ANDREAS WURPTS

MORPHODYNAMIC-NUMERICAL SIMULATIONS OF DREDGED MATTER OPEN DISPOSAL

ABSTRACT

Open disposal of dredged matter in coastal areas is common practice all over the world. Especially if cohesive sediment is considered, it is a known fact that the location where the long-term deposition takes place may essentially differ from the disposal site. Knowledge of the transport and fate of disposed sediment improves the economic and environmental aspects of off-site disposal.

Dredged matter which is placed at a disposal site usually differs from the local bottom-sediment with respect to grain sizes and grain size distribution. Moreover the bottom-topography at the disposal site changes as a result of the added sediment. The two aspects mentioned above usually lead to a "violation" of the local morphodynamic equilibrium state which is followed by a "reaction" of the topography (eg. increased erosion, changing sorting of the local sediment-mixture). Another important aspect related to unconfined disposals is the interaction between the disposed matter and the surrounding flow-field (e.g. density currents) which can become a dominant transport mechanism in the nearfield of the placement site.

This contribution deals with the development of a morphodynamic-numerical simulation model. SMOR3D consists of several modules which are fully coupled in a time-explicit mode. The model-approach consists of a 3D flow solver which is coupled with several transport modules for suspended sediments, bed-load sediment and salt. The movable bottom topography is balanced by a bed-model. All sediments (natural background and disposed matter) are represented by several fractions of different properties. The model allows the discrimination of disposed matter from the natural background sediment at every location and time. Results of numerical simulations of disposals by means of bottom doors and split barges are shown. The results are in good agreement with SPMC measurements carried out in the nearfield of different disposal locations.

The author wishes to thank Dr Peter Mewis, Chief Engineer and Prof Dr Ulrich Zanke both of the University of Technology Darmstadt, TUD, Germany for their collaboration and support. This paper was presented at the CEDA Dredging Days, November 2005 in Rotterdam, the Netherlands and appears in the conference Proceedings. It is reprinted here in a slightly revised form with permission.

Above, The area along the River Elbe for which results were simulated and measured. © Port of Hamburg (Germany) Marketing/ Hettchen.

INTRODUCTION

The present paper deals with numerical simulations of the near-field and thus short-term distribution of suspended sediment and shows the capabilities of three-dimensional morphodynamic-numerical modelling. It is part of a research project dealing with the enhancement of a three-dimensional hydro- and morphodynamic model in order to numerically reproduce observed spatial turbidity distributions which were measured during the disposal of dredged matter and to predict the fate of the disposed matter under complex hydrodynamic conditions.
The numerical model results shown here are compared to field measurements. These were carried out in the nearfield of disposal-events of fine-grained, silty dredged sediment. Spatial and temporal distribution of suspended particulate matter concentration (SPMC) was measured.

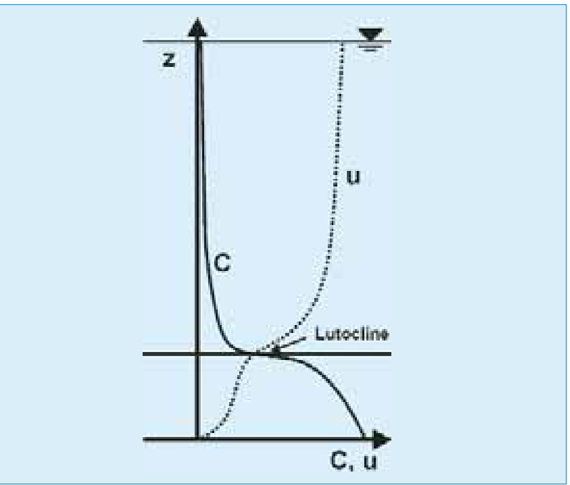


Figure 1. Sketch of stratified flow: Vertical profiles of SPMC and flow-velocity.

Model results confirm that as a result of density-effects a three-dimensional and fully coupled approach is necessary to numerically reproduce the measured nearfield distributions.

BACKGROUND

General

One aspect of dredged matter disposals is flow-stratification resulting from density effects. Flow-stratification results from varying densities inside the flowing water body. Density differences can be present as a result of significant amounts of suspended particulate matter concentration (SPMC) as well as dissolved substances (e.g. salt) or temperature differences. In the stratified case there exists a step in the vertical profile of density distribution, which can cause significant damping of turbulent (vertical) momentum exchange which in return stabilises the stratified situation. Figure 1 schematically shows a stratified flow, with vertical profiles of density and flow-velocity given.
The velocity profile is deformed where the maximum density-gradients are located. This is a result of the damping of vertical momentum exchange around this lutocline. The disposal process itself (by bottom-doors or split-barges) generates a huge amount of local turbulence which brings a major part of the disposed matter (especially the finer fractions) into suspension.

The resulting SPMC-values at the disposal site are usually much higher than the natural background concentration and therefore induce strong local density gradients which lead to density currents of suspended sediment. These are dominated by gravity forces and thus move according to local bottom gradients which can significantly differ from the surrounding flow direction. Depending on the properties of the disposed matter (grain-sizes, settling velocities, density) deposition and sorting take place which lower the suspended sediment concentration with time. In case of cohesive sediment, settling velocities are also concentration-dependant as a result of effects like flocculation and hindered settling.

A second considerable stratification can be found in most estuaries resulting from the mixing of fresh water from river-inflow with salt water from the sea. These mixing processes, if superimposed with tidal movement, can lead to large-scale density effects like vertical gravitational circulation (VGC). In areas of VGC an intensification of near-bottom net landward flow occurs which leads to altered sediment-transport patterns compared to unstratified conditions. Both effects, SPMC- and salinity-induced stratification, have to be modelled, if simulations in estuarine environment are considered.

