Project part-financed by the European Union (European Regional Development Fund)

The Interreg IVB North Sea Region Programme

Sediment Management Strategies in the Weser Estuary

– Study in the framework of the Interreg IVB project TIDE

Long version

In charge of the project:
Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency, Germany

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NLWKN

BIO CONSULT
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Project part-financed by the European Union (European Regional Development Fund)

Contents

Project part-financed by the European Union (European Regional Development Fund)
The Interreg IVB North Sea Region Programme

Figures and tables

Project part-financed by the European Union (European Regional Development Fund)

The Interreg IVB North Sea Region Programme

Project part-financed by the European Union (European Regional Development Fund))

The Interreg IVB North Sea Region Programme

1. Introduction

1.1 Background

The great importance of the TIDE project estuaries of the Elbe, Weser, Schelde and Humber for shipping and ports has led consistently to adaptations of the these (and other) estuaries to the requirements of increasing vessel sizes. This has led to considerable ecological deformations and impairments (regarding Elbe, Weser, Ems see amongst others SCHUCHARDT et al. 1993; 2007), which have been described several times and will be continued due to current deepening intentions. Securing the usability of the waterways requires partly substantial maintenance work including sediment relocations as well as river engineering measures like building of groynes. At the same time a great amount of the estuaries are part of the Natura 2000 Network due to their ecological relevance. Natura 2000 aims to build a European wide coherent network of conservation areas and develop it according to the conservation and maintenance goals. This is where corporate conflicts existed and still exist which have partly been taken to court.

Against the background of these conflicts, in particular by comparing the situation and the experience of the involved (as well as other) estuaries, the Interreg IV B Projects TIDE (Tidal River Development) aims to acquire practically orientated prospects and recommendations to reduce these conflicts.

One of the conflicts encompasses the sediment management in the estuaries, meaning the relocation of sediment to secure the water depth of the fairways with the goal of minimizing not only the effort but as well expenses while reducing the impact on environmental and nature conservation. As the concept for the "River Engineering and Sediment Management Concept for the Tidal River Elbe" demonstrates extensive synergies could generally be possible (HPA & WSV 2008).

1.2 Approach

As basis for a study which will compare all four estuaries of the TIDE project there are currently being compiled four studies regarding the respective sediment management. Within the TIDE project an outline proposal has been agreed upon to which the present study obeys as far as possible.

The study on the Weser estuary is based on data and information (written, telephone talk, conversations) provided by different institutions as well as existing reports and literature. Due to data provided from different organizations on a different level of aggregation and partly differing in regional and seasonal reference areas, which was not always completely documented and comprehensible, certain inconsistencies became apparent. After having consulted the owners of the regarding data inconsistencies could be solved to the greatest possible extent. Altogether, the compiled data does however provide an adequate overview of the specific situation regarding the sediment management in the Weser estuary.

2. Overview on the estuary and its ports

The Weser estuary encompasses the Lower and Outer Weser as well as the tide influenced tributaries Ochtum, Lesum, Hunte and Geeste. Kilometrage of the Weser estuary starts approx. at the tidal weir in Bremen-Hemelingen with Weser-km – 4 (see Fig. 1). The Lower Weser reaches from the weir in Bremen-Hemelingen to Bremerhaven at Weser-km 65 (corresponding kilometrage within the TIDE project: km 0–134). The Outer Weser stretches towards the North Sea and is ending at about Weser-km 130. Landward the land protection dike is restricting the water bodies. The tributaries are not part of this report, unless they are relevant for the sediment management of the Weser estuary.

The zonation of the Weser estuary within the TIDE-project consists of five different salinity zones (Fig. 7). The basic characteristics of these zones are hydrological and morphological characteristics, the average salinity distribution according to the Venice system and the influence of tributaries and anabranches.

