Reduction of Harbor Sedimentation at a Tidal River

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Abstract

Sedimentation in harbors at a tidal river cannot be avoided due to the tidal effect. But even limited reductions can reduce maintenance dredging costs and in case of contamination also reduce cost for deposition or processing to avoid environmental hazards. For the main basin (Neustadt Harbor) of the Port of Bremen at the tidal part of the Weser River the hydrodynamic situation was simulated, using the 2D RMA2 model. Exchange of sediment loaden waters entering the harbor basin could be significantly reduced in critical navigation areas with flow guiding installations. Reduction of sedimentation could be verified using the sedimentation modul SED2D

Introduction

Many ship landings and harbors are located at tidal rivers, where sediment transport and deposition of very fine (silt) and coarser sediments (sand) are major factors for maintenance of harbors and approaching channels. Increasing size and draft of ships, tight scheduling and high operational cost require permanent and safe approaches and berthing areas, which means independence of bed morphology and channel alignments changing with erosion and deposition of unavoidable sediments.

To understand the process of harbor sedimentation at tidal rivers it is important to know the dynamic behaviour of the tidal environment and resulting hydrodynamics, also influenced by variing discharges from the non-tidal part of the up-river system. Tidal harbors with their mostly rather complicated geometrical structure of basins and channels act as sinks and sources for sediments, i.e. transport of suspended material and bed load.

Dredging activities to keep harbors and rivers navigable result in large amounts of often contaminated materials, which are difficult and costly to dispose.

Port of Bremen at the Weser Estuary

The Port of Bremen, located at the upper end of the Jade-Weser estuary (Fig. 1) at the southern North Sea coast is one of the major ports of Germany with a throughput of 11.5 Mio tons annually. Navigation on the 70 km long Lower Weser river, which represents the inner part of the Weser estuary between Bremen and Bremerhaven and which has been continuously deepened and widened within the fairway over more then 110 years, allows ships to approach with a draft of up to 9 m at tidal low waters. Sediment intrusions into the various harbor basins require annual dredging of around 700,000 m^3 of sediment, to be disposed on land after separation and specific treatment of the various contents and fractions.