Numerical Model

SMOR3D is a three-dimensional time-explicit morphodynamic-numerical model.
It consists of a 3D instationary flow solver which is directly coupled with several transport modules for salt, suspended and bed-load-sediment at every calculational time-step. Sediment transport is balanced by a bottom evolution model, which provides bottom level changes and local resuspension properties as well as strict sediment continuity checking. Sediment is described by multiple fractions with different properties (e.g. grain size, settling velocity, cohesion). Local effects like hiding/exposure and armouring is accounted for by the bottom evolution model. The model allows sediment transport in areas of restricted erodibility and is capable of sediment-transport on fixed beds. For calculations in tidal areas a robust wetting/drying-scheme is implemented to consider moving boundaries within the calculational domain.

The flow-solver calculates the instationary three-dimensional Reynolds-averaged Navier-Stokes-equations (RANS) in a time-explicit way. Spatial discretisation is done by the method of finite elements, in time domain a three-level leap-frog scheme is implemented. SMOR was originally developed by Mewis and was validated for scouring at alluvial river bends considering single-fraction sediment (Mewis 2002).

For the calculation of dredged matter disposals several extensions and modifications were added:

- The single-grain-size sediment transport was replaced by a multi-fraction-approach.
- The bed-evolution model was replaced by a multi-fraction multi-layer model which allows the evaluation of every (disposed) fraction at every calculational time-step.
- Salinity transport was added for calculations in estuarine environments and a recoupling with the turbulence-model to consider density-stratification was implemented.
- An abstracted initial condition for the disposal process was implemented which allows disposed matter to be added to the water column and the bottom-sediment layer.

The structure of the information-flow inside SMOR3D is given by Figure 2.

Hydrodynamic Model

The 3D RANS-Equations with additional terms for bottom-friction, density-stratification and Coriolis-forces are given in equations (1) to (3)

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=f_c v-\frac{1}{\rho}\frac{\partial p}{\partial x}+ \frac{\partial}{\partial x}\nu_{t,h}\frac{\partial u}{\partial x}+\frac{\partial}{\partial y}\nu_{t,h}\frac{\partial u}{\partial y}+\frac{\partial}{\partial z}\nu_{t,v}\frac{\partial u}{\partial z}-\frac{\tau_x}{\rho} \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-f_c u-\frac{1}{\rho}\frac{\partial p}{\partial y}+ \frac{\partial}{\partial x}\nu_{t,h}\frac{\partial v}{\partial x}+\frac{\partial}{\partial y}\nu_{t,h}\frac{\partial v}{\partial y}+\frac{\partial}{\partial z}\nu_{t,v}\frac{\partial v}{\partial z}-\frac{\tau_y}{\rho} \quad (2)$$

IADC AWARD 2005
PRESENTED AT CEDA DREDGING DAYS, ROTTERDAM, THE NETHERLANDS NOVEMBER 2-4 2005

In 2005 an IADC Award was presented to Andreas Wurpts, who is presently teaching at the Darmstadt University of Applied Sciences. Mr Wurpts studied at the University of Hannover, Germany, and also spent a year at the Technical University of Delft, the Netherlands. He returned to the University of Hannover where in 2000 he received his degree as an engineer in hydraulic engineering. He then became a scientific assistant and teacher at the University of Technology Darmstadt, Germany in the Institut für Wasserbau und Wasserwirtschaft (Institute for Hydraulic Sciences) where the research for this paper was conducted. Each year at selected conferences, the International Association of Dredging Companies grants awards for the best papers written by younger authors. In each case the Paper Committee is asked to recommend a prizewinner whose paper makes a significant contribution to the literature on dredging and related fields. The purpose of the IADC Award programme is "to stimulate the promotion of new ideas and encourage younger men and women in the dredging industry". The winner of an IADC Award receives Euros 1000 and a certificate of recognition and the paper may then be published in Terra et Aqua.

Andreas Wurpts (right) recipient of an IADC Award for young authors with IADC Secretary General Constantijn Dolmans.

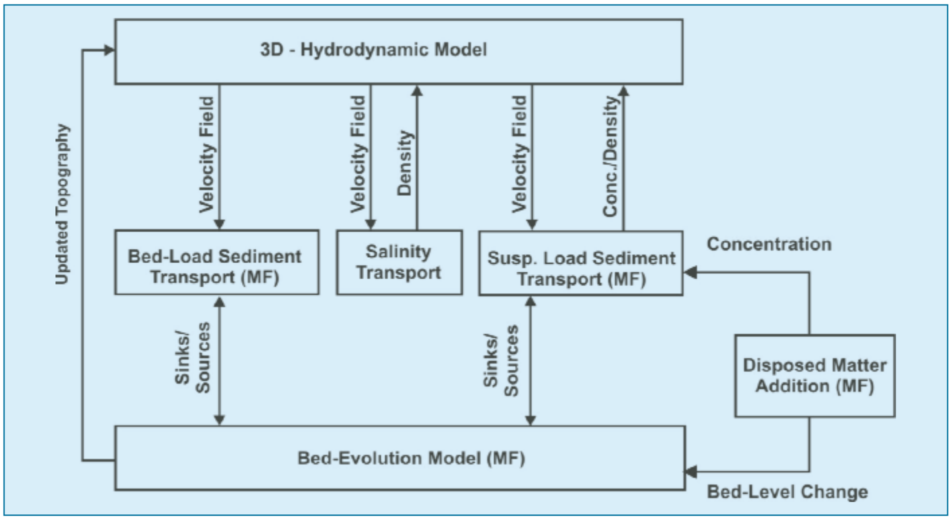


Figure 2. Structure of model-coupling SMOR3D.

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-g-\frac{1}{\rho}\frac{\partial p}{\partial z}+ \frac{\partial}{\partial x}\nu_{t,h}\frac{\partial w}{\partial x}+\frac{\partial}{\partial y}\nu_{t,h}\frac{\partial w}{\partial y}+\frac{\partial}{\partial z}\nu_{t,v}\frac{\partial w}{\partial z}-\frac{\tau_z}{\rho} \quad (3)$$

The continuity-equation reads:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (4)$$

where u, v, w are the directional flow-velocities for resp. x, y and z direction, g acceleration of gravity, ν_t turbulent diffusivity and ρ fluid-density.

