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. 71-76

Total volume concentration and size distribution of suspended matter at sites affected by water injection dredging of subaqueous dunes in the German Weser Estuary

Svenja Papenmeier[1], Kerstin Schrottke[1] & Alexander Bartholomä[2]

[1]Institute of Geosciences and Cluster of Excellence 'Future Ocean', Kiel University, Germany
[2]Senckenberg Institute Wilhelmshaven, Germany

Abstract

A laser based in-situ particle sizer (LISST) was used to analyse spatial and temporal variability of total volume concentration (TVC) and particle-size distribution (PSD) of suspended particulate matter (SPM) during water-injection dredging (WID) of subaqueous dunes in the German Weser estuary. Ground-truthing was done by water sampling. Investigated WID sites are located in the brackish and freshwater zone, respectively. Measurements were conducted in June 2008, during neap tides and low river-discharge. TVC of SPM is tidal controlled. Site-specific differences of SPM amount and sizes are recognisable, but dredging impact is hardly visible in the data.

1 Background and Motivation

Migrating subaqueous dunes are well known features of estuarine systems. Consequently, cost-intensive sediment dredging is frequently ongoing in estuarine navigation channels to guarantee save ship access. Interest is given to dredging techniques, which reduce maintenance costs such as water-injection dredging (WID), which was introduced in the eighties. Since then, worldwide operation has widely been increased (Meyer-Nehls et al. 2000). During WID, huge amounts of water are pumped from the river surface to a dredging sledge, equipped with jets injecting water into the sediment surface. Pumping capacity and water pressure can mostly be adapted to bed characteristics. Cost-intensive sediment transfer to dumping sites is redundant. Efficiency of WID has been proven for muddy (Aster 1993, Woltering 1996) and sandy deposits (Clausner 1993, Nasner 1992). It has been frequently used in harbours (Spencer et al. 2006) and in navigation channels (Stengel 2006). So far, only few studies deal with dredging-induced dispersal and behaviour of SPM. Investigations in Hamburg and Emden harbor (Germany) have shown, that dredging induced increase of suspended sediment concentrations (SSC) only occurred over a distance of 100 m (Meyer-Nehls et al. 2000) and 200 m (Aster 1993), respectively. Vertical intrusion did not exceed 1-2 m in height above the riverbed, as found in Hamburg harbor (Meyer-Nehls et al. 2000). So far, WID-induced changes in PSD of estuarine SPM are not known. Mikkelsen & Pejrup (2000) reported on dredging-related changes of PSD in the Scandinavian, non-tidal Øresund. Due to particle flocculation, size spectra changed from fine, poorly sorted to coarse, moderately sorted particles with increasing distance from the dredging device.

2 Objectives

This study focuses on potential changes of TVC and PSD during WID of subaqueous dunes in the navigation channel of the Weser estuary to assess spatial and temporal related dredging impact on estuarine suspended sediment dynamics. Two sites are chosen to verify differences linked to brackish or freshwater conditions.

3 Study area

The meso- to macro-tidal Weser estuary is located at the German North Sea coast (figure 1).

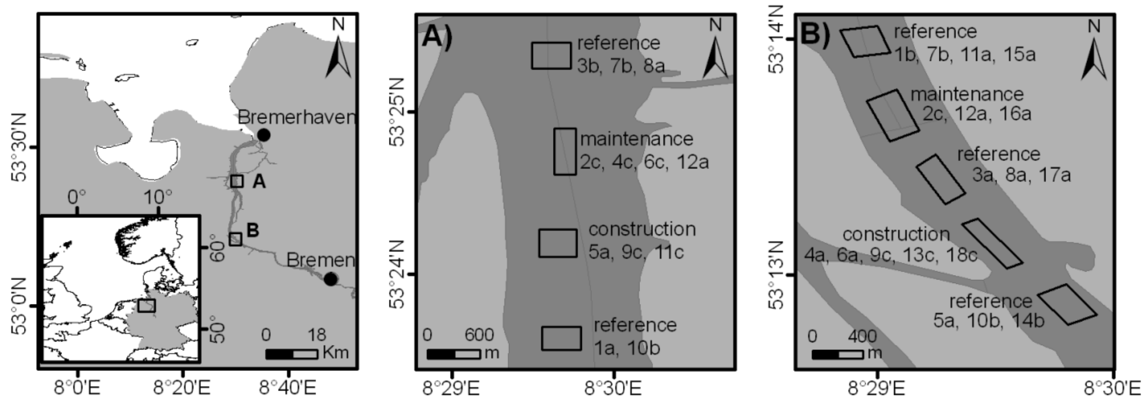

Figure 1: Left: Overview of the Weser estuary with markings of the two sites A and B. Centre and right: study sites in detail with subsections.

