Schwarzer, Schrottke & Stattegger (eds.):
From Brazil to Thailand – New Results in Coastal Research
***Coastline Reports 16 (2010)**, ISSN 0928-2734, ISBN 978-3-9811839-9-3*
S. 97-100

Effects of Changes in Sea Level on the Tidal Dynamics of the River Weser

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Abstract

A system study was conducted with the aid of a 3D hydrodynamic numerical model to enable the impact of changes in sea level on the estuary of the River Weser to be estimated more accurately. During the study the mean tide level and mean tidal range were raised and the results were subsequently analysed with regard to the tide-related characteristic values. The results show an increase in the tidal range in the estuary along with an increase in the current velocities, in particular in the flood current velocity. In addition, an intrusion of high salt concentrations further upstream was observed. Within the range of values examined, the system variables within the estuary reacted linearly to the changes introduced at the boundaries of the model.

1 Background

The rise in mean sea level (IPCC 2007) is directly affecting the mean tide level in the estuary of the River Weser. In addition, the amphidromic points in the North Sea are likely to be influenced so that changes in the phases and amplitudes of the partial tides can be expected (Plüß 2004). This in turn is affecting the tidal range which determines how much energy enters the estuary.

As a starting point for modelling climate change scenarios it is important to be able to estimate the reaction of the estuary to such changes and to understand their causes and relationships. The parameters “mean tide level” (MTL) and “tidal range” (TR) were therefore varied and the changes in the mean conditions in the estuary analysed in the system study described in this paper.

2 Model and concept of the investigation

The investigations were conducted with the combined UnTRIM-SediMorph modelling system. The UnTRIM numerical method was used to solve non-steady state, non-linear equations for free surface flow problems (Casulli & Zanolli 2002). The morphodynamic modelling method SediMorph (Malcherek et al 2005) was used to calculate the bottom friction.

The model covered the entire area of the Jade-Weser estuary, for which the hydrodynamics and salt transport were calculated in a high resolution 3D data set. The model was validated for present-day conditions using measured data and it delivers realistic results. It was steered via the water levels on the seaward boundary and the fresh water inflow from the Weser on the landward boundary. The period of time selected for the analysis was a spring-neap cycle.

The boundary conditions for MTL and TR were varied both separately and jointly in the system study. The changes in MTL ranged from -20 cm to +80 cm and those in TR from -20 cm to +40 cm. All other boundary conditions in the model were identical. Thus the freshwater inflow was a constant 180 m^3/s in all variations of the model and was therefore in the range of the most frequent freshwater inflow.

3 Results – Tide-related characteristic values of water level, current and salt content

An increase in the two parameters TR and MTL in the seaward boundary conditions resulted in an increase in the high water elevation (HW) along the Weser estuary (Figure 1, left panel). The specified changes in the boundary values were sustained virtually unaltered in HW up to the tidal limit.

Increasing TR in the boundary conditions resulted in a lowering of the low water elevation (LW) while, by contrast, raising MTL led to an increase in LW. Figure 1 shows that changes in LW introduced at the seaward boundary decreased towards the tidal limit, in contrast to HW. TR thus increased in the direction of the tidal limit. At the same time, the duration of the ebb tide increased between W-km 20 and W-km 100 compared with the duration of the flood tide.

It is noticeable that the tide-related characteristic values reacted approximately linearly to the changes in the boundary values. Thus the changes in the tide-related characteristic values can be expressed by varying MTL and TR by means of regression equations. In particular, there was a good correlation between the characteristic values of the water level obtained in this way and the values obtained in the simulation (Figure 1, right panel).

Furthermore, an increase in TR and MTL in the seaward boundary conditions resulted in greater current velocities. The increase in the flood current velocities was more pronounced than the increase in the ebb current velocities so that several of the areas previously dominated by the ebb current were subsequently dominated by the flood current (Figure 2).

An increase in MTL and TR at the seaward boundary of the model also resulted in saltwater intruding further upstream. Thus, for example, water with a mean salt content of 5 psu intruded up to 5 km further upstream for MTL +55 cm and TR +30 cm.