By neglecting dynamic pressure, equation (3) becomes to (5) (hydrostatic pressure approximation) and after integration over the vertical to (6).

$$0=-g-\frac{1}{\rho}\frac{\partial p}{\partial z} \quad (5)$$

$$p=g\rho z \quad (6)$$

This assumption is valid for all cases, where (especially vertical) accelerations in the flow-field can be neglected, i.e. for large-scale calculations, and is used here because of its considerable saving of calculational effort.

Bottom-friction is implemented by means of a Newton-Taylor-Coefficient, equation (7) with ρ flow-density, H flow-depth, u flow-velocity and τ friction-stress.

$$\frac{\tau}{\rho}=r_f\frac{u^2}{H} \quad (7)$$

Coriolis-force must not be neglected in wide channels (i.e. estuaries), thus coefficient $f_c = 2\omega\sin\phi$ times the component-wise flow-velocity gives the additional momentum in the RANS-equations with ω angular velocity and ϕ geographical latitude.

Turbulence closure is achieved by an eddy-viscosity-approach. Horizontal and vertical directions are treated separately which accounts for the different dimensions of the calculational domain in horizontal and vertical direction (anisotropy of turbulence). Vertical turbulent diffusivity is calculated by a density-modified mixing-length-formulation, equation (11), which can handle density-stratified flows.

The basic Prandtl mixing-length-approach

$$\nu_{t,v}=\kappa^2 z^2\left(1-\frac{z}{H}\right)\frac{\partial u}{\partial z} \quad (8)$$

reproduces the logarithmic velocity-profile, with κ Karman-number. To account for density-induced effects the local gradient-Richardson-number Ri is calculated according equation (9):

$$Ri=-\frac{g}{\rho}\frac{\partial\rho/\partial z}{\left(\partial u/\partial z\right)^2} \quad (9)$$

Equation (8) is modified according to (10) and (11) (Orton 2001; Smith and McLean 1977) with: γ, σ empirical stratification coefficients.

$$\varsigma = \frac{\sigma Ri}{1-\sigma\gamma_{strat} Ri} \tag{10}$$

$$\nu_{t,strat} = \frac{\nu_t}{1+\gamma_{strat}\varsigma} \tag{11}$$

Given $\gamma_{t,strat} = 4.0$ as suggested by Smith and McLean, equation (11), describes a linear decrease of $\nu_{t,strat}$ over Ri with complete decoupling for Ri-values of 0.25 and above.

Salinity-Transport

Salinitity-transport is modelled by an advection-diffusion-type equation

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = \frac{\partial}{\partial x} K_{t,h,s}\frac{\partial C}{\partial x} + \frac{\partial}{\partial y} K_{t,h,s}\frac{\partial C}{\partial y} + \frac{\partial}{\partial z} K_{t,v,s}\frac{\partial C}{\partial z} \tag{12}$$

With: C local salinity concentration, K turbulent diffusivity. The turbulent Schmidt-Number is assumed to be 1. This means turbulent diffusivity of dissolved substances is assumed equal to that of momentum. Salt is transported conservative, which means that there are no sinks or sources except at open boundaries of the model domain.

Sediment-Transport

Entrainment of non-cohesive sediment is calculated according to (Van Rijn 1994a), equation (13).

$$E_{i,uni} = p_i 0.00033 \cdot \rho_{s,i} \cdot \left(\Delta_i g D_i\right)^{0.5} \cdot D_{*,i}^{0.3} \cdot T_i^{1.5} \tag{13}$$

Van Rijn originally derived his entrainment formulation for single-grained Sediment. Equation (13) therefore shows a modification for multi-fraction sediment, where D* is the dimensionless sediment diameter after Bonnefille and T "transport stage"- parameter after Van Rijn and p_i local availability of fraction i.

For cohesive sediment a friction-stress-based approach yields equation (14) after Partheniades, with: τ_e critical shear-stress for initiation of erosion, E_0 entrainment-rate.

$$E_{coh} = E_0 \exp\left(\alpha\left(\tau_b - \tau_e\right)^{0.5}\right) \tag{14}$$

Suspended sediment transport is calculated by means of an advection-diffusion-type equation:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = \frac{\partial}{\partial x} K_{h,sus}\frac{\partial C}{\partial x} + \frac{\partial}{\partial y} K_{h,sus}\frac{\partial C}{\partial y} + \frac{\partial}{\partial z} K_{v,sus}\frac{\partial C}{\partial z} + Q_{sus} + S_{sus} \tag{15}$$

Turbulent diffusivity of suspended sediment is assumed equal to that of momentum. Equation (15) is balanced by sinks and sources at the bottom boundary represented by entrainment and deposition.

Deposition of non-cohesive sediment is calculated by grain-specific settling velocity after (Zanke 1982):

$$w_s = \frac{11\nu}{d}\left(\sqrt{1+0.01D_*^3} - 1\right) \tag{16}$$

Equation (16) provides a good transition to the stokes-range, with: ν dynamic viscosity, D* dimensionless particle diameter after Bonnefille.

In case of cohesive sediment concentration-dependant settling velocities $w_{s,m}$ have to be considered due to effects like flocculation and hindered settling, equations (17) and (18):

$$w_{s,m} = k \cdot C^m$$

if C < 10000 [mg/l] (17)

$$w_{s,m} = w_s\left(1-\alpha C\right)^{\beta}$$

if C > 10000 [mg/l] (18)

Deposition is calculated according equation (19)

$$S_{ges,sus} = \sum_i w_{s,i} \cdot C_{a,i} \tag{19}$$

Bed-Load-Transport

Equation 13 describes total sediment transport. By multiplication with a characteristic, sediment-depending step-length λ one obtains a bed-load-transport per unit-width. In fraction-wise formulation this can be written as equation (20), where p_i denotes the portion of fraction i from the total sediment load.

$$q_{b,i} = E_{i,n} \cdot \lambda_i \cdot p_i \tag{20}$$

with:

$$\frac{\lambda_i}{D_i} = 3D_{*,i}^{0.6} \cdot T_i^{0.9} \tag{21}$$

Bed-Evolution Model

The bed-evolution model calculates bed-level-changes resulting from local erosion and deposition. Local sediment continuity is described by the Exner-equation, where n describes the porosity of the local sediment mixture:

$$(1-n)\frac{\partial a}{\partial t} = \frac{\partial q_{b,x}}{\partial x} + \frac{\partial q_{b,y}}{\partial y} + Q + S \tag{22}$$

Q and S are sources and sinks with respect to suspended sediment transport. Variable a denotes the actual bed-level elevation.