Site A was located at the southern end of the brackish reach and of the turbidity maximum zone (TMZ) during the experiments (figure 1). Depending on tidal phase, meteorological conditions and freshwater discharge, this zone can be shifted further up or down-stream (Grabemann & Krause 2001). The water column is well mixed due to tidal flow velocities of 1-1.3 m/s on average. SSC can reach values of up to 1.5 g/l in the water column of the TMZ (Grabemann & Krause 1989, 2001) with increasing values in the near-bed zone (Schrottke et al. 2006). Spatial distribution of SSC strongly depends on the tides. Whereas SPM is well distributed during ebb and flood phases, particle settling starts with decreasing tidal flow. Large particle aggregates of > 100 µm are formed (Wellershaus 1981).

Site B represents the freshwater reach (figure 1). Tidal currents, which amount to 1 m/s, are slightly lower (Schuchardt et al. 1993). SSC is mainly controlled by riverine input. Generally, SSC values do not exceed 0.05 g/l in the tidal dominated freshwater zone (Grabemann & Krause 2001, Schuchardt et al. 1993). Tidal induced SSC variation is less pronounced.

Riverbed morphology in the channel sections of both sites is characterised by subaqueous dunes of up to 6 m in height and of up to 150 m in length (Schrottke et al. 2006). The dunes are mainly two- or three-dimensional, lateral orientated to the main flow direction in the navigation channel and reflect ebb dominance (Schrottke et al. 2006). Dunes are mainly consist of medium-sized sands (Stengel 2006). Dune morphology and grain-size composition are frequently impact by dredging.

4 Material and Methods

In-situ PSD is detected by laser diffraction with a 'Laser In-Situ Scattering & Transmissometry' system LISST-100x (type-C, Sequoia® Scientific Inc.). A collimated laser beam is scattered at small particles in the water column and processed at a multi-ring detector. PSD is displayed in 32 logarithmically-spaced size classes, ranging from 2.5 to 500 µm (8.6 to 1.0 Phi). Particles beyond the measuring range are assigned either to the finest or largest size class, respectively (Agrawal & Pottsmith 2000). This can cause rising tails at the boundaries. There is no option for differentiation between particles and air bubbles. PSD is presented as volume concentration (VC) of each size class, summed-up to TVC. This is related to optical transmission (τ) detected with a photodiode. Multiple scattering can appear at $\tau < 0.3$, which leads to an overestimation of small particles (Agrawal & Pottsmith 2000). A path reduction module (50 %) was installed to reduce the optical path length and thus the sample volume. Checking the overall health of the instrument and in order to correct for optical attenuation by water and microscopic imperfections on the optical surfaces, a background scattering was acquired in the morning of each measuring day. A full technical description of the LISST is done by Agrawal and Pottsmith (2000) and Agrawal et al. (2008). The LISST was applied from a drifting vessel in profiling mode down to the near riverbed. Minimum distance between dredging and research vessel amounted to ~30 m.

TVC calibration was done by horizontal water sampling (2.2 litre, Hydro Bios©), at two different water depth. In the laboratory, an aliquot of defined volume was vacuum-filtered (glass-fibre filters, 1.2 µ). The filters were dried at 60°C for 12 hours. SSC was calculated by dry mass per unit sample volume.

Measurements were done on 10 June 2008 at site A and on 24 June 2008 at site B under low river discharge (180 m³/s, Water & Shipping Authority Bremen, pers. comm.) and neap tides. Both sites were subdivided in 4-5 subsections, representing the type of dredging impact such as maintenance or constructional work or unaffected subsections (reference), displayed in figure 1. All subsections exhibited comparable hydrodynamics and sedimentology. Profile indexes indicate relation of measuring position to WID: a) luv-site, b) lee-site c) on-site.

5 Results

TVC and τ significantly correlate, as found at both sites with R^2=0.89 (figure 2). Overall, τ did not exceed 0.6, more often it decreased below 0.3, as found for 80 % and 15 % of all measurements, carried out at site A and B, respectively (table 1).

