Proceedings of the 7th International Conference on HydroScience and Engineering

Philadelphia, USA September 10-13, 2006 (ICHE 2006)

ISBN: 0977447405

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UNTRIM MODELLING FOR INVESTIGATING ENVIRONMENTAL IMPACTS CAUSED BY A NEW CONTAINER TERMINAL WITHIN THE JADE-WESER ESTUARY, GERMAN BIGHT

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ABSTRACT

A new seaport for container transhipment named JadeWeserPort will be built near Wilhelmshaven in the Jade Bay, which belongs to the Jade-Weser Estuary (German Bight). As a basis for planning and environmental impact assessment, respectively, the changes induced by the port in the abiotic characteristics of the Jade Bay were investigated extensively using results from in-situ measurements and 2D/3D UnTRIM-SediMorph numerical model simulations. Essential impacts of the port on the tidal and morphological characteristics of the Jade Bay could be identified.

1. INTRODUCTION

Germany has two major container seaports: Hamburg and Bremerhaven. Both are growing continuously. Despite the existing capacities, a new seaport for container transhipment will be built near Wilhelmshaven in order to add an essential component to Germany`s logistic network. This port is required because the container handling in the German seaports is predicted to double over the next 10 to 15 years. The terminal handling capacity for the future JadeWeserPort is designed to be 2.7 million TEU (= Twenty Feet Equivalent Unit). The length of quay is 1,725 m and the reference water depth is 18 m below chart datum (= mean low water springs (MLWS)). For land reclamation of 360 ha sediments are taken from two offshore sand-pits in the vicinity of the site. The construction of the JadeWeserPort is likely to start in 2007. The port should be in service in 2011.

The Jade Bay as part of the German Wadden Area is a tidal dominated system with no significant freshwater inflow and a tidal range of up to 3.8 metres. The JadeWeserPort will be located offshore Wilhelmshaven in the bay area in order to provide direct access to the existing deep water fairway. Thus, the port is located between pile founded jetties permeable to tidal currents, that are used for handling chemicals, oil and coal. In the neighbourhood there are ecological valuable wadden areas of the "Jadebusen" and the "Innenjade" (see Figure 1). These large extended wadden areas belong to the German "Wadden Sea National Park" and are strictly protected by several national and international laws. Therefore, the planning of the port layout requires much attention to avoid:

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- impacts on the existing harbour, waterway and industrial facilities,
- ecological impacts on the Wadden Sea National Park, and
- significant changes to the existing hydrodynamics and morphodynamics of the Jade Bay as well.

The optimization of the quay wall position with respect to tidal currents, tidal volume changes and sediment transport patterns was important to achieve these objectives.

As a basis for planning and environmental impact assessment, respectively, the changes induced by the JadeWeserPort in the abiotic characteristics of the Jade Bay were investigated extensively using results from in-situ measurements and 2D/3D UnTRIM-SediMorph numerical model simulations. All investigations were carried out on behalf of the JadeWeserPort Realisierungsgesellschaft mbH. Essential impacts of the port on the tidal and morphodynamic characteristics of the Jade-Weser Estuary as well as the cooling water propagation at a neighbouring power station could be identified.

The objective of this paper is to present these impacts by applying UnTRIM and SediMorph. According to the domain of study, agreement with observed data regarding tidal dynamics and sediment transport (morphodynamics) is shown first. Subsequently some major results regarding the impact of the future JadeWeserPort on the Jade Bay are given.