Disposal Process

Disposal with hopper barges is a very dynamic process where the hydrostatic pressure assumption may be (weakly) violated. Modelling the disposal process in detail (beginning with opening the bottom doors) would require a different modelling approach, i.e., a multiphase transport formulation as well as solving the momentum equations including the dynamic pressure distribution. The latter point forces to solve an elliptic problem or at least iterative pressure correction method at much higher computational costs.

Nonetheless in the present context the most important aspect of modelling the disposal process is the conservation of both the mass of fluid and (disposed) sediment involved. This in particular applies since in most cases no detailed data on the initial sediment composition in the hopper is available.

The disposal process is implemented by means of an abstracted initial condition which allows matter to be added to the water-column and the active bottom-sediment layer. This is done over a period of time which corresponds to the duration of the disposal. The ambient flow field is not explicitly changed by initial conditions but begins to "react" implicitly as the increasing density gradients more and more impact the flow. Disposed matter this way can be added to the water column according to constant or parabolic distributions over depth.
The aforementioned approximation can be shown to reproduce the overall dynamics of the disposal process in the nearfield of the disposal site reasonably well (Figure 4).

MEASUREMENTS

Measurements of time- and space-dependant SPM concentrations were carried out under tidal (River Elbe near Hamburg) as well as estuarine (outer estuary of River Weser) situations by subcontractors. The disposed matter was followed by a moving vessel equipped with broad band ADCP and CTD profiler instrumentation. The CTD carried optical attenuation and backscatter sensors. SPMC-values were derived from the optical signals and the ADCP backscatter intensities by calibration with samples repeatedly taken in parallel. ADCP-based SPMC-values were calculated from acoustic backscatter-intensities by an inverse modelling technique (SEDIVIEW).
The combination of the three methods mentioned above allows nearly continuous SPMC determination between 20 and 3000 mg/l throughout the whole water column except the most upper and lower 0.5 m. Further information on the measurements and the instrumentation used can be found in Witte (1996) and Riethmüller (2005).

MODEL RESULTS

Simulation results for disposals at River Elbe and outer estuary of River Weser are shown.

Tidal Environment (River Elbe)

The hydrodynamic situation at the disposal site (blue rectangle in Figure 3) is dominated by tidal currents up to 2 m/s. Salinity is not present. The measurement shown took place at beginning ebb flow (from right to left). Four split-barges loaded with cohesive matter dredged some miles upstream were synchronously emptied. After holding position 3 directly downstream of the disposal position for some minutes the survey vessel sailed downstream along the crossing course-line shown in lower Figure 3.

The measured (right column) and calculated (left column) SPMC-profiles along the transsections numbered with 4 to 8 are shown in Figure 4. The time of the vertical profiles in minutes with respect to the beginning of the disposal are associated to the middle of each plot. The measured and calculated SPMC-values are given by the legend above each column.

A clear stratification of the water column can be observed after the first minutes since the start of the disposal. Moreover the resulting density-current after 8 minutes already crossed two thirds of the channel width while moving almost rectangular to the ambient flow. The situation (especially the time-dependency) is well reproduced by the numerical model.

The situation mentioned above lasts for almost an hour after which the SPMC-values become too low for further

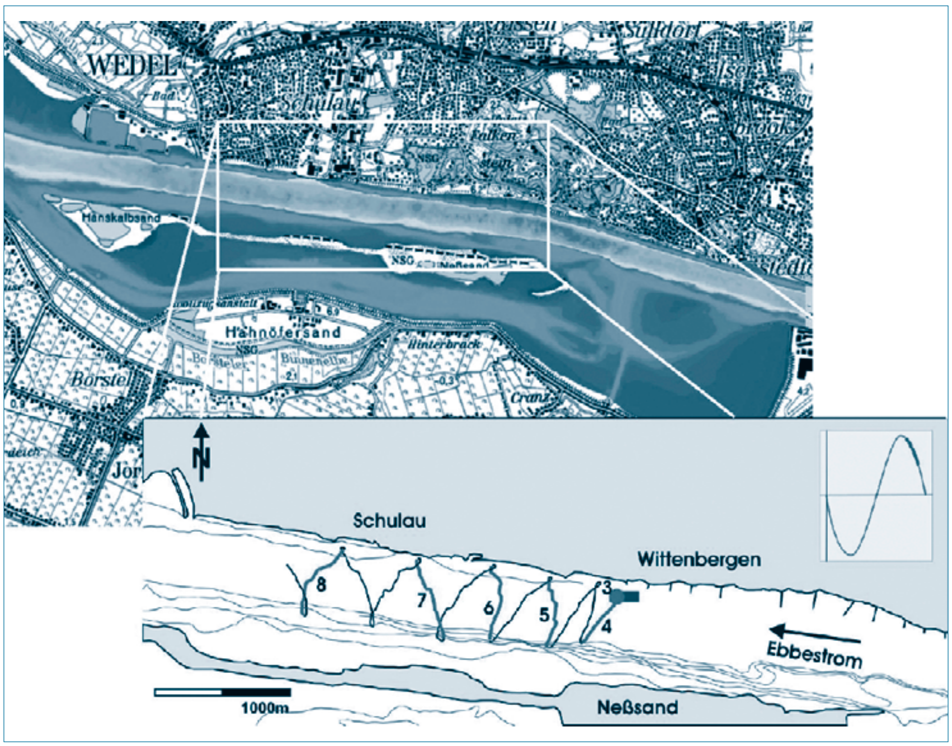


Figure 3. River Elbe: Overview with topography, detailed survey path.