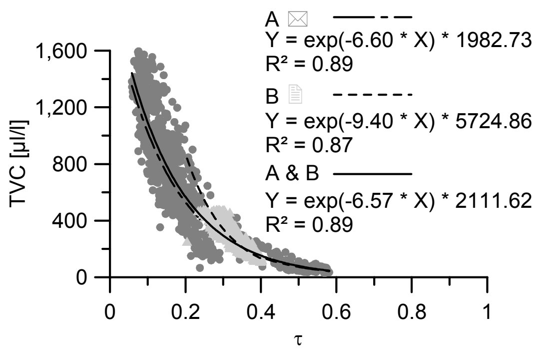

Figure 2: Correlation of optical transmission (τ) and TVC for site A and B

PSD changed within seconds from unimodal curves to the ones with rising tails at the coarse end of the size spectra. Depth-related changes of PSD and VC at site A are displayed in figure 3. Mean particles sizes range from 2.0 to 4.9 Phi (table 1) with a downward particle coarsening of 0.6 Phi on average as well as a slight increase of VC for size spectra > 8 Phi. A distinct development in mean particle size between the profiles is not obvious. Several times, water turbidity was announced to be too high before reaching the ground at subsections b and c without specific changes of TVC or particle sizes, as found by comparing measurements 7b and 8a in figure 3. At site B, mean particle-size range with 1.9 to 3.3 Phi (table 1) was slightly smaller, but again with no depth-related change (figure 4). Mean particle size only varied among the subsections.

Highest TVC at site A amounted to ~1,600 µl/l during slack-water ebb (figure 3: 7c, 8a) and ~470 µl/l for site B around slack-water flood (figure 4: 1b - 3a, 15a -18c). SSC values ranged from 22 to 320 mg/l and 26 to 128 mg/l at site A and B, respectively.

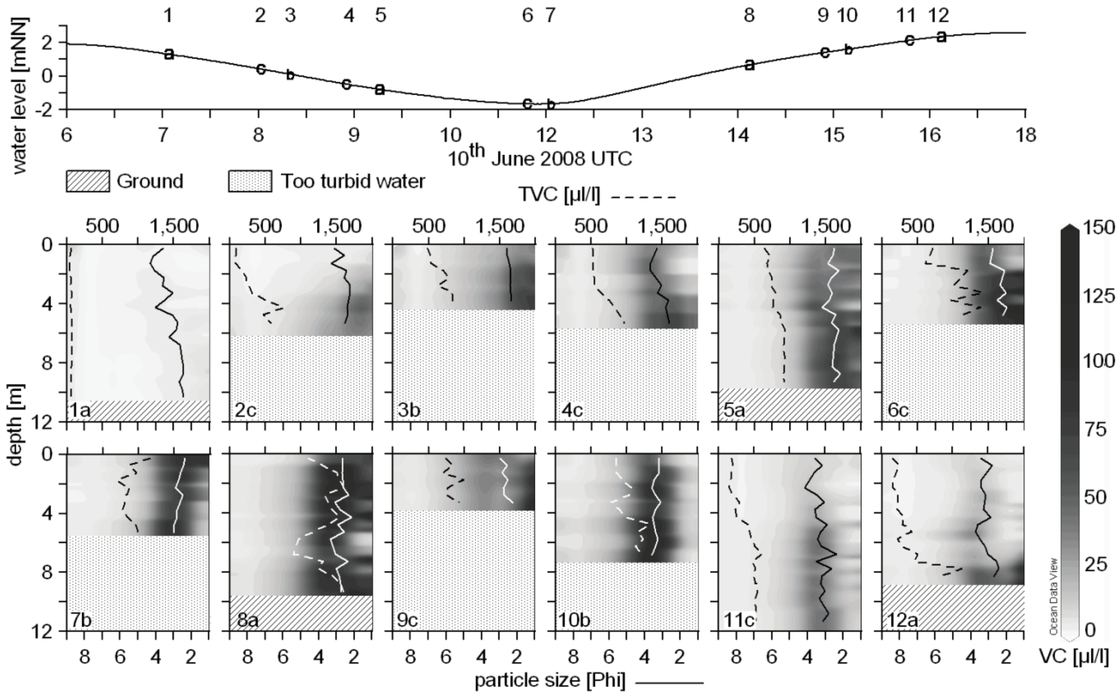

Figure 3: Depth-related VC and PSD at site A (brackish water zone). Solid curves represent mean particle size; dashed lines visualise TVC.

