment rating curves throughout the river system.

First, the improvement of acoustical measuring methods includes the inversion of ADCP (Acoustic Doppler Current Profiling) backscatter to suspended sediment concentration with multimodal sediment distribution, measuring bedload transport with the bottom track feature of an ADCP and measuring bedload with MBES (multibeam echosounder).

Secondly, the improvement of estimating sediment flux using transport equations is focused on the relation between bedform geometry and transport efficiency in the lower delta, as well as the relation between superposed secondary bedforms and flow, dune migration and sediment transport.

Third, combining improved methodology to infer sediment transport from acoustical measurements and increased understanding of transport dynamics in the lower delta, total sediment discharge estimations are gathered from available data.

3 WORK PLAN

3.1 Suspended sediment concentration (SSC) from ADCP backscatter.

Due to the large spatial and temporal variation of suspended sediment, sampling is usually not sufficient to estimate the total suspended sediment discharge through a channel. As an alternative, suspended sediment can be estimated by inversion of ADCP backscatter intensity. However, the acoustic signal is largely dependent on the particle size distribution. For a measuring frequency of 1.2MHz, common for moving-boat deployment, finer sediment fractions mainly contribute to attenuation of the signal, where coarser fractions form the largest contribution to scattering. We aim to improve the estimation of suspended sediment concentration by quantifying the attenuation by fine sediment, through employing a tilted sensor. The following two questions were defined:

How can inversion of backscatter to SSC be improved using a tilted transducer?

How can ADCP be used to estimate SSC in areas with a multimodal sediment distribution?

A dataset will be analysed that is gathered through a 13-hour survey at a junction in the Rhine-Meuse estuary (the Netherlands) and data from a measurement campaign in the Ems-Dollard estuary. Reference sediment concentration and particle size distribution are determined from water samples.

3.2 Laboratory experiments

A series of laboratory experiments aims at answering two questions:

How do ripples contribute to dune migration and sediment transport?

How can ADCP-BT be used to measure bed-load transport and with what accuracy?

A first objective of the laboratory study is to elucidate the role of superimposed ripples to dune migration and sediment transport.

The common assumption when estimated bed load transport through dune tracking is that superimposed ripples dissipate at the lee side of dunes and thus contribute to dune migration. The experiments offer the opportunity to investigate how ripples contribute to sediment transport, especially in the case of low-angle dunes.

Secondly, we aim to improve the method of estimating bedload transport using the bottom track feature of an ADCP, building on previous work that included both field and laboratory experiments (Gaeuman and Jacobson, 2006; Rennie and Millar, 2004).

Experiments will be conducted at the Kraijenhoff van de Leur laboratory (Wageningen University) and we plan to include measurements with multiple ADCPs and an AVCP (Acoustic Concentration and Velocity Profiler), which enables very precise measurements of sediment fluxes and flow velocity (Hurther et al., 2011).

3.3 Field campaign: MBES and ADCP

A second method to estimate bedload transport based on acoustics is dune tracking using multibeam echo sounding. Here we aim to include the movement of superimposed bedforms.

A recently obtained dataset includes simultaneous MBES and ADCP measurements over five neighbouring transects in the River Waal. Based on this data we aim to answer two questions:

Can continuous MBES be used to measure bedload transport over a transect (both ripples and dunes)?

What is the relation between cross-varying flow, bedform dimensions and transport?

3.4 Bedforms and sediment transport equations

To determine what the relation between bedforms and sediment transport is, and with that, the applicability of transport equations, we aim to answer the following question:

What is the relation between bed form geometry and transport efficiency in the Dutch delta and how does this affect the accuracy of transport equations?

A first approach to answer this question is to analyse available bed elevation data, which is measured with MBES, two-weekly, in a major part of the Dutch river system. This analysis focuses on bedform geometry through the delta, from up- to downstream. Secondly, the presence and dimensions of superimposed secondary bedforms are determined.

Based on this analysis, field campaigns will be designed at two contrasting locations in the Dutch Rhine-Meuse delta. Those field campaigns will also be used to test developed acoustical methods.

4 CONCLUDING REMARKS

By answering the defined research questions, we aim to improve transport measurements through acoustics, already used for regular discharge and bathymetry measurements. Secondly, through investigating the relation between bedforms—dune geometry and superimposed secondary bedforms—and sediment transport, numerical modelling will be improved.

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