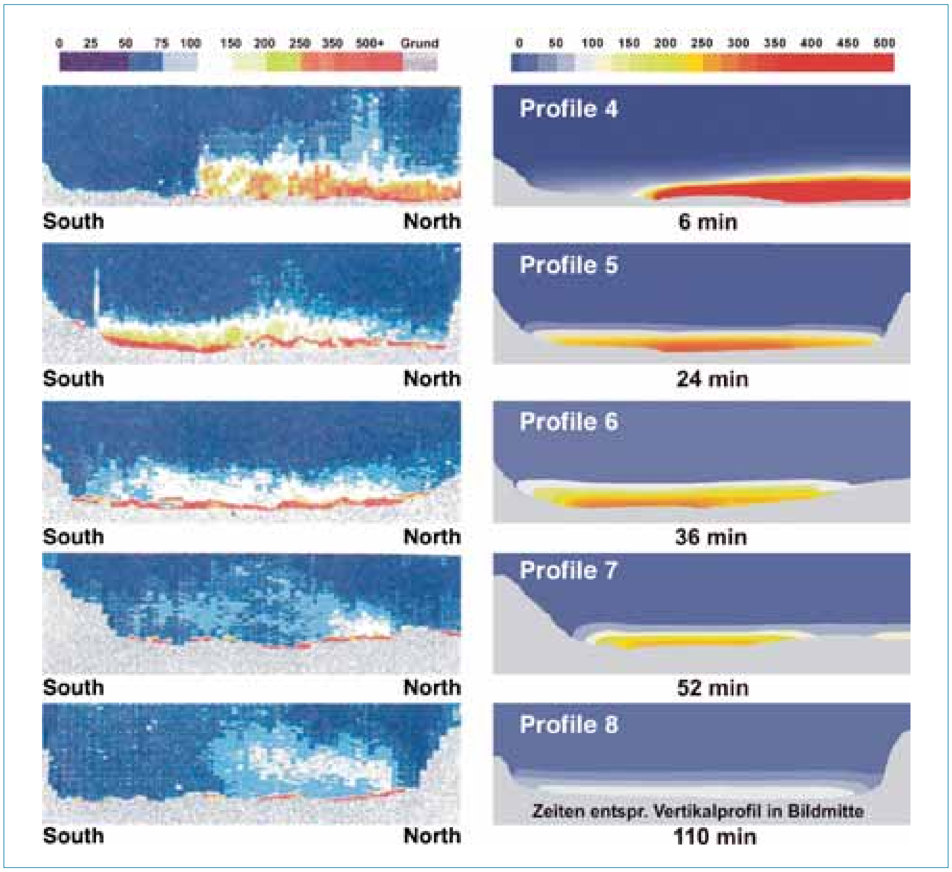


Figure 4. Comparison of measured and calculated SPMC-values along survey path.

stabilising the stratification because of the continuous deposition of disposed matter.

At this point the remaining sediment suspension becomes mixed into the whole water column. This process is calculated in a more averaged manner than the measurements show mainly as a result of local turbulence effects not resolved by the chosen numerical method and element mesh. Nonetheless the model reproduces the time- and space-dependant spreading of the disposed matter within agreeable precision.

Figure 5 shows 3D-iso-surface-plots of SPMC-values. The situation for three points of time is given.

Estuarine Environment (Outer Weser Estuary)

Figure 6 gives an overview of the Jade-Weser Estuary. The German North Sea coast consists of mudflats of some 5 to 20 km wide. The flats are crossed by deep tidal

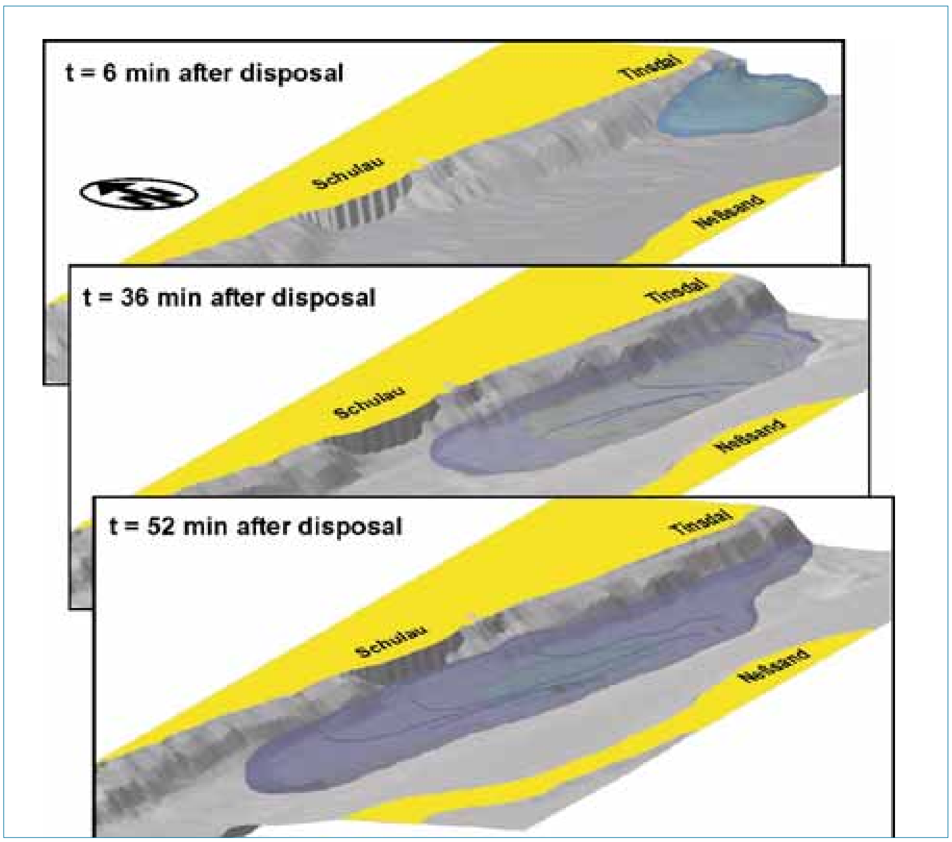


Figure 5. 3D-view of 100 mg/l (blue) and 200 mg/l (yellow) iso-surfaces at three points of time.

channels which provide tidal flooding and drying. River Weser as one of three major rivers disemboguing in the German Bight discharges fresh water into the above-mentioned area, leading to a partially stratified estuarine situation. The main flow at the disposal site (blue circle) is confined between longitudinal embankments. Additional groins orthogonal to the embankments intensify the currents in the deep channel which closely follows the southwest embankment.