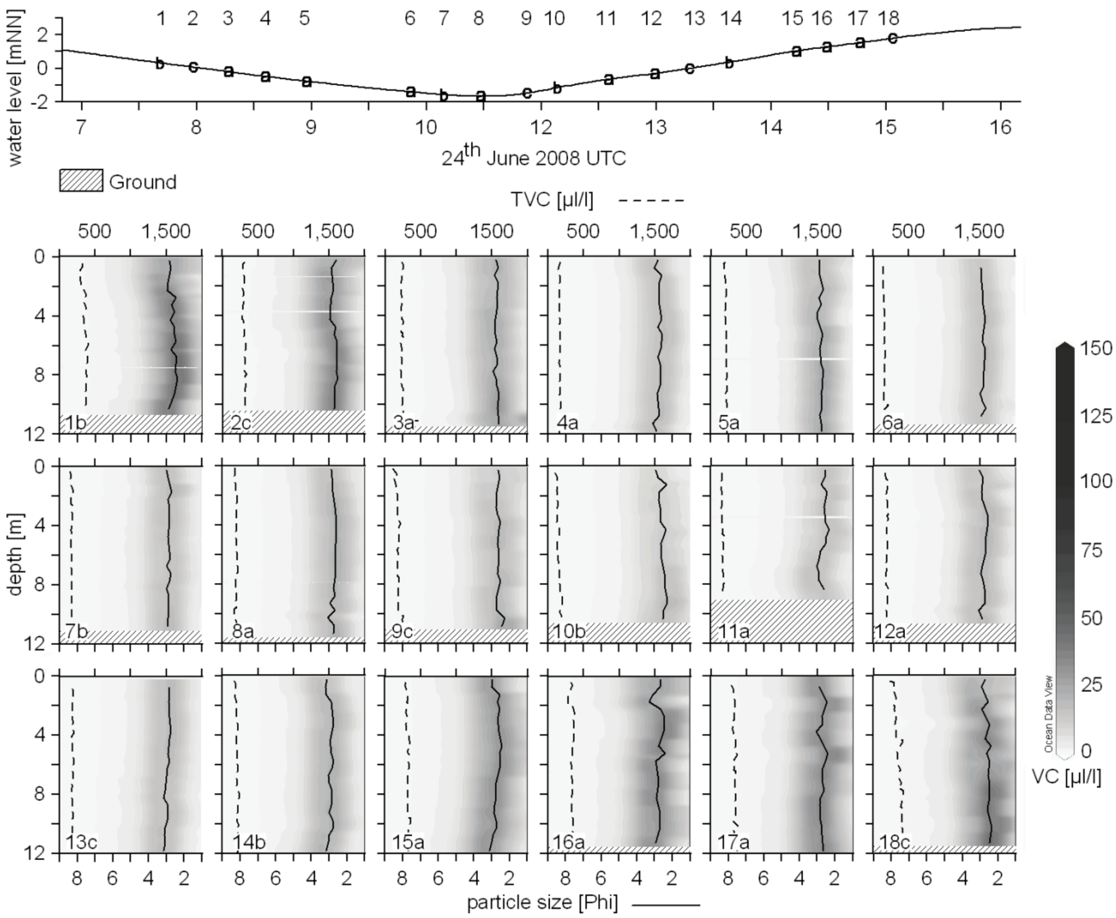

Figure 4: Depth-related VC and PSD at site B (freshwater zone). Solid curves represent mean particle size; dashed lines visualise TVC.

Table 1: Measured parameter at site A and B.

site	A				B			
	Ø size [Phi]	TVC [µl/l]	τ	SSC [mg/l]	Ø size [Phi]	TVC [µl/l]	τ	SSC [mg/l]
min	2.0	29.9	0.06	22	1.9	103.7	0.2	26
max	4.9	1598.4	0.58	320	3.3	469.4	0.4	128
Ø	2.9	650.2	0.22	113	2.8	239.2	0.3	47
τ < 0.3			80%				15%	