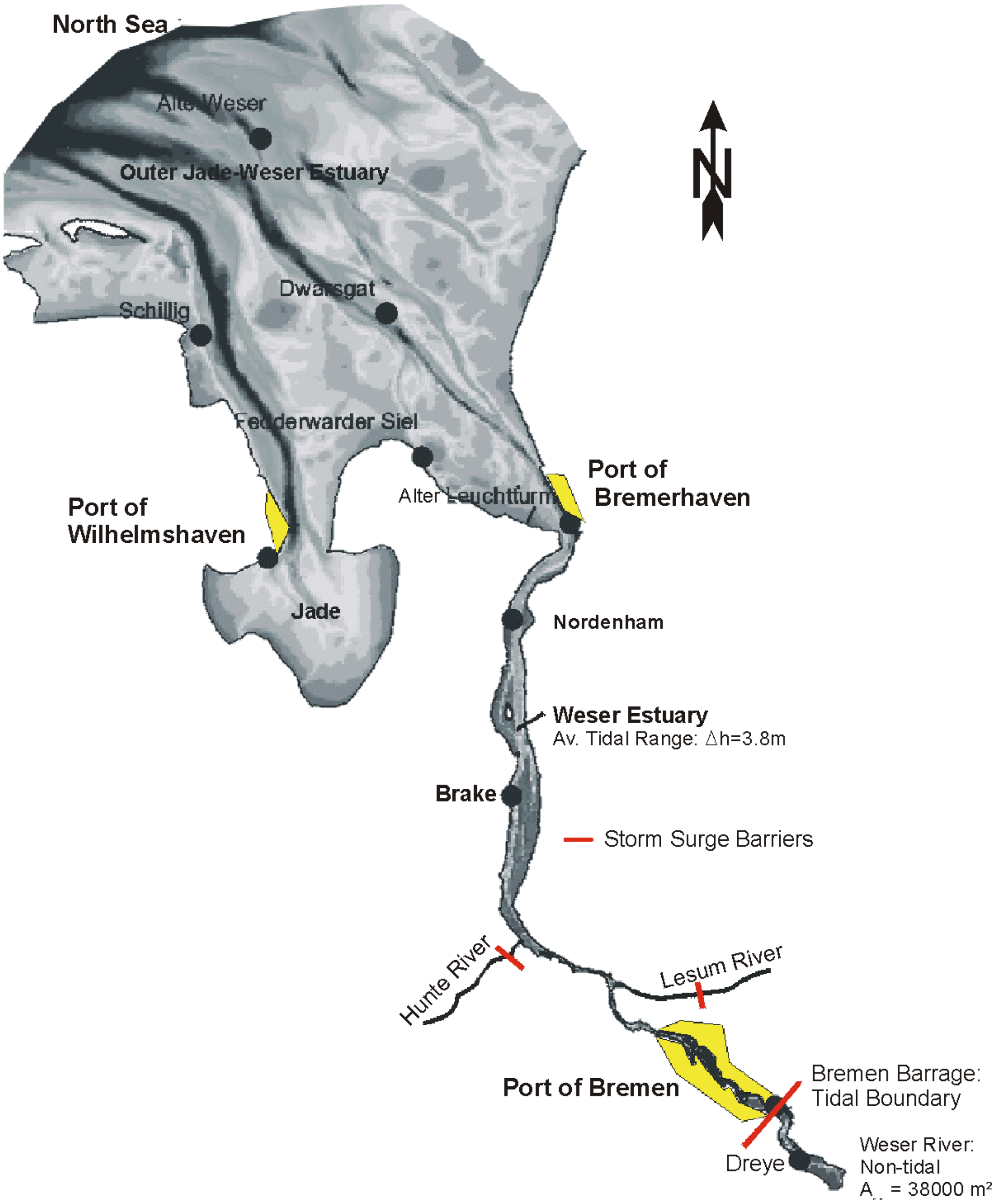


Figure 1: Weser Estuary and Port of Bremen

The non-tidal part of the river Weser, which collects the run-off of 38.000 km², is separated from the estuary by a barrage in the south-east of Bremen.

Tides are semidiurnal and asymmetric. The mean tidal range is about 3.8 m at Bremerhaven and above 4 m at Bremen. The long-term mean river discharge recorded about 30 km upstream from the tidal barrage at gauge "Intschede" is about 320 m^3/s. The long-term minimum is $Q = 120\ m^3/s$ and maximum is $Q = 1200\ m^3/s$. Sediment discharges from upstream vary from 10 kg/s to 310 kg/s (Fig. 2).

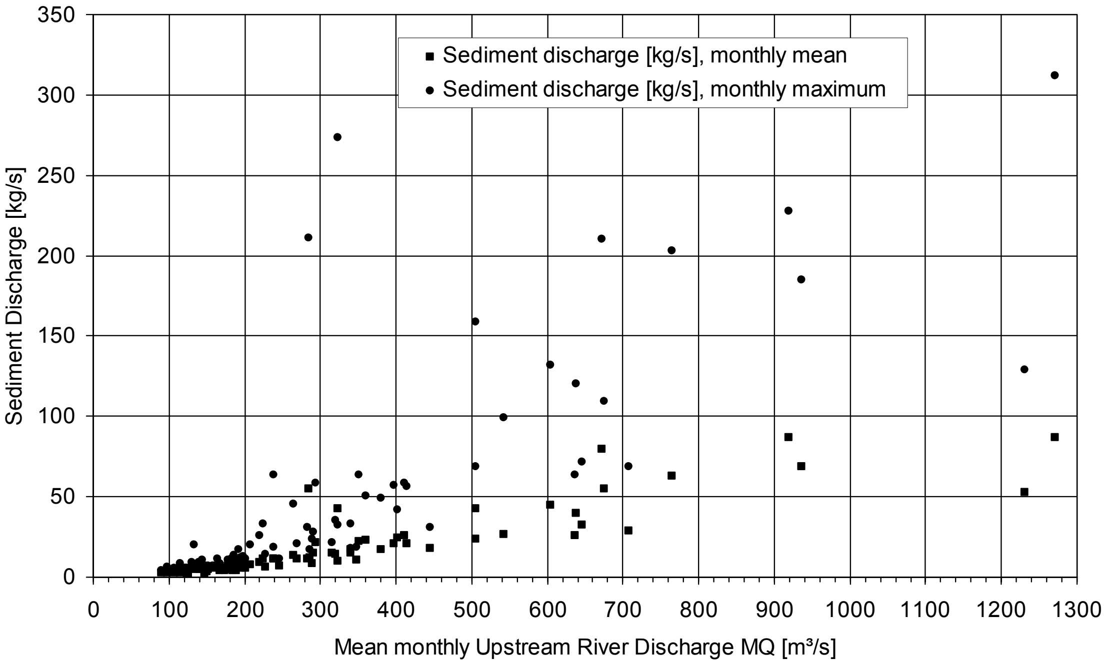


Figure 2: Upstream Sediment Discharge in the Weser River
(DEUTSCHES GEWÄSSERKUNDLICHES JAHRBUCH 1990 BIS 1996)

Problem Analysis

The Port of Bremen has a dock harbor system and a number of harbor basins with direct access to the Weser River and thus is affected from its discharges and tidal behaviour (Fig. 3).

The largest and most important basin is the Neustadt Harbor basin in the south-west. Here maintenance dredging of upto 350.000 m³/a is necessary in order to have continuous access for berthing ships with 9 m draft.

Sedimentation is unevenly distributed over the basin and may reach over 200 cm/a in certain areas (Fig. 4). Sediments reach from very fine silts <0,01 mm to fine sands ~0,1 mm.