The disposal site is located at the northeast border of the confined area close to the northern embankment. The deep channel near the disposal site provides an average flow depth of 18 m to 22 m. At disposal location the water depth is about 8 to12 m below chart datum, slightly sloping towards the deep channel. Dredged matter was disposed of through a hopper-dredger's bottom doors. It consisted of a major amount of fine-grained silt which was dredged some miles upstream.

The local hydrodynamic situation at the disposal area is dominated by tidal currents and barocline stratification effects as a result of the presence of salinity gradients which vary in time and space. The tidal range at the disposal location varies between 2.5 to 3.5 m, the local salinity between 8 to 30 ppt. The disposal site is located at the outer edge of the average turbidity maximum.

For the local hydrodynamic situation measurements have shown a distinct vertical gravitational circulation because of barocline stratification effects. Near-bottom the flood starts about 1.5 hours earlier than the surface. As a result during low-water slack and for the first 3 hours of the flood period a clear stratification can be observed in the deep channels. For the residual part of the tidal cycle the water column is fully mixed. The mentioned mechanism causes longer and stronger inward flow periods in the near-bottom area which also affects net sediment transport capacity and direction.

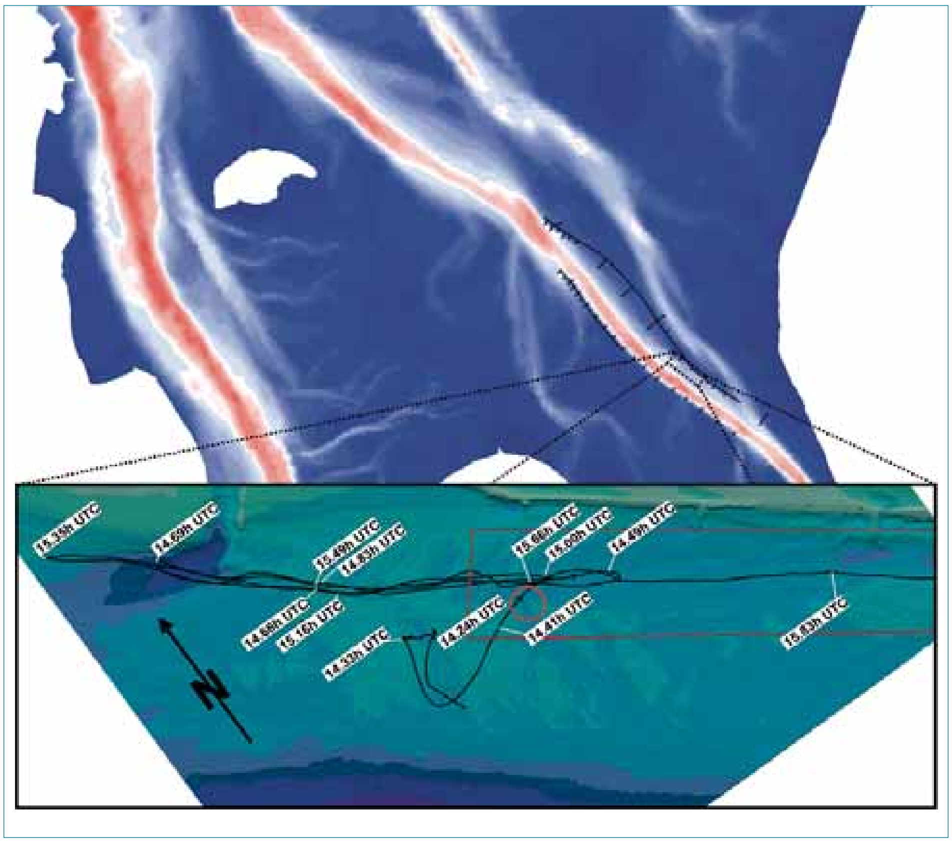
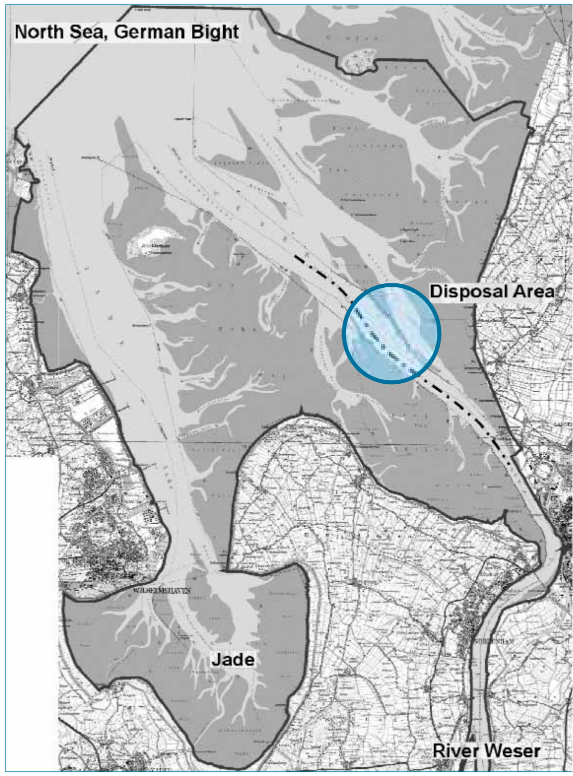


Figure 7. Track of survey vessel with time stamps, nearfield topography and disposal position, marked by the red circle.

Figure 6. Outer estuary of the River Weser, overview of model and disposal area.