The twin ports of Bremen and Bremerhaven constitute the second largest port complex in Germany. With regard to container turnover, Bremerhaven ranks as fourth largest in Europe. The port of Bremerhaven specialises in handling container ships, car carriers and temperature-controlled fruit ships. The terminals of the port of Bremen, 65 km further south and thereby the most southern German seaport, concentrate mainly on general and heavy-lift cargo and on the handling of bulk commodities. Brake and Nordenham, two ports situated at the lower end of the Weser in Lower Saxony, also play a prominent role in the shipment of bulk cargo. Brake is the largest port to handle the entry of animal feed into Germany.

The Weser River is a federal waterway and maintained by the Waterways and Shipping Administration (WSV). Between the City of Bremen and Brake the Water and Shipping Authority (WSA) Bremen, as a subunit of the WSV, is responsible for the waterway of the Weser. Downstream of Brake, the WSA Bremerhaven is managing the Lower and Outer Weser. Most of the port area (the twin ports of Bremen and Bremerhaven) of the state of Bremen is supervised by bremenports GmbH & Co. KG as regards infrastructural development and maintenance, whereas in Brake Niedersachsen Ports and in Nordenham resident companies are in charge of the management.

Great parts of the foreland, tidal flats, branches and also the fairway in the Weser estuary outside of the ports and built-up areas are part of the Natura 2000 Network for protected areas (an Integrated Management Plan has been made available recently (http://www.nlwkn.niedersachsen.de/portal/live.php?navigation_id=8311&article_id=45641&_psmand=26)); the Outer Weser (without fairway) is part of the Wadden Sea National Park of Lower Saxony.