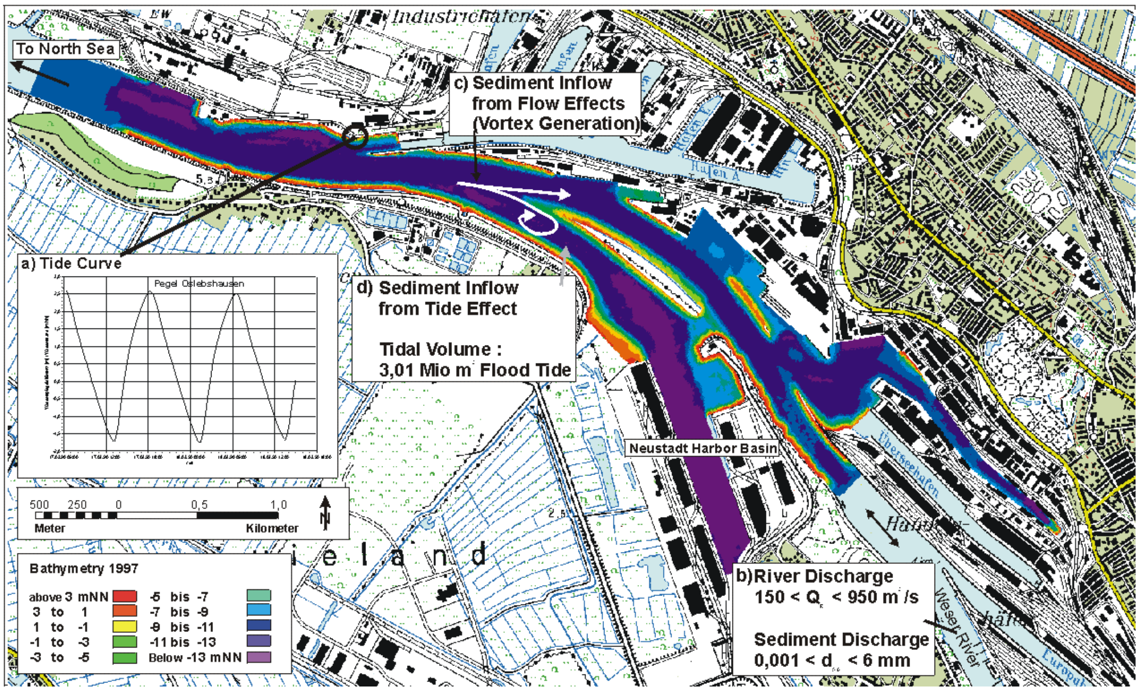
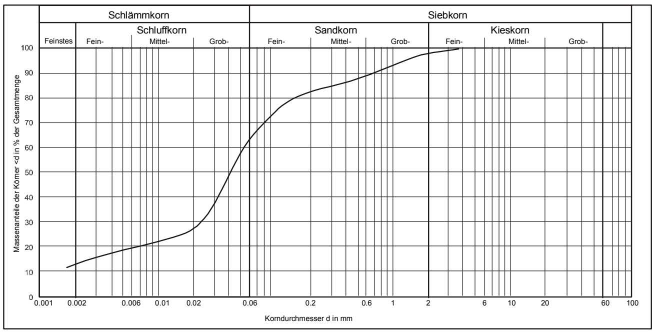


Figure 3: Port of Bremen with Area of Investigation (Neustadt Harbor Basin) and Hydraulic Boundary Conditions

Sieve Curve from inner Harbor



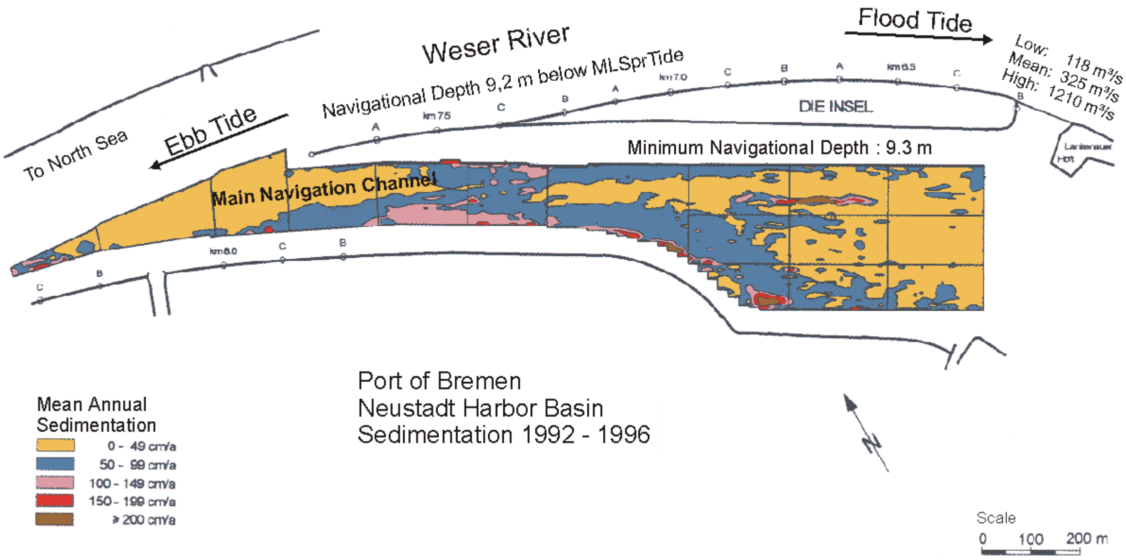


Figure 4: Sedimentation in Neustadt Harbor Basin, Port of Bremen

There are two reasons for this heavy sedimentation. The first but only minor sediment intrusion originates from the flow induced water exchange and from this resulting vortex generation in the harbor entrance (Fig. 5).