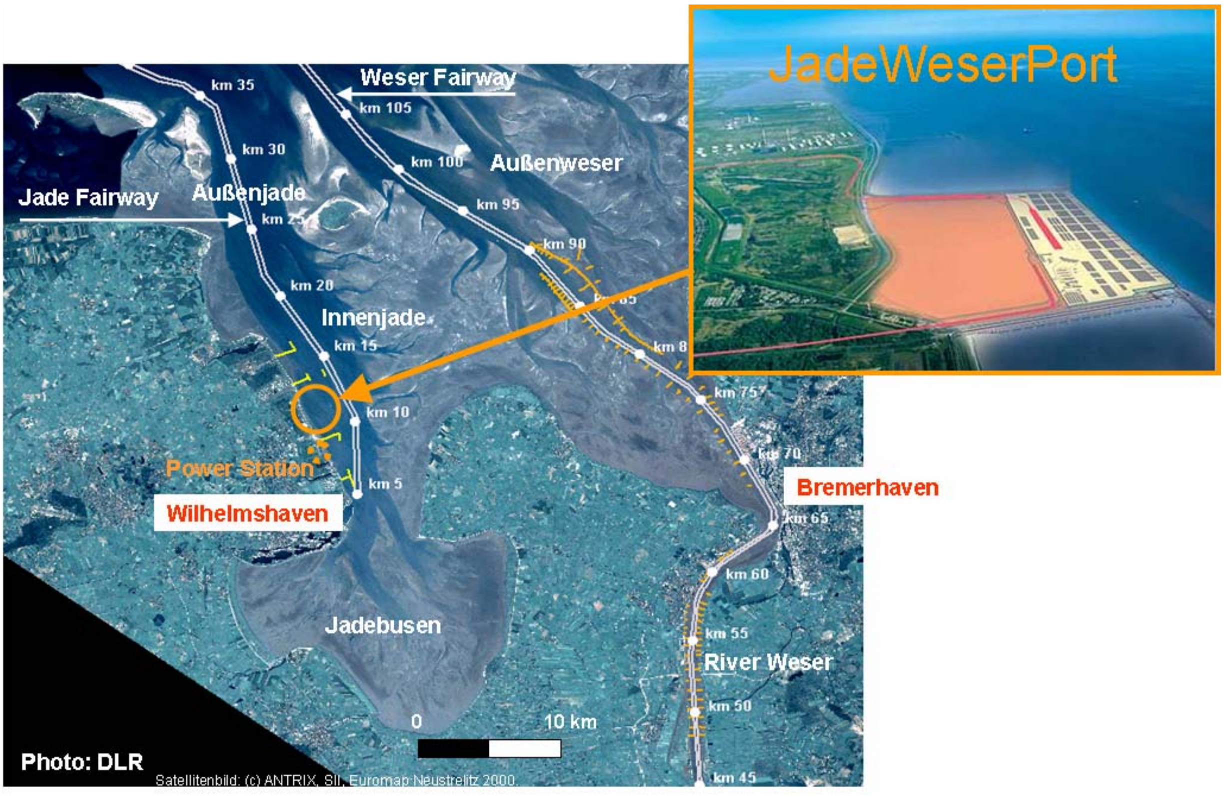

Figure 1 The prospective deep sea port of Wilhelmshaven in the Jade-Weser Estuary (German Bight).

2. MODEL AREA, MODEL GRID, BOUNDARY AND INITIAL CONDITIONS

The numerical model used encompasses Jadebusen, Innenjade, Außenjade, River Weser, and Außenweser (Figure 1).

For application of the model to storm surge studies, the closed land-side edge corresponds to the flood protection line. The open, sea-side edge forms an arc from Spiekeroog Island through the German Bight to Sahlenburg on the west of Cuxhaven (Figure 2). The model area has been chosen so large in order to allow the expected reactions due to the JadeWeserPort to die out within the model area and therefore not to be influenced by model boundary conditions.

In the Innenjade and Jadebusen, the model topography was based on soundings dating from 2000 and 2001 (multibeam echosoundings, line soundings, aerial photographs by laser beam scanning). Sounding data for the areas of the River Weser and the Außenweser dated from 1998 and 2000. For the other areas, in part, older topographical data from an existing digital terrain model of BAW had to be used, reaching sometimes back to 1992. These “other areas” were mainly located in the North Sea, subject to small morphological changes and without a significant impact on the overall result of the JadeWeserPort-dependent modifications of the tidal dynamics and morphodynamics. The fairways of the Weser and the Jade have been included in the model application with their officially approved design depths.

The domain was simulated for the 3D-studies with about 3 million elements having a vertical resolution of 1 m (below -30 mNN, a vertical resolution of 2 m was chosen) and a horizontal resolution of about 10 m to 2,200 m. Especially for the Innenjade, a high resolution was applied in order to allow nature-like imitation of the processes in the closer surroundings of the JadeWeserPort. The time step was 2.5 minutes.

Boundary and initial conditions have been chosen that represent a characteristic system state regarding the tidal currents and water levels, and cover the period of one neap-spring-cycle. 31/05/2002 to 15/06/2002 was chosen as the simulation period and 02/06/2002 to 14/06/2002 as the analysis period. The following data were used as boundary conditions (Figure 2):

- water levels at the open, sea-side model edge, measured at the model edge during the simulation period,
- daily average discharge from upper River Weser for the simulation period recorded at Intschede water gauge,
- hourly wind data taken from a hindcast model of the Deutscher Wetterdienst DWD made available by the Bundesamt für Seeschifffahrt und Hydrographie BSH,
- sediment data taken from several sources for modeling sediment transport (bed load and suspended load) and bed evolution as well,
- for simulations of cooling water propagation: cooling water circulation with intake and outfall discharge of 30 m^3/s.

Other freshwater inflows into the Jade-Weser Estuary have not been considered as they do not contribute to the tidal dynamics of the Innenjade in a significant way and can therefore be neglected in the modelling without any predictability losses.