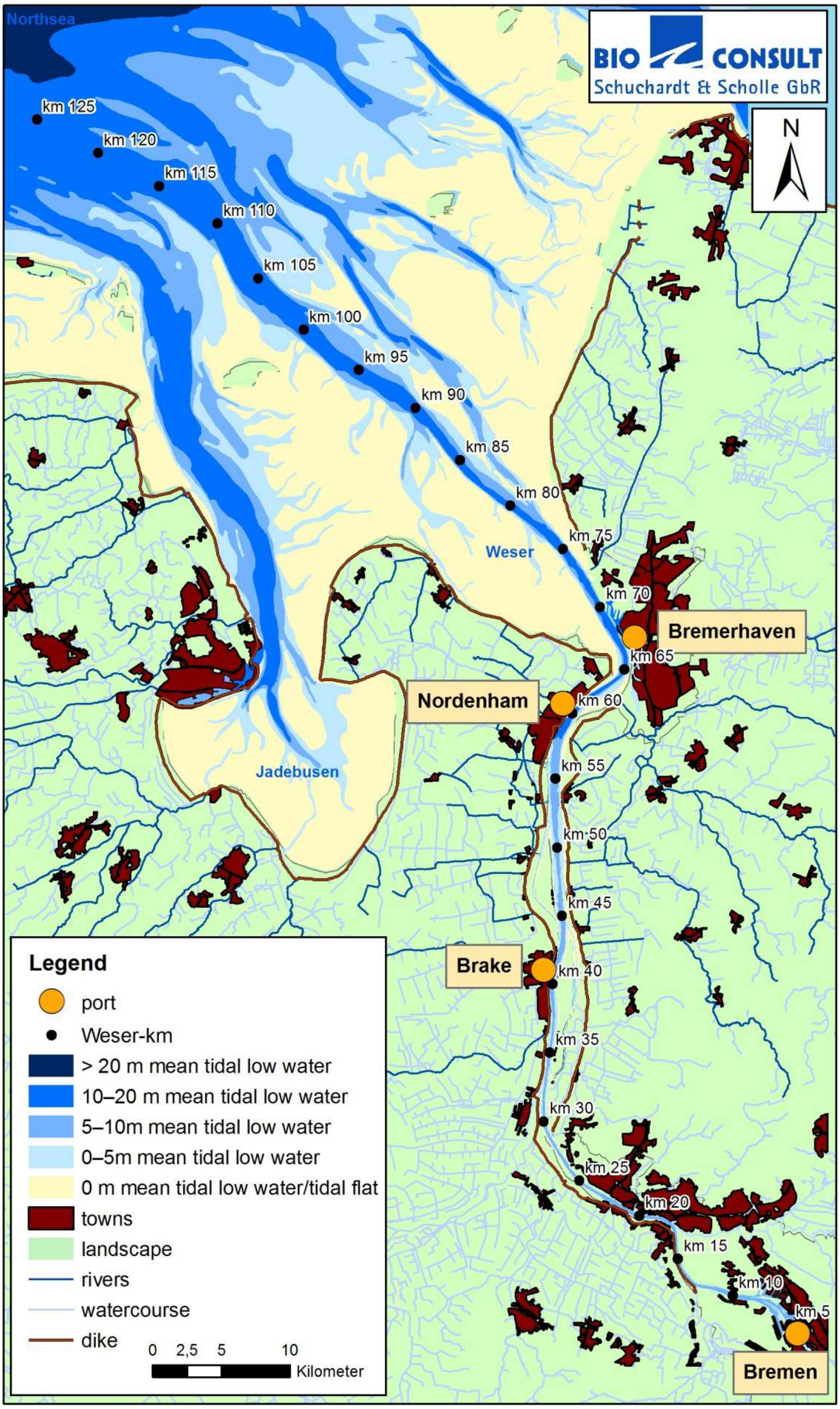


Fig. 1: Weser kilometrage and the ports of the Weser estuary (TIDE kilometrage of the Weser see note in the text above).

3. Traffic

In 2011 67.7 million tons of ocean cargo were turned over in the port of Bremerhaven, 12.9 million tons in the City of Bremen, 5.3 million tons in Brake and 3.8 million tons in Nordenham (Fig. 2). The volumen of inland shipping turned over in 2011 was 1.63 million tons for the port of Bremerhaven, 4.72 million tons in the City of Bremen, 1.26 million tons in Brake and 1.73 million tons in Nordenham (Fig. 3) (STATISTISCHES LANDESAMT BREMEN 2011; LSKN 2012; SENATOR WUH 2011).

The ocean cargo is believed to develop until 2025 for Bremerhaven up to 147.15 million tons, the City of Bremen 20.15 million tons, Brake 8.69 million tons and Nordenham 5.81 million tons (Fig. 2). Cargo volumes for inland shipping are assumed to rise until 2025 in Bremerhaven up to 2.17 million tons, in Bremen 5.67 million tons, Brake 1.40 million tons and Nordenham 2.78 million tons (Fig. 3) (WSD NW, BP & N PORTS 2011).