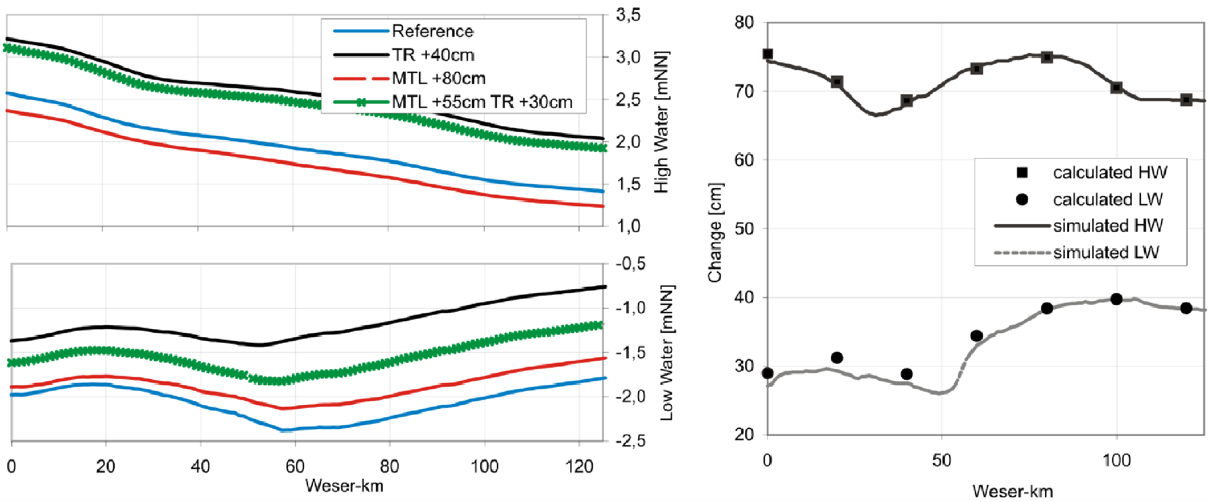

Figure 1: High water (HW) and low water (LW) along the Weser navigation channel with km-0 close to the tidal limit and km-125 at the end of the navigation channel in the North Sea. The left panel shows depth-averaged results of the reference run, two runs with variation only of tidal range (TR) and mean tide level (MTL) respectively and one with variation of TR and MTL. The right panel shows the change (relative to the reference run) in HW and LW for MTL +55 cm and TR +30 cm calculated with the help of linear regression equations and compared to simulated values.

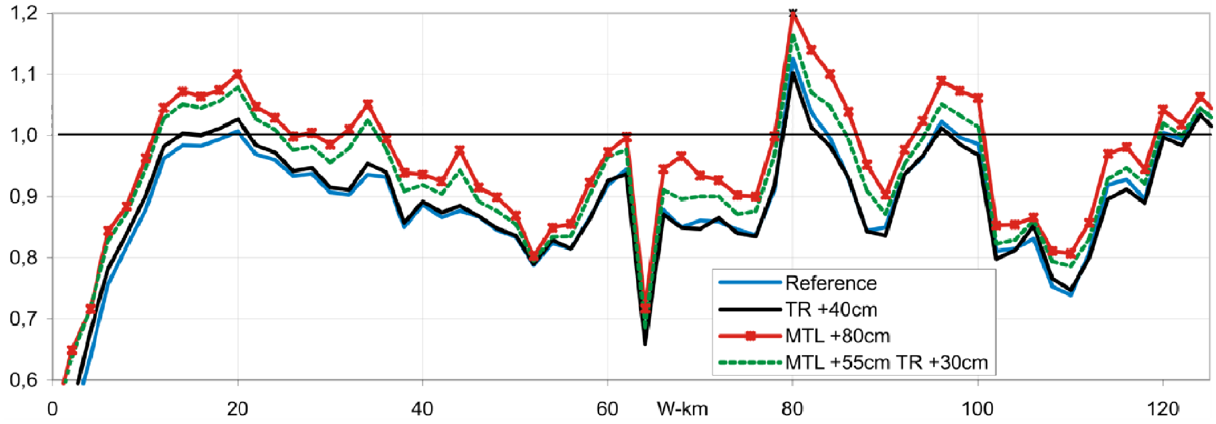

Figure 2: Ratio of mean flood current velocity to mean ebb current velocity. Values above 1 indicate flood current dominated sections.

4 Discussion and conclusion

The investigations described above show that the reactions in the system caused by a rise in mean tide level are basically similar to those caused by a deepening of the estuary. Thus changes in water levels at high water are sustained virtually unchanged throughout the estuary while changes in the water level at low water decrease in the upstream direction. The resultant increase in the tidal range leads to higher current velocities, with the flood current velocities increasing to a greater extent than the ebb current velocities owing to the less pronounced effect of bottom friction.

The strengthening of the flood current is significant for the transport of suspended matter. If the ebb current becomes weaker than the flood current it will no longer be capable of removing the sediment transported upstream by the flood current. This can result in greater siltation of the areas dominated by the flood current.

The intrusion of water with a higher salt content further inland owing to the rise in the mean water level principally affects the flora and fauna in those areas and has an impact on the suitability of the river water for agriculture.

Finally, it should be pointed out that the aim of the system study described above was not to model climate scenarios but to analyse the behaviour of certain state variables under two modified boundary conditions. Climate scenarios would cover additional boundary conditions, such as changes in temperature, wind speed, wind direction and freshwater inflow. The system study described in this paper was conducted with a fixed fresh water inflow, i.e. the quantitative statements made in this study only apply to the selected fresh water inflow situation.

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