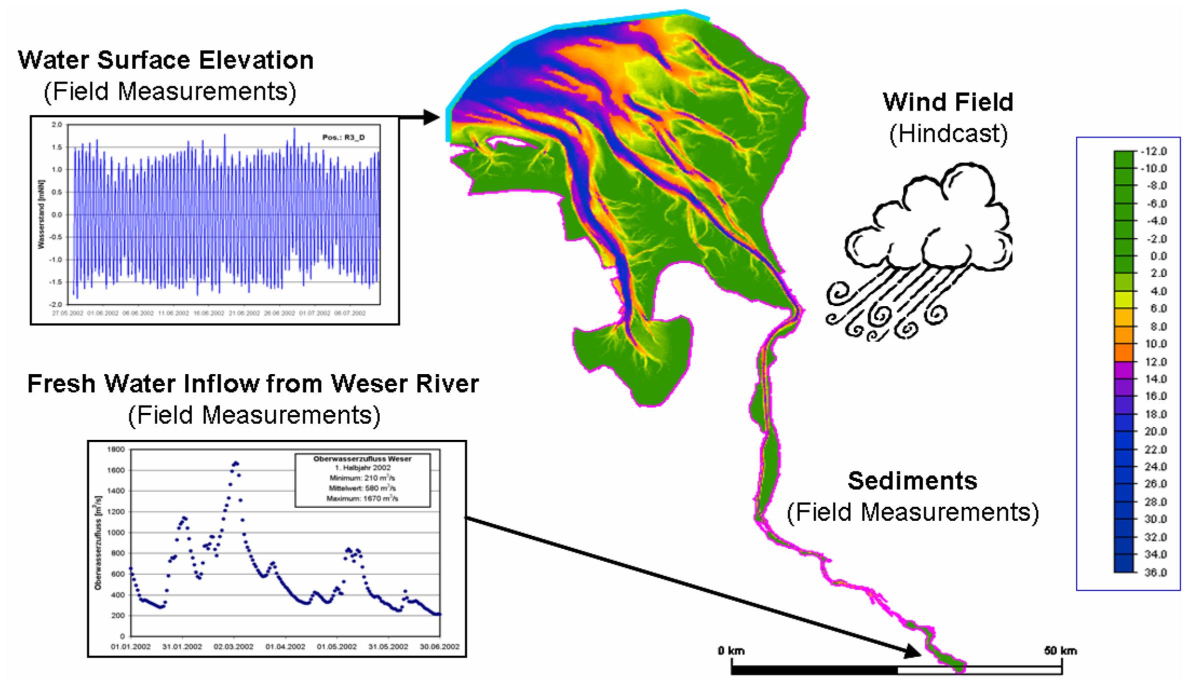

Figure 2 Overview of model area and data included in model application.

3. MODEL VALIDATION

3.1 Tidal dynamics

Comparison of measured and calculated water levels and flow velocities showed that the numerical model allows accurate simulation of all characteristic system properties of the Jade-Weser Estuary. Validation of agreement with observed data was executed: regarding water level dynamics for the hydrographic gauge stations *Schillig* (SLG), *Hooksiel* (HOO), *Voslapp* (VLP), *Wilhelmshaven Neuer Vorhafen* (WNV) and *Wilhelmshaven Alter Vorhafen* (WAV); regarding flow dynamics for four permanent flow stations (WSA 1 to 4) of the Wasser- und Schifffahrtsamt Wilhelmshaven (Figure 3). As examples, the comparison of the water level time series for the water gauge station *Wilhelmshaven Neuer Vorhafen* is shown in Figure 4 and the comparison of the velocity time series for the position WSA 4 in Figure 5.

The comparison of the water level time series in the Innenjade resulted in a standard deviation between measurement and calculation of 2.8 cm (water gauge station *Wangerooge Nord*) and 7.2 cm (water gauge station *Wilhelmshaven Alter Vorhafen*) indicating a high degree of agreement between observed and predicted water levels. Also the comparison of the velocity time series in Figure 5 for the four measurement stations in the Innenjade results in a very high correspondence between measured data and calculated results. When comparing flow velocities, the standard deviation is between 8.4 cm/s (WSA 4) and 10.7 cm/s (WSA 3). The comparison of the flow time series, based on measured and calculated flow velocities, was undertaken at a level of about 3.0 m above ground; for the calculated flow velocities, an average of the flow velocities over a cell height of 1.0 m was taken.

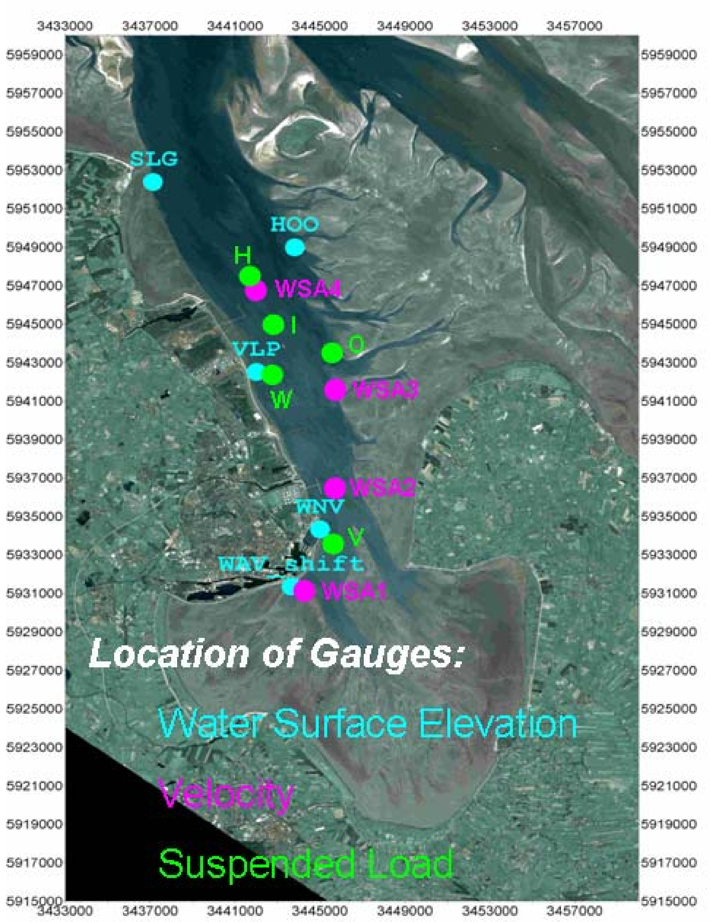

Figure 3 Location of hydrographic gauge stations.