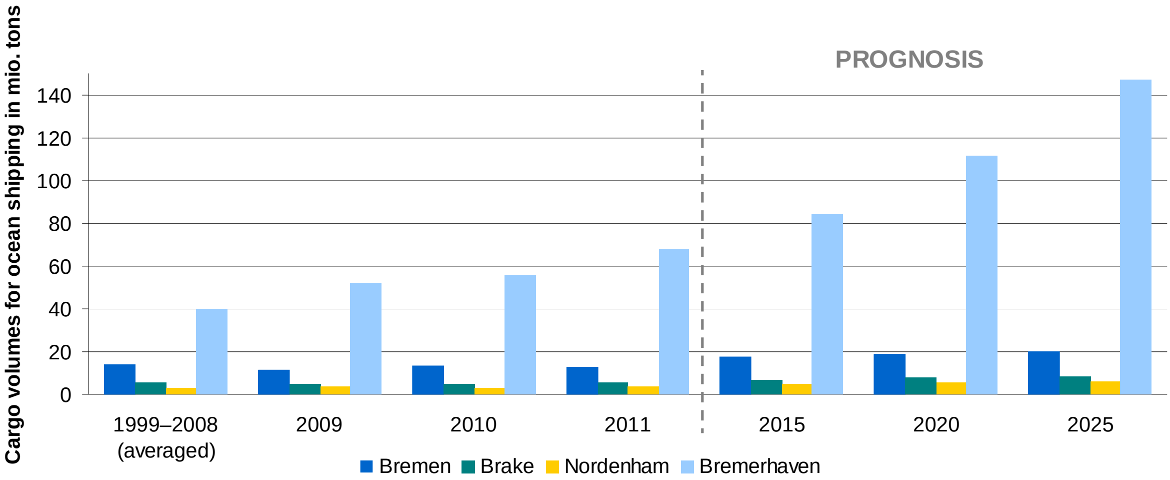


Fig. 2: Cargo volumes for ocean shipping in million tons at the ports Bremerhaven, City of Bremen, Brake and Nordenham (own figure, data LSKN 2012; SENATOR WUH 2011; WSD NW, BP & N PORTS 2011).

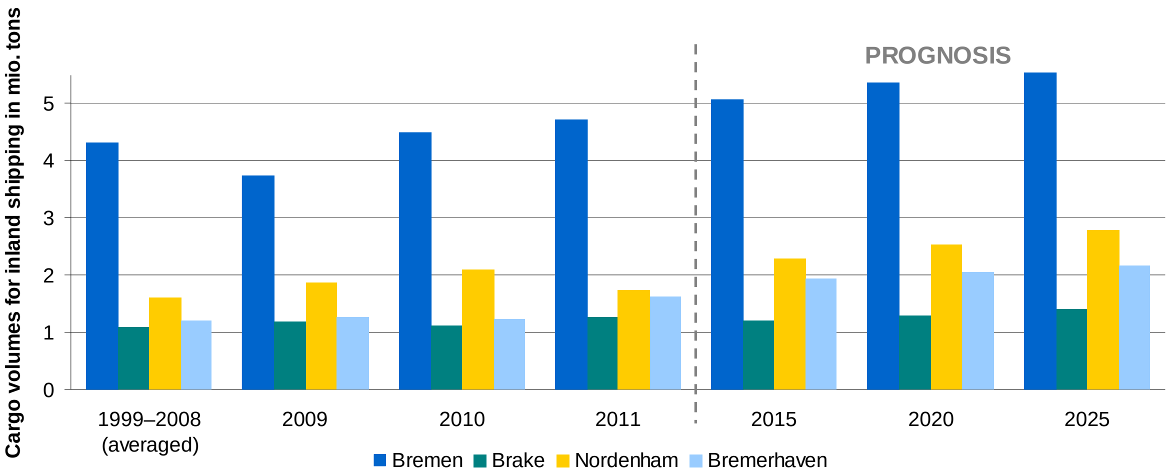


Fig. 3: Cargo volumes for inland shipping in million tons at the ports Bremerhaven, City of Bremen, Brake and Nordenham (own figure, data STATISTISCHES LANDESAMT BREMEN 2011; LSKN 2012; WSD NW, BP & N PORTS 2011).

The development of the traffic in the Weser estuary is shown in Fig. 4 for all ship types and in Tab. 1 for the bigger vessels of Bremerhaven, Brake and the ports of Bremen. In 2007, 25 vessels with more than 10,000 TEU (Twenty-foot Equivalent Unit) (> 150,000 tdw (tons dead weight)) called for the port of Bremerhaven. The greatest tdw in the port of Bremen and Brake was for bulk carriers with 54,739 and 73,957, respectively, in 2007. The maximum vessel draught for the ports along the Weser estuary dependent and independent from tides are given in Tab. 2. Further deepening of the Lower and Outer Weser is approved (see section 4.3), but taken to court by nature conservation organisations and others.