To be able to consider the VGC within the numerical simulations the model area had to be extended to the whole estuary including the complete tidal-influenced part of River Weser (approximately 1000 km^2).

Figure 7 shows the detailed near-field topography of the disposal site. The survey vessel sailed along the shown track, continuously taking measurements as described above. The disposal was started at about 14.20h close to the end of ebb tide. The upper left corner shows a deep scour near a groin head which was crossed by the survey-vessel two times (see Figures 7 and 8). The disposal position is marked by the red circle.

Figures 8 to 10 compare observed and calculated values along the track. One has to consider the plots implicitly showing a variation in space and time. All time-values are given in hours UTC with decimal hours instead of minutes.

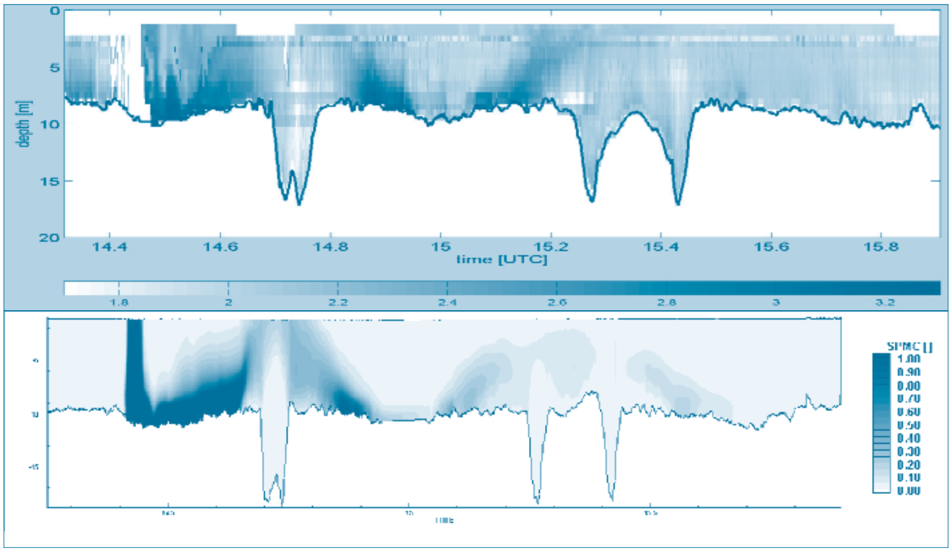


Figure 8. Comparison of measured (upper image) and calculated (lower image) SPMC distribution along surveyed track

Attention should be paid on the skew distribution near and in the scour hole around 15.20h with higher SPMC near-surface than near the bottom. The measured as well as calculated turbidity-distribution show this pattern which is a result of a salt-water "bubble" that remained in the scour hole.

The turbid water does not enter the scour as the saltwater is denser (Figure 9) and deflects the disposal-induced turbidity.

The simulation shows that the accumulation of water with higher salinity in the scour persists until approx. one hour after low-water slack (15.50h). This detail shows the good quality of the numerical simulation.

Figure 8 shows observed vs. calculated SPMC-values along the surveyed track. The vessel first entered the turbidity cloud at approx. 14.45h. The corresponding vessel position can be seen from Figure 7.

The massive local entry of momentum and turbidity resulting from the disposal accounts for a gap in the measured concentrations because of an exceedance of the ADCP working range. The lower image of Figure 8 shows calculated SPMC values resulting from the disposed matter. Turbidity of the natural background is blanked out.

When first entering the turbidity cloud at 14.45h the water column appears fully mixed. After a short way upstream (Figure 7) the vessel altered its direction to northwest (downstream direction) and reached the groin head scour at approx 14.70h. The measurements as well as the calculations show an increased agglomeration of suspended sediment in the lower water column. Increasing SPMC values in the upper column are found towards the 14.75h turn at the groin head scour.

The same pattern with lower concentrations is passed at the subsequent course in upstream direction. After reaching the upstream edge of the turbidity cloud around 15.00h a new course in downstream direction is taken. The cloud is passed again and concentrations decreased.

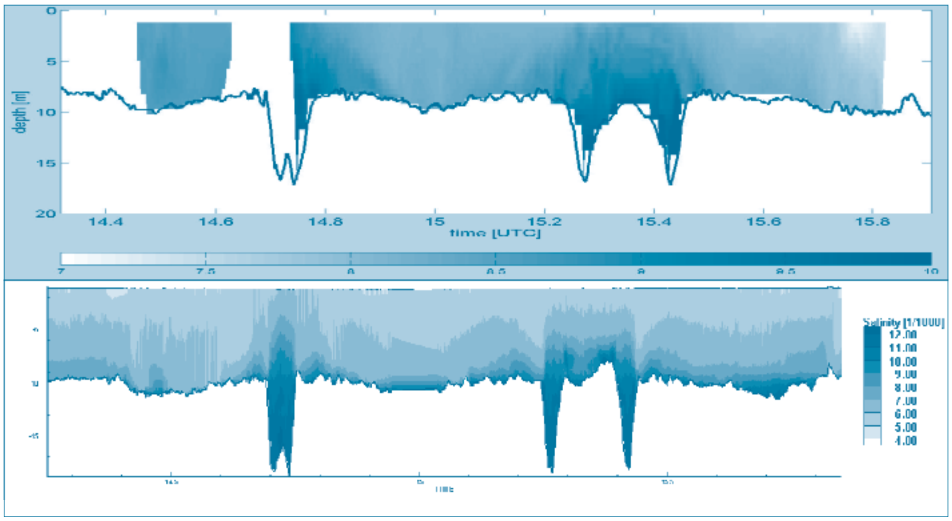


Figure 9. Comparison of measured (upper image) and calculated (lower image) salinity distribution along surveyed track