Differences between measured and calculated results may above all be caused by: undetected local wind effects; deviations in the model topography due to the time difference between water level gauging (flow measurement) and sounding; change in position of the flow meters due to high flow velocities; inaccurate gauging and flow measurement.

3.2 Morphodynamics

In the dynamic equilibrium system of the Jade-Weser Estuary, distribution and properties of the surface sediments are part of the resisting forces. Sediment properties are: erosion resistance, sinking velocity, grain density, grain size distribution, cohesion and bulk density. Despite a heterogeneous sediment distribution in the area under examination, a rough distinction can be made between characteristic areas:

- Periodically dry areas (sea muds of euliteral: sandy, mixed and silty mud-flats as predominant sea mud types)
- Water-wetted areas (shallow water, fairway and other deep channels or gullys)
- Other areas (oyster-shell and mussel beds, vegetation)

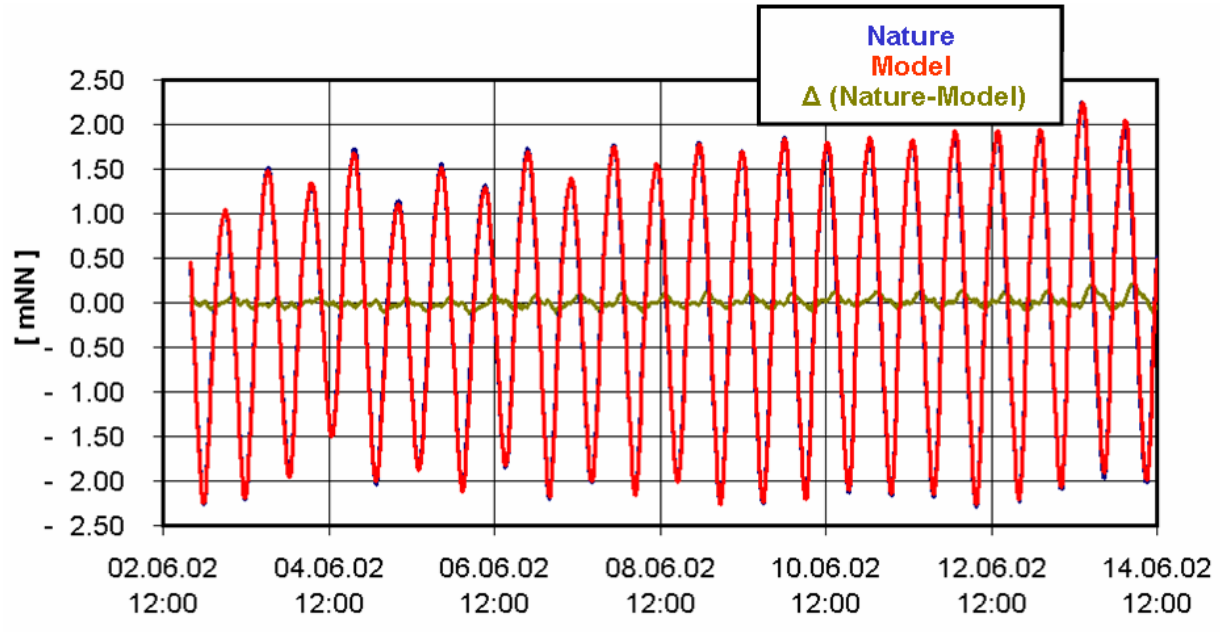

Figure 4 Comparison of measured and calculated water level time series for water gauge station *Wilhelmshaven Neuer Vorhafen* (Station location shown on Figure 3).