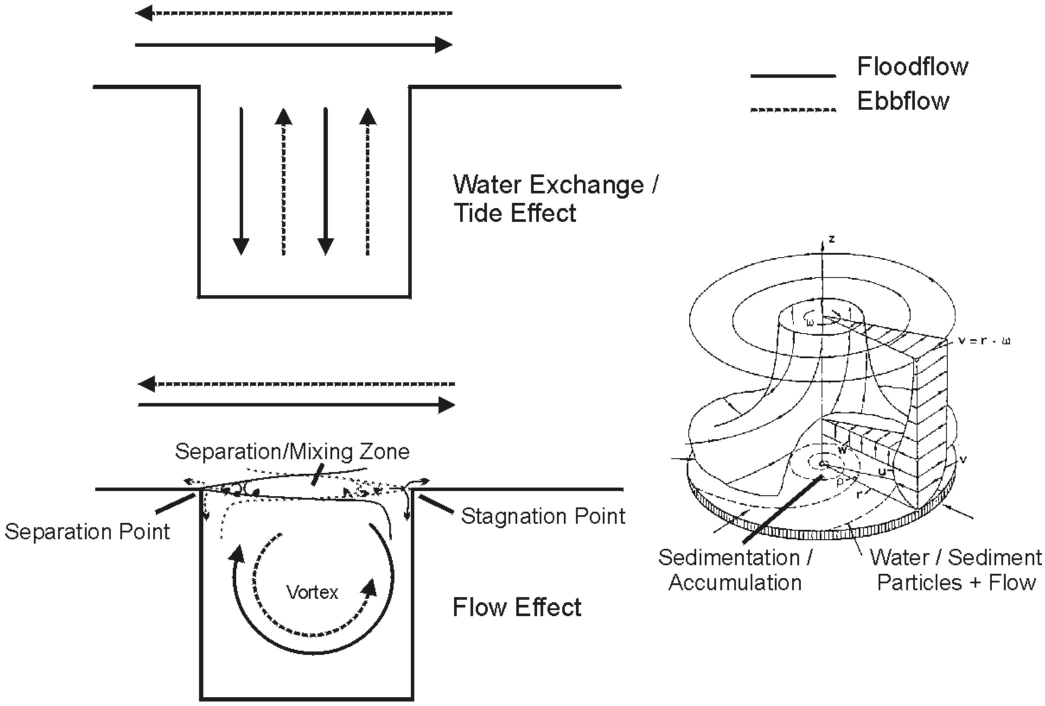


Figure 5: Flow Induced Vortex Generation in a Harbor Entrance and Tide Effect

The second and more sediment producing effect comes from the continuous exchange of sediment loaden waters from the river due to rising tides, the so called tide effect. For Neustadt Harbor Basin the average tidal volume flowing in and out twice a day is appr. 3.2 Mio m³, with sediment concentrations variing according to upstream river discharges (see Fig. 2).

Solutions for reductions in maintenance dredging therefore can only come from a reduction in flow induced water exchanges between river and harbor and a concept for guidance of inflows and sedimentation so that access to berthing areas is secured.

Numerical Model and Calibrations

To simulate the situation and various solutions, a hydrodynamic-numerical model has been installed, using the 2-dimensional Surface Modelling System SMS with the Algorithms RMA2 from Resource Management Associates (Hydrodynamic Modelling), both of which are developments from the US Army Corps of Engineers (1997), together with the Sedimenttransportmodel SED2D (Roig, 1998). The model area is shown on Fig. 6. To simulate the rather sophisticated bathymetry a combined triangular/quadratic mesh with element sizes from 25 to 3200 m² with an overall of 16078 elements, was applied.