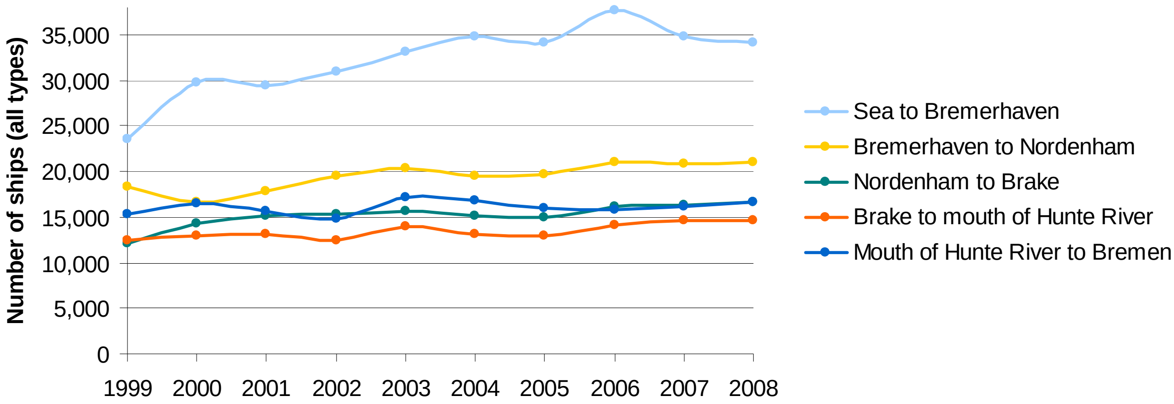


Fig. 4: Mean traffic of all ship types on the Weser estuary between 1999 and 2008 (own figure, data WSD NW, BP & N PORTS 2011).

Tab. 1: Development of the structure of vessels for Bremerhaven, Brake and the ports of Bremen in tdw (tons dead weight) (own table, data PLANCO 2009).

Size classes in tdw	Number in 2007			Number in 2015			Number in 2025		
	Bremer-haven[a]	Brake	Bremen	Bremer-haven	Brake	Bremen	Bremer-haven	Brake	Bremen
0 to 20,000	3546	582	1607	4116	298	676	5277	127	318
20,000 to 50,000	638	129	274	742	170	267	933	213	203
50,000 to 100,000[b]	713	42	42	1127	76	45	1948	105	53
over 100,000	183	–	–	400	–	–	750	–	–

[a] Bremerhaven 2006; [b] Bremen 60.000 bis 100.000 tdw

Tab. 2: Accessibility of the ports via tideways – maximum vessel draught in m.

Port	Maximum vessel draught (m) dependent on tides	Maximum vessel draught (m) independent from tides
Bremen	10.70	7.60
Brake	11.90	7.90
Nordenham	13.10	10.00
Bremerhaven	14.50	12.80

4. Shipping channels

4.1 Hydrography

The Weser has a total length of approx. 433 km (excluding the Outer Weser) and its catchment area encompasses 46,306 km². The hydrographical features are mainly influenced by the incoming tide from the North Sea that is stopped by a tidal weir in Bremen built in 1912. Apart from the tide, the head water discharges form another feature of the hydrological conditions in the Lower and Outer Weser. However, their influence diminishes seawards. Furthermore, the hydrological-morphological activity in the Weser estuary is characterized by the low slope and funnel-shaped mouth that opens towards the northwest.

The tidal range, particularly in the Lower Weser, has changed significantly due to the deepening of the Lower and Outer Weser and has increased in Bremen since the first deepening from approx. 0.2 m to a current level of 4.1 m. The mean tidal range rises upstream from approx. 2.9 m at the lighthouse Alte Weser (approx. km 115) to approx. 3.8 m at Bremerhaven (approx. km 66) and then to approx. 4.1 m at Bremen-Oslebshausen (approx. km 8).

Lower Weser

As a consequence of various expansion measures, the Lower Weser, which runs in a southeast-northwest or south-north direction, now consists of a main arm and the few remaining branches. The location of the main arm and branches is kept extensively stable by means of river engineering structures. The discharge activity is concentrated on the main arm due to the considerable water depths and cross-sectional areas as compared to the branches. The branches predominantly fall dry during low tide.