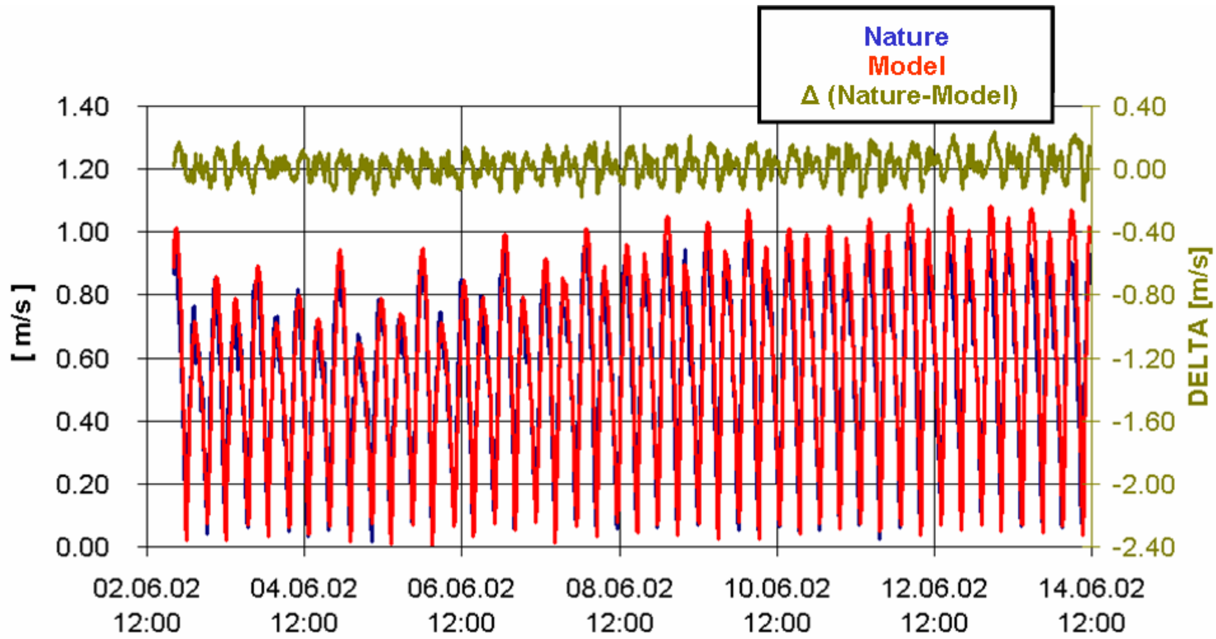

Figure 5 Comparison of measured and calculated flow velocities for the permanent flow measurement station *WSA 4* (Station location shown on Figure 3).

For the hydraulic system analysis, the various facets of the natural surface sediment structure of the Jade-Weser Estuary had to be converted into a simplified synthetic representation. Starting from up-to-date sediment samples, taken by

- Niedersächsisches Landesamt für Ökologie for the tidal-flat areas,
- Wasser- und Schifffahrtsamt Wilhelmshaven for the Jade fairway,
- Wasser- und Schifffahrtsamt Bremerhaven for the Weser fairway,
- JadeWeserPort Realisierungsgesellschaft mbH (respectively BioConsult GbR) for the Innenjade, and
- BAW for the Außenjade

and by applying an interpolation algorithm, the entire domain was divided into different areas presenting a representative natural sediment structure; the predominant grain fractions of medium silt, coarse silt, fine sand, medium sand, and coarse sand were used. In the artificially deepened sections of the development state, the former sediment coverage of the reference state was used further. For steering in the depth-averaged suspension concentration at the sea-side model edge, the equilibrium concentration approach is applied. Additionally, the simulated suspended sediment concentrations in the Innenjade were compared with the measured suspended sediment concentrations (Figure 3, 6 and 7).

In the Innenjade, the cloud of suspended sediments oscillates with the tide in the area stretching from Minsener Oog into the deep tidal gullys of Jadebusen. The model results indicate significantly higher suspended sediment concentration west of the fairway and lower suspended sediment concentration east of the fairway. Average suspended sediment concentrations are up to 0.075 kg/m^3 (= 75 mg/l). This magnitude corresponds to the average measured sediment concentration in Figure 6. A direct comparison of measured and calculated suspended sediment concentrations was not possible as the period of suspended sediment measurement did not correspond to the simulation period. Furthermore, the results of the reference state show that in the lower River Weser, the typical turbidity zone arose in the model calculations. The turbidity zone of the lower River Weser oscillates with the ebb and flood current between Sandstedt and Bremerhaven. These results show a good level of agreement with the characteristic turbidity zone of the River Weser.

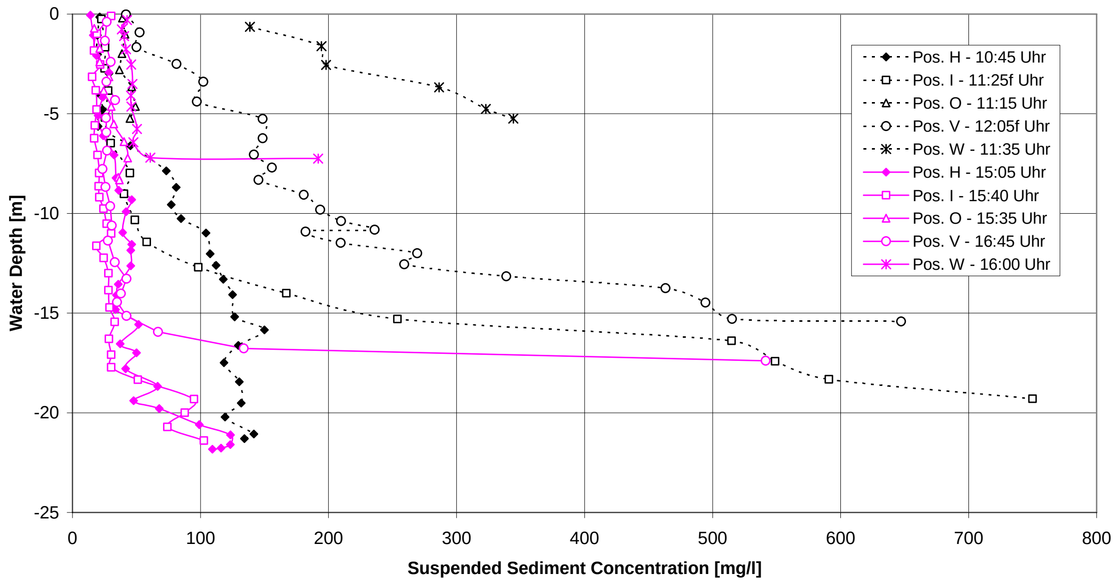

Figure 6: Suspended sediment concentration in the Innenjade at measurement stations *H*, *I*, *O*, *W* and *V* during flood current (dashed lines) and slack water of a spring tide at 16.07.2003 (Station location shown on Figure 3).