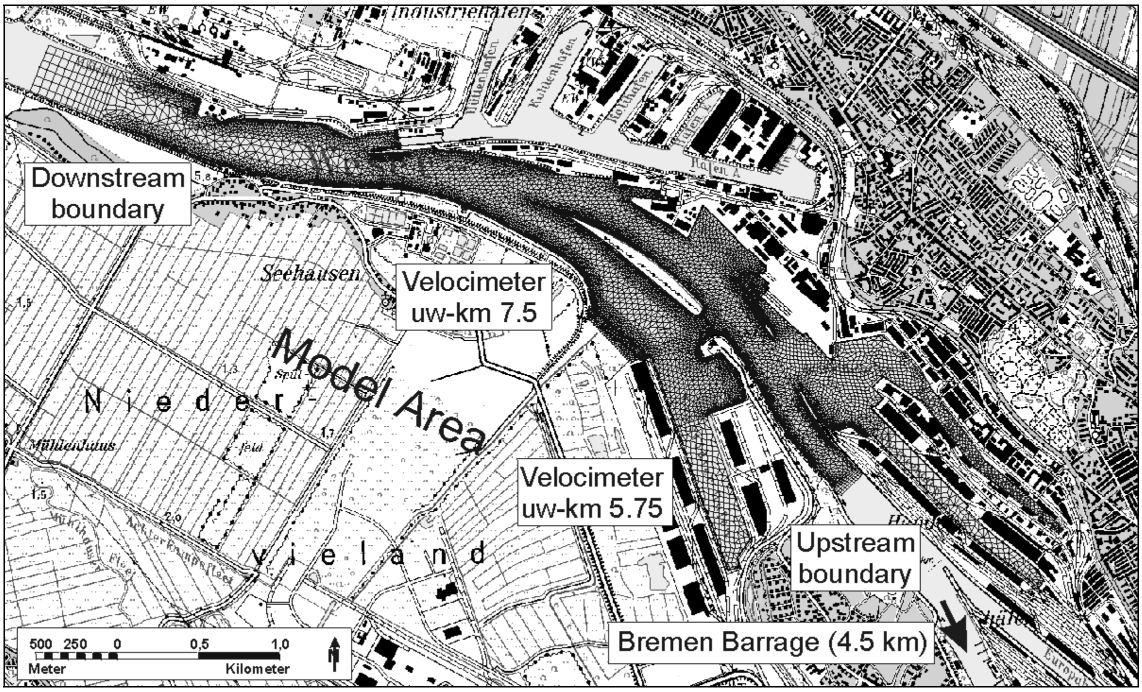


Figure 6: Model Area and used FE-Mesh (RMA2/SED2D: combined triangular/quadratic mesh, element size 25 – 3200 m^2, 16078 elements)

Calibrating the model with local water level and flow velocity measurements shows good agreement, i.e. water level deviations less than 2 cm, negligible deviations in peak levels and current flow velocities and direction, (Fig. 7a, 7b).

Area	Peclet-Number [-]	Manning-Number [-] (d < 2 m)	d > 2 m
River	20	0.030	0.030
Harbours	20	0.030	0.025
Embankments	20	0.030	0.035

Table 1: Model Parameters after Calibration and Validation (RMA2)