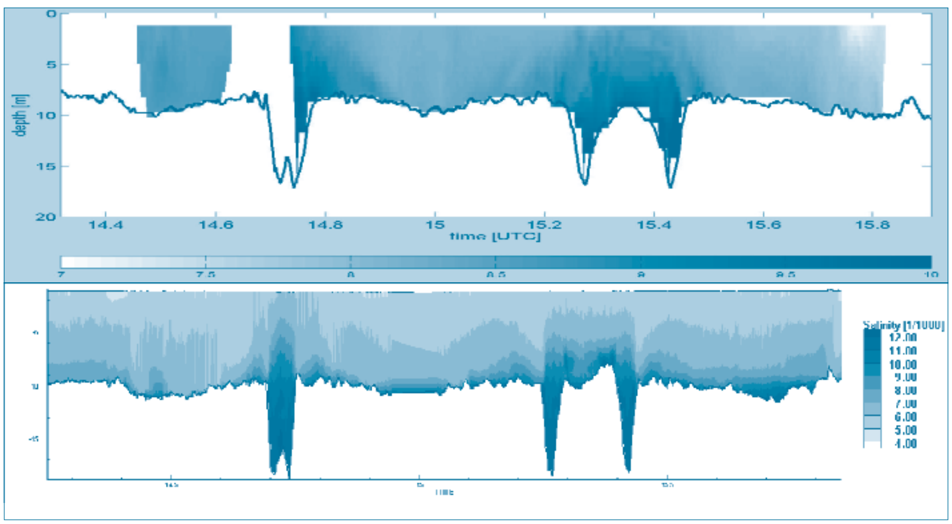


Figure 10. Comparison of measured (upper image) and calculated (lower image) flow-velocity along surveyed track

Figure 10 shows observed vs. calculated absolute flow velocities along the surveyed track. Since flow velocities were measured by the ADCP device the measured plot (upper image) shows a data gap when the turbidity-cloud was first entered by the survey vessel as a result of the exceedance of the working range of SPMC values.

CONCLUSIONS

The present paper shows the model capabilities of an extended 3D-morphodynamic model to reproduce measured nearfield distributions of disposal-induced suspended sediment. The model calculates a 3D flow field as well as transport of salt, suspended and bed-load sediment. Sediment is represented by different fractions. The observed processes are fully three-dimensional and require a direct coupling of all relevant processes especially between momentum exchange and local density-gradients. Based on a local density-dependant approach, the near-field spreading of disposal-induced turbidity-plumes can be qualitatively well reproduced. The disposal process is implemented by means of an abstracted initial condition. A proper numerical representation of the overall hydrodynamic situation is very important. This in particular applies for estuarine environments, where wide area density effects like vertical gravitational circulation have major influence on the flow- and sediment-transport situations.

Measurements in the extended nearfield of disposal-induced turbidity are compared to numerical simulations. The results are in good agreement and confirm the validity of the initial sediment disposal assumption. The model-approach allows predictions of the near-field spreading as well as the long-term fate of disposed matter.
For the latter case field measurements for comparison purposes are hard to get because of the difficulties regarding the discrimination of disposed matter against the natural sediment in the farfield. SMOR3D can help to improve economical and ecological aspects of off-site disposal of dredged matter.

REFERENCES

Dyer, K.R. (1973). *Estuaries: A Physical Introduction,* John Wiley & Sons, London New York Sydney Toronto, A Wiley-Interscience Publication.

Dyer, K.R. (1986). *Coastal and Estuarine Sediment Dynamics,* Wiley-Interscience, New York.

Mewis, P. (2002). Morphodynamisch-numerische Modellierung von Flusskurven, Mitteilungen des Institutes für Wasserbau und Wasserwirtschaft, Technische Universität Darmstadt, Heft 126 (in German).

Orton, P.M. and Kineke, G.C. (2001). "Comparing Calculated and Observed Vertical Suspended Sediment Distributions from a Hudson River Estuary Turbidity Maximum". In: *Estuarine, Coastal and Shelf Science,* 52(3).

Riethmüller, R. et al. (1988). "Hydrographic Measurements in the Turbidity Zone of the Weser Estuary". In: *Physical Processes in Estuaries,* edited by J. Dronkers and W. van Leussen, Springer Verlag.

Riethmüller, R, Wurpts, A. and Mewis, P. (2004). „Tide Dependent Dispersion of Dumped Material in the Outer Weser Estuary", *Proceedings of the Ninth International Symposium on River Sedimentation (9th ISRS).* Yichang, China, 2004.

Riethmüller, R. (2005). Datenbericht für den F&E-Auftrag "Baggergut", GKSS Forschungszentrum Geesthacht, Institut für Küstenforschung, 2005 (in German).

Smith, J.D. and McLean, S.R. (1977). "Spatially averaged flow over a wavy surface". *Journal of Geophysical Research,* 82, 1735-1746, 1977.

Wellershaus, S., (1981). "Turbidity Maximum and Mud Shoaling in the Weser Estuary". *Archive of Hydrobiology,* Vol. 92, pp. 161-198.

Witte, G., Land, J. and Kirby, R., (1996). Untersuchungen zur Baggergutausbreitung und Wassergüte nach Umlagerung vor Wittenbergen – Kurzzeitausbreitung, Gutachten für die Freie und Hansestadt Hamburg Wirtschaftsbehörde, Amt für Strom- und Hafenbau, SB 224/95 SF (in German).

Van Leussen, W. (1988). "Aggregation of particles, Settling velocity of mud flocs: A Review". In: *Physical Processes in Estuaries,* edited by J. Dronkers and W. van Leussen, Springer Verlag.

Van Rijn, L.C. (1993). *Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas.* Aqua Publications, Amsterdam, the Netherlands.

Van Rijn, L.C. (1994). "Sediment Pick-Up Function". *Journal of Hydraulic Engineering,* Vol.110, No. 10.

Witte, G. (1996). Untersuchungen zur Baggergutausbreitung und Wassergüte nach Umlagerung vor Wittenbergen – Kurzzeitausbreitung, Bericht SB 224/95 SF, Amt für Strom- und Hafenbau Hamburg, (in German).

Zanke, U. (1982). *Grundlagen der Sedimentbewegung.* Springer Verlag, Berlin, Heidelberg, New York (in German).