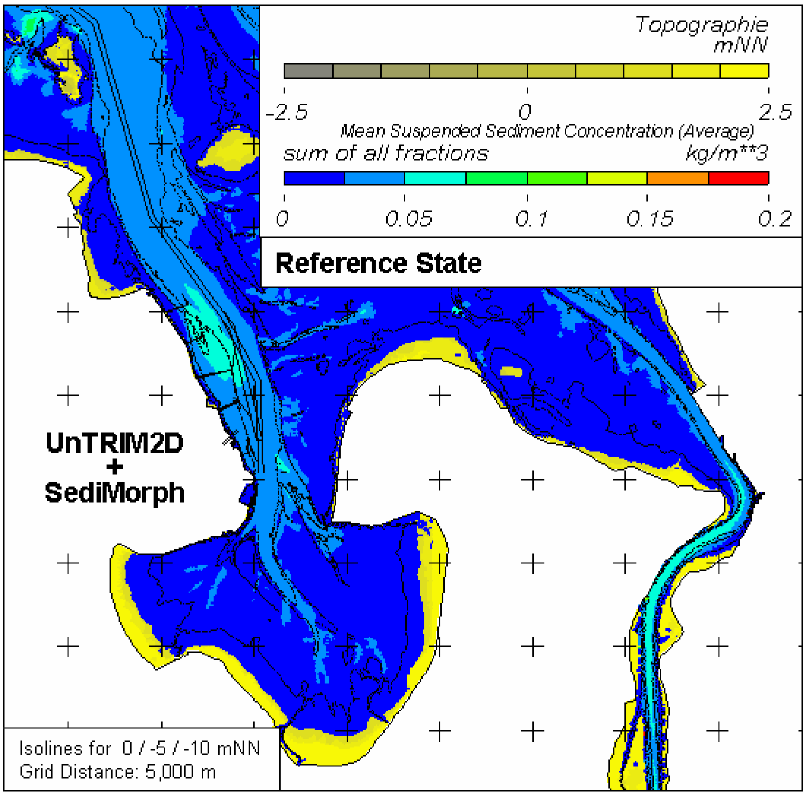

Figure 7 Mean suspended sediment concentration for the reference state.

4. IMPACTS OF JADEWESERPORT ON TIDAL DYNAMICS AND MORPHODYNAMICS

The far field changes in the abiotic system parameters caused by the future JadeWeserPort are due to the non-linear superposition of different individual effects, caused by the new fairway, the access area, the quay position and the embankments once the port construction has been finalized. Given the complex topography of the Jade-Weser Estuary and the non-linear physical processes during the propagation of a tidal wave, a simple linear superposition of the respective hydraulic effects of the individual elements of the JadeWeserPort is not possible; it can only be undertaken on the basis of a high-resolution hydrodynamic-numerical model which considers the complex topography as well as the non-linear physical processes. This is particularly applicable if the effects of the different elements, e.g. the effects of fairway dislocation / harbour access area and quay position are opposite to each other and it becomes thereby possible to minimize the port-induced changes. From this, it follows that (Figure 8 and 9):

- due to the opposite physical effect of deepening (fairway and access area) and narrowing (quay projection), the port-induced changes are concentrated in the closer vicinity of the JadeWeserPort;
- because of the changed tidal subharmonics due to reflections, the tidal range increases around the southern embankment and decreases around the northern embankment;
- flow diversion at the embankments has a local impact on water levels and on flow velocities;

- vortices arise in the flow shadows behind the structure during a fully-developed flood and ebb current;
- the current deflected at the embankments separates at the quay corners and a zone of low flow velocity thereby arises in front of the quay;
- outside the zone of low flow velocities, the velocities increase directly in front of the quay due to flow contration in this area.