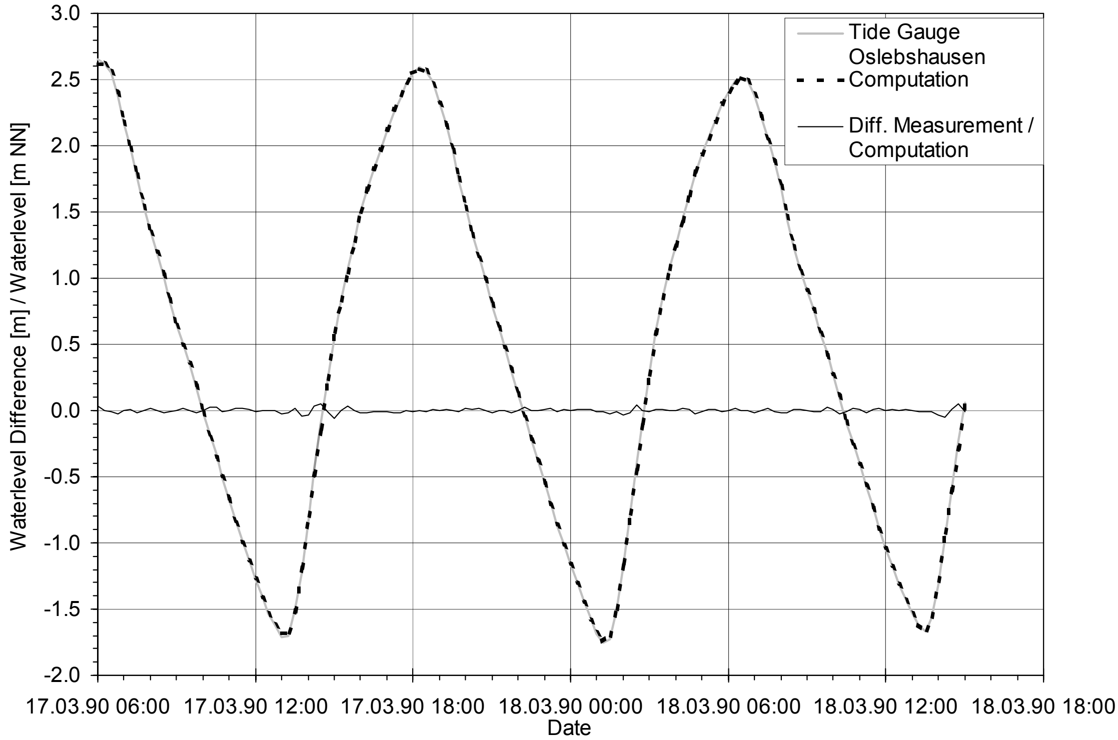


Figure 7a: Measured and Computed Tidal Water Levels

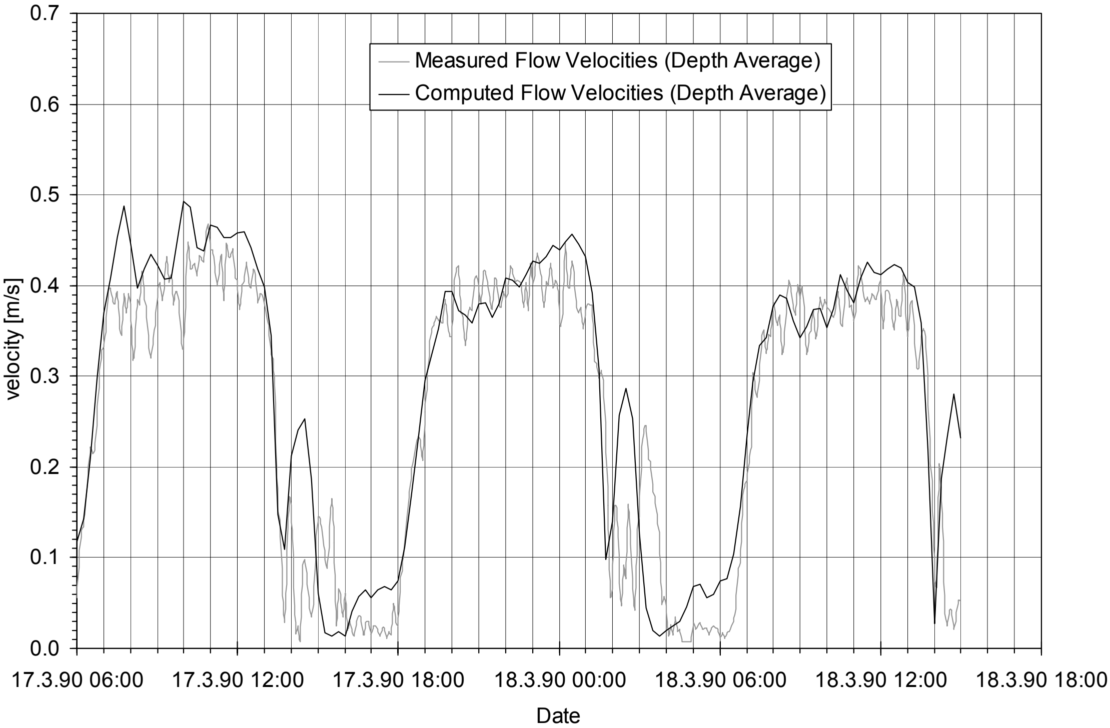
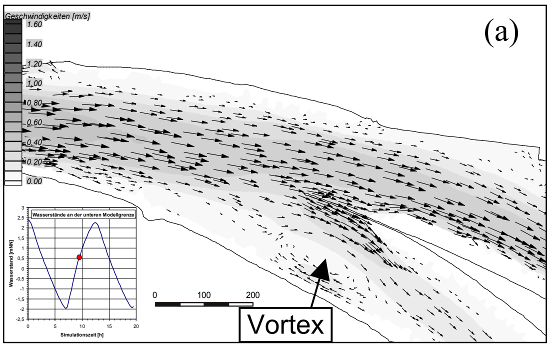
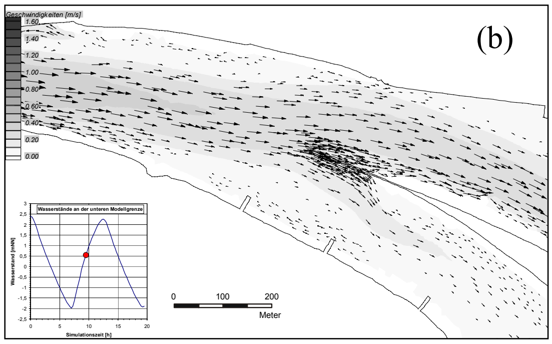


Figure 7b: Measured and Computed Flow Velocities and Directions

Reducing River Flow Induced Sediment Intrusion

To reduce exchange of flows between Weser River and Neustadt Harbor Basin the basic approach is the destruction or reduction of the large entrance vortex with its center as major spot for sedimentation as induced by the passing extended flood flows (Fig. 8a).





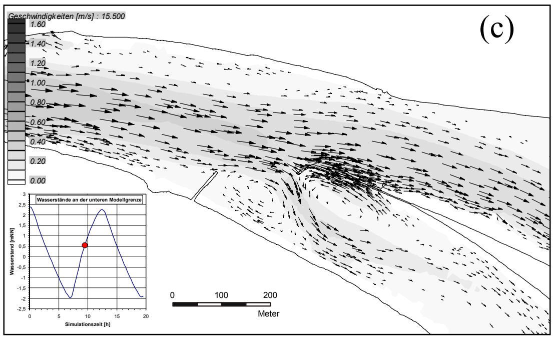


Figure 8: Flood Flow Situation for a River Discharge of Q = 150 m^3/s at Gauge "Intschede": (a); (b) Placement of 3 Groines; (c) Reduction of Harbor Entrance Width

Reducing the entrance width and thus the length of flow contact with the harbor induces two smaller vortices, shifting the areas for sedimentation outside the main navigation channel, (Fig. 8b). However, pilots objected because of the limited entrance width.

Trying a number of different solutions with groynes at the southern bank it finally turned out that 3 groynes, shifted to the inner harbor and with a distrance of 200 m, showed only small vortices near the banks and outside the navigation channel (Fig. 8c). Flow velocties in the navigation channel are increased with the chance for reduced settling and increased erosion in this part of the harbor basin. This solution therefore was recommended and adapted for simulations in the sediment transport model.

Simulation of Sediment Intrusion

Simulating intrusion of sediments from the Weser River into Neustadt Harbor basin with SED2D was done for silt fractions (d_{50} = 0.018 mm) and sand (d_{50} = 0.10 mm), as it was found in samples from the basin, and for 4 different river discharges (Q_R = 150; 350; 650; 950 m³/s) superimposed to the tidal flows. Table 2 shows the model parameters as applied.