6 Discussion and conclusion

In the Weser estuary, suspended sediment dynamics are mainly controlled by tides and river-discharge. This is clearly reflected in data sets of TVC, PSD and SSC, especially at site A, which was located in the brackish zone, at the southern end of the TMZ. Whereas no clear indication of WID impact is given at site B, some dredging induced effects can be derived from data-sets of site A. It is assumed that WID induces temporary increase of near-bed suspended particles (Meyer-Nehls et al. 2000, Stengel 2006). Based on that, TVC must consequently increase. This might have caused repeated near-bed interruption of LISST measurements at site A during WID, where background TVC, SSC and mean particle size are side-specifically higher (brackish zone) as found at site B (freshwater reach). SSC did not rise simultaneously. This seems to be reasonable, taking into account that τ can also be considerably reduced by only few large particles or air bubbles (Mikkelsen & Pejrup 2000). Large particle-aggregates can enhance TVC without affecting mass concentration. Indeed, measured PSD indicated rising tails at the coarse particle-size spectra, repeatedly. Overall, it can be concluded that WID does not seem to have a significant impact on suspended sediment dynamics at the sites investigated with these methods.

References

Agrawal, Y.C. & H.C. Pottsmith (2000): Instruments for particle size and settling velocity observations in sediment transport. In: Marine Geology 168: 89–114.

Agrawal, Y.C., A. Whitmire, O.A. Mikkelsen & H.C. Pottsmith (2008): Light scattering by random shaped particles and consequences on measuring suspended sediments by laser diffraction. In: Journal of Geophysical Research 113: 11.

Aster, D. (1993): Der Einfluss von Wasseinjetionsbaggerung auf die Wassertrübung. In: Hansa 130: 64–65.

Clausner, J.E. (1993): Water injection dredging demonstration on the Upper Mississippi River. U.S. Army Corps of Engineers, Waterways Eperiment Station. Dredging Research, DRP-93-3.

Grabemann, I. & G. Krause (1989): Transport proccesses of suspended matter derived from time series in a tidal estuary. In: Journal of Geophysical Research 94: 14373–14379.

Grabemann, I. & G. Krause (2001): On different time scales of suspended matter dynamics in the Weser estuary. In: Estuaries and Coasts 24: 688–698.

Meyer-Nehls, R., G. Gönnert, H. Christiansen & H. Rahlf (2000): Das Wasserinjektionsverfahren: Ergebnisse einer Literaturstudie sowie von Untersuchungen im Hamburger Hafen und in der Unterelbe. Ergebnisse aus dem Baggeruntersuchungsprogramm 8: 111.

Mikkelsen, O.A. & M. Pejrup (2000): In situ particle size spectra and density of particle aggregates in a dredging plume. In: Marine Geology 170: 443–459.

Nasner, H. (1992): Injektionsbaggerung von Tideriffeln. In: Hansa 129: 195–196.

Schrottke, K., M. Becker, A. Bartholomä, B.W. Flemming & D. Hebbeln (2006): Fluid mud dynamics in the Weser estuary turbidity zone tracked by high-resolution side-scan sonar and parametric sub-bottom profiler In: Geo-Marine Letters 26: 185–198.

Schuchardt, B.,U. Haseloop & M. Schirmer (1993): The tidal freshwater reach of the Weser estuary: riverine or estuarine? In: Netherlands Journal of Aquatic Ecology 27: 215–226.

Spencer, K.L., R.E. Dewhurst & P. Penna (2006): Potential impacts of water injection dredging on water quality and ecotoxicity in Limehouse Basin, River Thames, SE England, UK. In: Chemosphere 63: 509–521.

Stengel, T. (2006): Wasserinjektionsbaggerung in der Unterweser: Eine ökologische und ökonomische Alternative zu Hopper Baggerung. PIANC Deutschland - Schifffahrt, Häfen, Waserstraßen, S. 204–208.

Wellershaus, S. (1981): Turbidity maximum and mud shoaling in the Weser estuary. In: Archiv für Hydrobiologie 92: 161–198.

Woltering, S. (1996): Einsatz eines Wasserinjektionsgerätes zur Hafenunterhaltung. In: Hansa 133: 62–66.

Acknowledgement

This study was funded by the Deutsche Forschungsgemeinschaft in the frame of the Cluster of Excellence‚The Future Ocean'. It was part of the interdisciplinary project 'Weser adaptation', coordinated by the Water & Shipping Authority (WSA) Bremen and Bremerhaven, together with other German partner institutions. Thanks are given to the WSA Wilhelmshaven for providing additional ship capacity and support as well as to all partners for the good cooperation.

Address

Svenja Papenmeier
University of Kiel - Institute of Geosciences
Cluster of Excellence: The Future Ocean, Sea-Level Rise & Coastal Erosion
Otto-Hahn-Platz 1
24118 Kiel, Germany

sp@gpi.uni-kiel.de