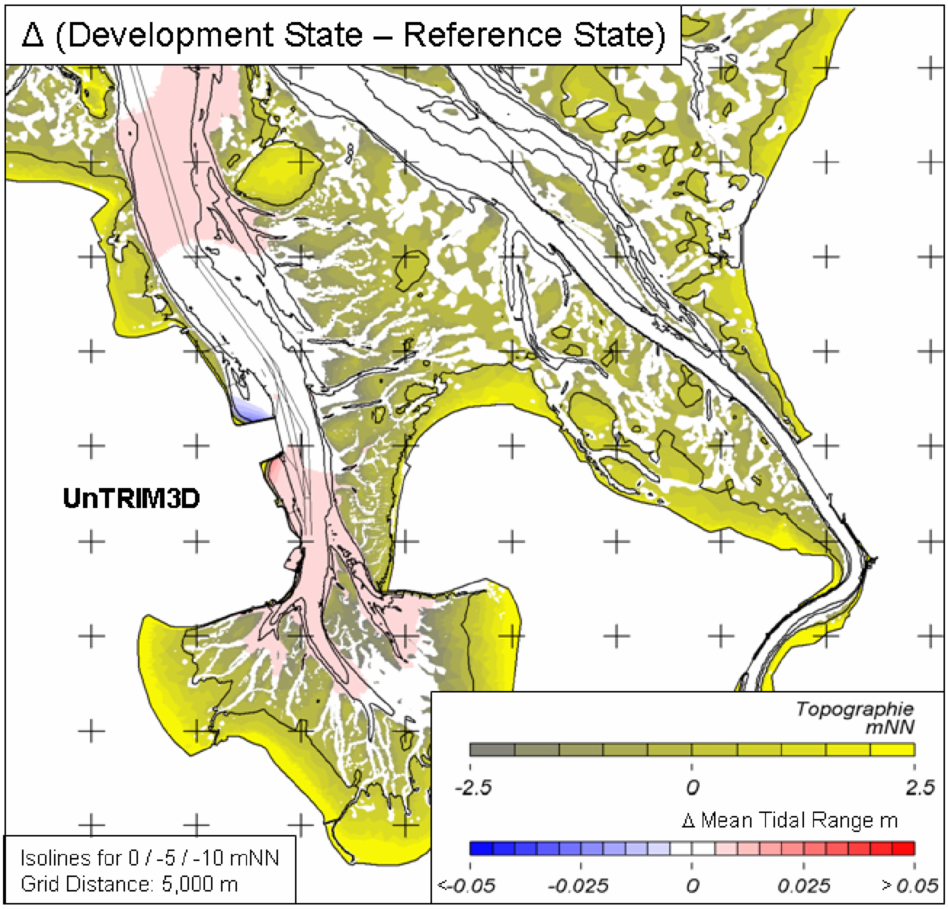

Figure 8 Port-induced changes of tidal range.

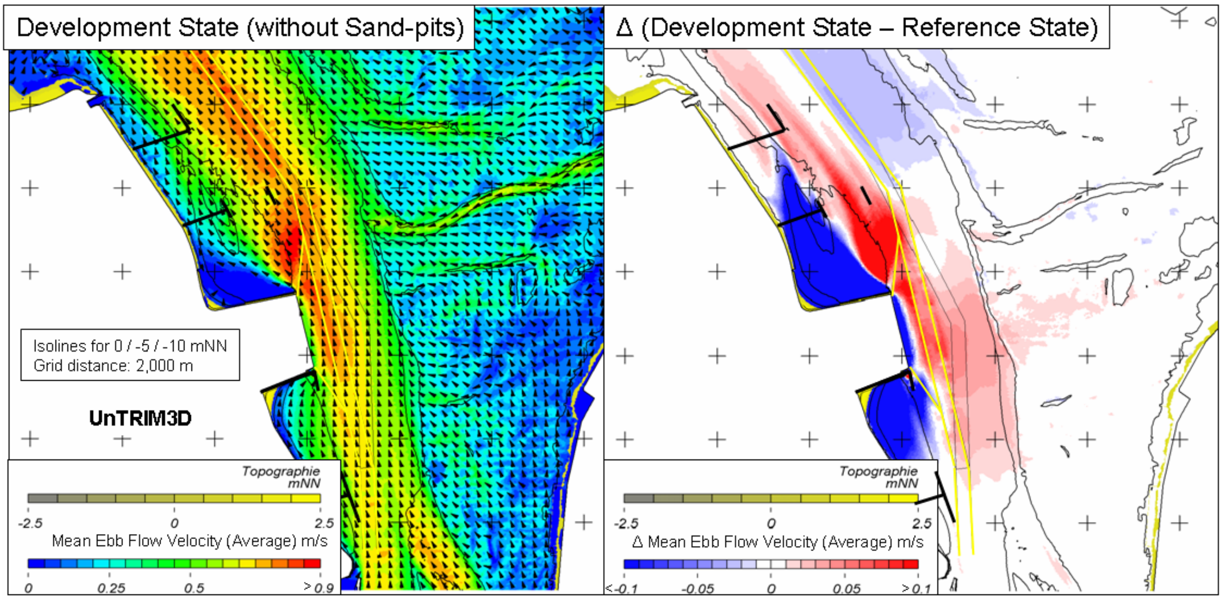

Figure 9 Mean ebb flow velocities for development state (left) and port-induced changes in mean ebb flow velocities (right).

As morphodynamic reactions are a result of port-induced changes in tidal dynamics, the primary findings pertaining to erosion and sedimentation trends are (Figure 10 and 11):

- morphodynamic reactions concentrate in the closer vicinity of the future JadeWeserPort,
- sedimentation in the flow shadow of the embankments due to reduced flow velocities,
- scour around quay ends due to increased flow velocities and generation of turbulences,
- flattening of slope areas between harbour access area and undisturbed bathymetry,
- sedimentation directly in front of the quay due to current detaching at the quay ends,
- erosion trends in the new fairway and in parts of the access area due to focussing of currents in that part of cross section,
- clear decrease in suspended sediment concentration in the Innenjade west of fairway.