	Sand Fraction (d_{50} = 0.10 mm)	Silt Fraction (d_{50} = 0.018 mm)
sand grain size for transport [m]	0.08	-
sand grain size for roughness [m]	0.5	-
crit. depos. shear stress [N/m^2]	-	0.06
crit. erosion shear stress [N/m^2]	-	0.06
dispersion coeff. in x/y[m^2/s]	5.0/5.0	-
diffusion coeff. in x/y [m^2/s]	-	1.0/1.0
initial boundary conc. [g/m^3]	8/11/16/20*	10/20/40/60*
mean settling velocity [m/s]	0.007	0.00015

* for discharges 150; 350; 650; 950 m^3/s

Table 2 Sediment Transport Parameters after Calibration/Validation

While intrusion of sand can be neglected (5 % of total compared to silt) efforts were focused on silt behavior in the harbor basin (Fig. 9a, 9b).

Analysis of the various areas in the Neustadt Harbor basin (Fig. 10) shows considerable differences in sedimentation distribution (Table 3). There is a shift of sedimentation to the south due to the 3 groynes. In addition, increased inflow and outflow velocities and suppressed entrance vortices prevent significant amounts of silt from sedimentation, i.e. up to 26 % reduction in the vital central basin areas.

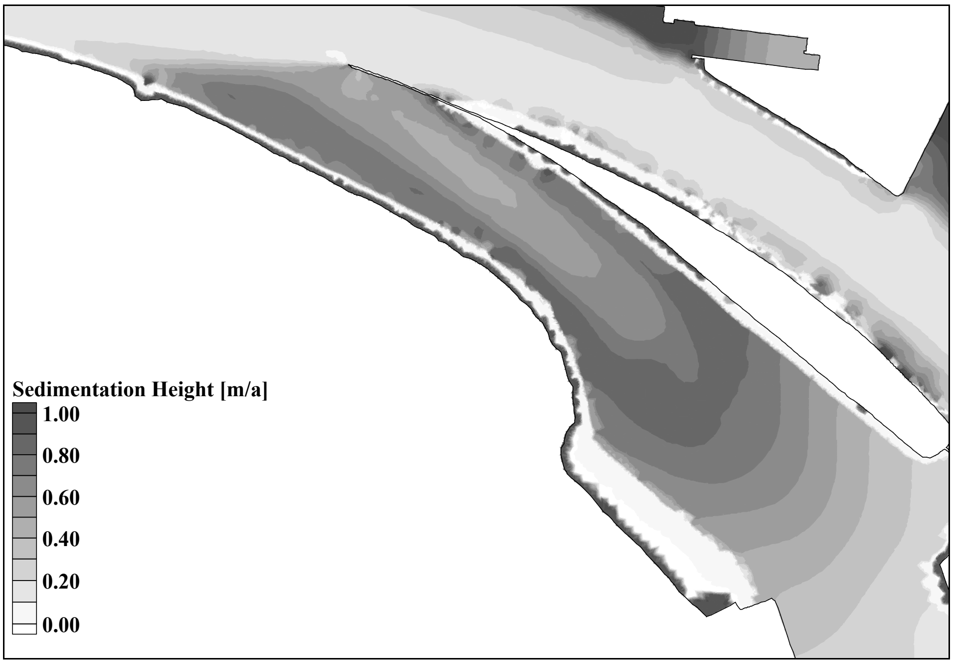


Figure 9a: Silt Sedimentation after one Year in Neustadt Harbor Basin (Initial Situation)

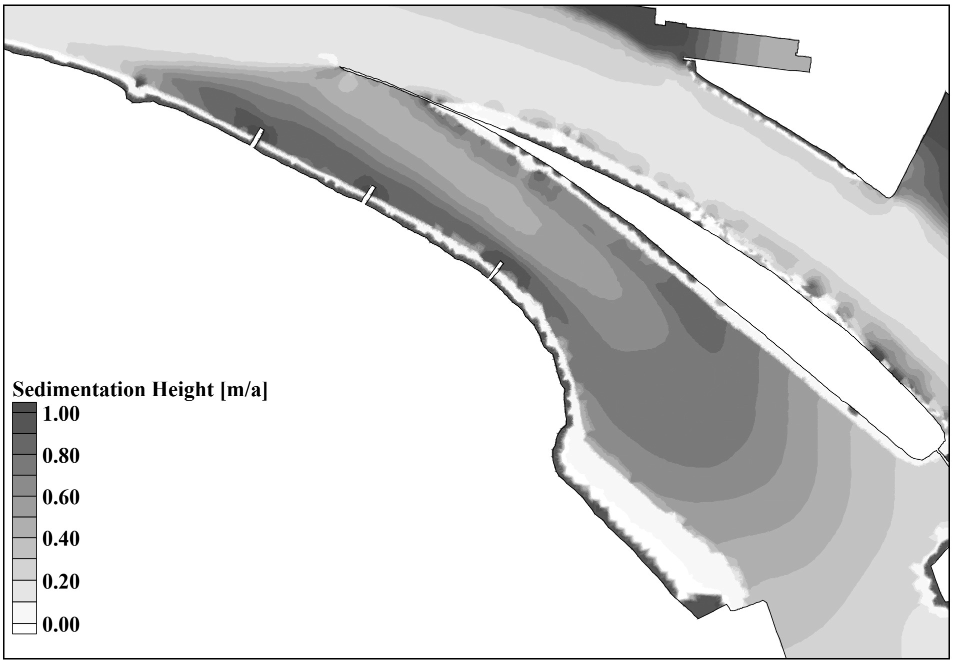


Figure 9b: Silt Sedimentation after one year in Neustadt Harbor Basin
(3 Groynes at South Bank)