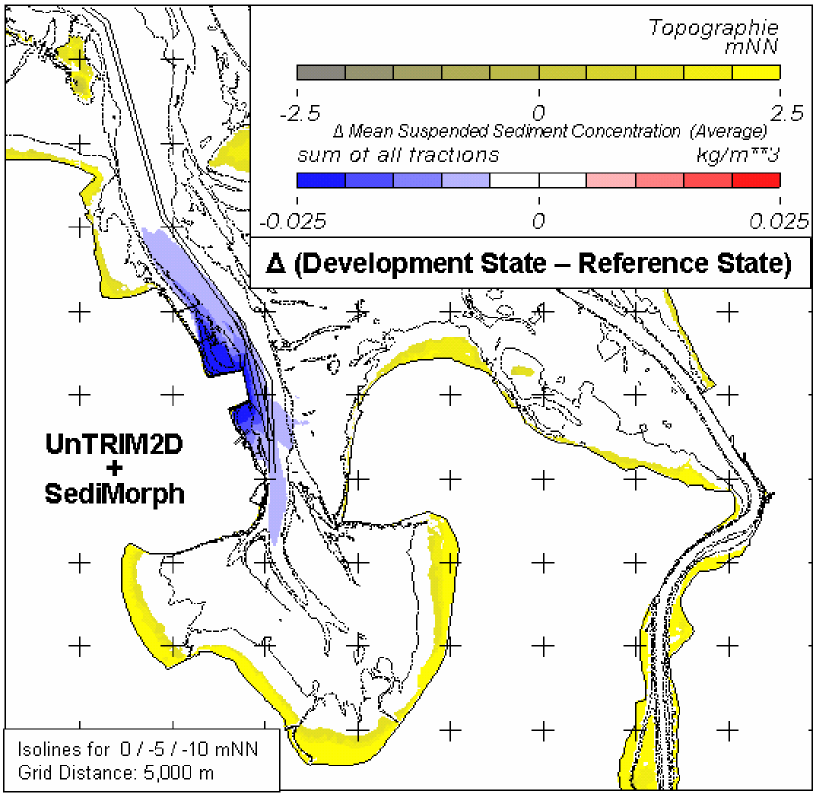

Figure 10 Port-induced changes of mean suspended sediment concentration.

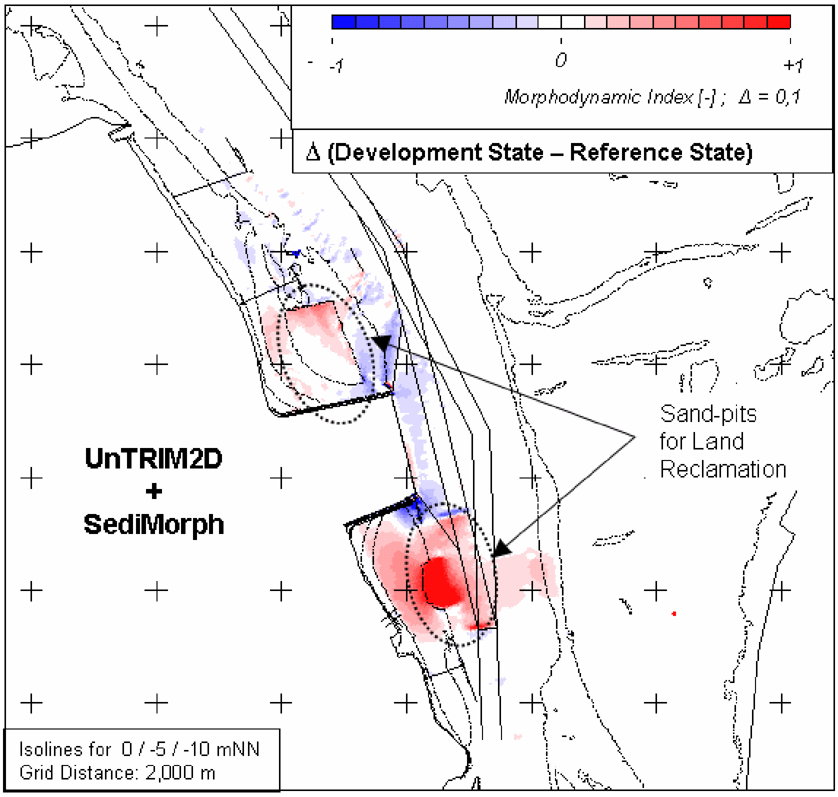

Figure 11 Port-induced changes of sea bed.

5. CONCLUSION

Construction of the JadeWeserPort has been planned in the Innenjade in front of Voslapper Groden. Given its dimensions (area of 360 ha, quay length of 1,725 m and reference bottom depth of 18 m below chart datum (= MLWS)), a hydraulic system analysis was undertaken in order to investigate the structure's impact on tidal and morphodynamics of the Innenjade.

The results of the hydraulic system analysis regarding the port-induced changes of tidal and morphodynamics caused by the JadeWeserPort can be summarized as follows:

- No significant changes of tidal characteristics in River Weser, Außenweser and Jadebusen,
- Locally limited changes of tidal characteristics in the Innenjade,
- Increase in flow velocities in the access area and in the new fairway of the Innenjade,
- Good prerequisites for access area and new fairway to be kept clear from sedimentation,
- Sedimentation in the flow shadow of the embankments due to flow reduction in these areas,
- Clear decrease in suspended sediment concentration in the Innenjade west of fairway.

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