Area		Sedimentation height [m/a]		Sedimentation Volume [m³/a]		Changes in Sedimentations / Sand-Fraction		Changes in Sedimentations / Silt-Fraction	
		Sand	Silt	Sand	Silt	[m^3/a]	[%]	[m^3/a]	[%]
I	North	0.12765	0.50478	3036	12007	-	-	-	-
		0.12789	**0.46535**	**3042**	**11069**	**6**	**0.2**	**-938**	**-7.8**
	Center	0.14013	0.66019	5419	25529	-	-	-	-
		0.14201	**0.64528**	**5492**	**24953**	**73**	**1.3**	**-576**	**-2.3**
	South	0.04402	0.57967	1778	23417	-	-	-	-
		0.04515	**0.64874**	**1824**	**26208**	**46**	**2.6**	**2791**	**11.9**
II	North	0.01478	0.55146	760	28352	-	-	-	-
		0.01478	**0.52196**	**760**	**26836**	**0**	**0.0**	**-1516**	**-5.3**
	Center	0.02822	0.62560	1614	35784	-	-	-	-
		0.02812	**0.60662**	**1608**	**34699**	**-6**	**-0.3**	**-1085**	**-3.0**
	South	0.00969	0.54820	405	22927	-	-	-	-
		0.00950	**0.54702**	**397**	**22877**	**-8**	**-2.0**	**-50**	**-0.2**
III		0.00553	0.36127	1606	104918	-	-	-	-
		0.0055;3	**0.34177**	**1605**	**99255**	**-1**	**-0.1**	**-5663**	**-5.4**
Total				14618	252935	-	-	-	-
				14729	**245896**	**111**	**0.8**	**-7066**	**-2.9**

normal – "Initial Situation"; **bold - " 3 Groynes"**

Table 3: Effects of Groynes on Sedimentation Distribution and Total Sediment Intrusion after one year

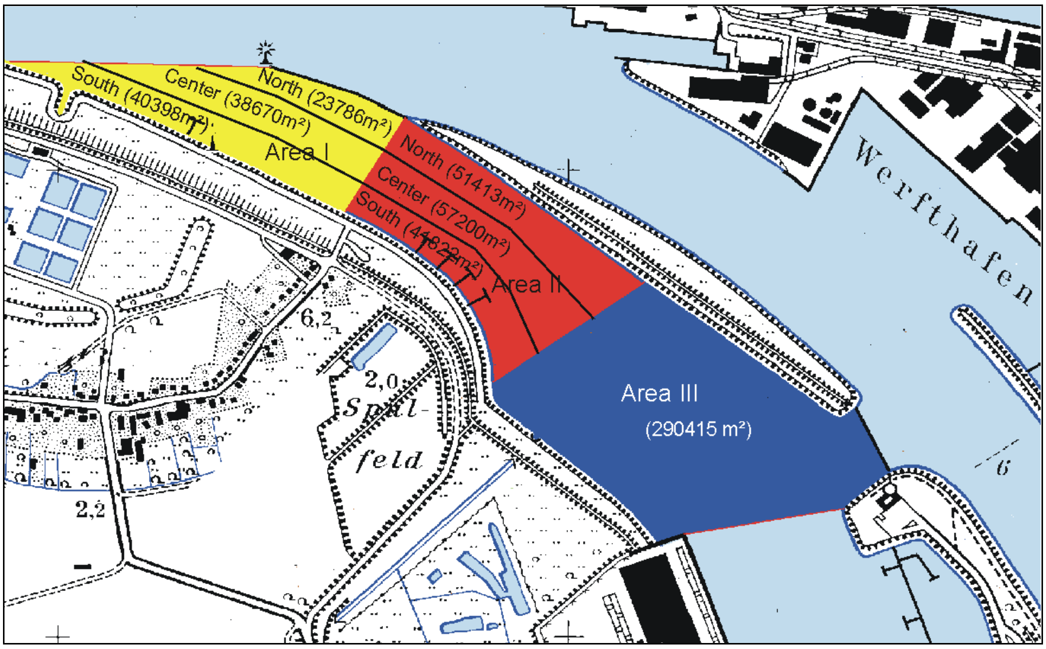


Figure 10: Sedimentation Areas in Neustadt Harbor Basin

Conclusion

Analysis and simulation of flows and sedimentation into a harbor basin of the Port of Bremen shows that,

- major sediment intrusions occur during high river discharges superimposed on the tidal flows;
- a total of over 350,000 m³ of sediment is intruded into the harbor basin per year;
- effect from suppressing the entrance vortex on sedimentation is marginal by shiftings to south bank;
- reduction of sedimentation from tide effects (2 x 3.2 Mio m³ per day) due to positioning of 3 groynes at south bank results in 26 % of reduced dredging and deposition costs;
- reduction in dredging and deposition costs in berthing areas is above 5 %.

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