The structure of the river bed of the main arm of the Lower Weser can be divided into several sections. The ripple section (subaquatic dunes) (km 18–54) is characterized by high morphodynamics and constant internal relocation of the predominantly sandy sediments. Ripples are formed whose height is altered primarily by the head water (heights up to over 4 m). The centre of the maximum estuarine turbidity is located in the area around the so-called "Nordenham mud section" (km 55–58), pronounced rhythmic tidally influenced sedimentation and remobilization of particulate matter occur. For this reason fine sand-mud sediments dominate on the river bed (MÜLLER 2002).

In the area around Blexer Bogen (km 62–65) a complex hydrographic situation prevails with stable kolks separated by a kind of bar. The bar is partially located in the fairway and causes increased maintenance dredging volumes (MÜLLER 2003). In connection with low to medium head water influxes from the Outer Weser, moreover, an upstream transport of sediments from the Outer Weser takes place near the river bed and they are then deposited here to an increased extent.

Overall, a sediment deficit mainly affecting the section from km 40 to 65 appeared to exist in the main arm of the Lower Weser and can be regarded as a consequence of the dredging involved in the 9 m deepening, sand removal for measures carried out by third parties in the 1980s and possibly increased current speeds (MÜLLER 2002). The large sediment volumes removed within a short time in some cases, e.g. for dike construction measures in the Hunte area, were completely removed from the system and could not be compensated for by the river. Sand removal in the Lower Weser has been discontinued since the mid-1980s. The river bed has stabilized since then and erosion processes have not been observed. The branches, by contrast, display tendencies to silt up.

Outer Weser

The Outer Weser opens to the northwest in the North Sea in a funnel shape. The main channel (Fedderwarder Fahrwasser, Hohewegrinne), in which the fairway is located, and parallel to it a secondary channel (Wurster Arm/Tegeler Rinne) run between large tidal flats with the associated tidal flat channels, which are part of the Lower Saxony Wadden Sea National Park. The two channels are separated from each other by Robbenplate and Tegeler Plate. The location of the main channel with the fairway is kept stable between km 68 and 91 by river engineering structures. The main channel takes up the majority of the discharges and the tidally influenced, rhythmically in- and outflowing water masses due to the larger cross-sectional areas in comparison to the secondary channels.

The fairway of the Outer Weser mainly consists of sandy sediments. The surface structure of the river bed between km 96 and km 100 is characterized by subaquatic dunes and in extensive sections by marginal tongues extending diagonally into the fairway. According to WIENBERG (2003), the subaquatic dunes between km 111 and 118 are 2–6 m high and have a crest spacing of 160–400 m. The marginal tongues are created by the sideward deposition of sediment into the fairway.

According to studies by WSA Bremerhaven, due to the asymmetry of the tidal curve and the dominance of the ebb tide in tidal activity, residual sediment transport seems to take place seawards on a large scale in the Outer Weser (GFL, BIOCONSULT, KÜFOG 2006a), though according to BFG (1992) it is not so pronounced that it would lead to a deepening of the channels. In the area of approx. km 110–120 this transport direction is overlapped by the west-east transport along the coast, which also results in a shifting of the large river bars and channels in a northeast direction (ZEILER et al. 2000). According to DIECKMANN & POHL (1991), the influence of the tide on the morphology of the channels and tidal gully (see below) in the Outer Weser is greater overall than that of the sea state.

4.2 River engineering

In the course of deepening the Weser estuary as a shipway and its successive adaptation to increasing vessel sizes the Lower and the Outer Weser have been exposed to considerable river engineering measures (WETZEL 1987; WIENBERG 2003).

Lower Weser

The first deepening of the Lower Weser and therewith a profound river engineering over shaping was conducted under the direction of Ludwig Franzius from about 1887 to 1895. In general, its principles are still in use today: they are aiming for the concentration of the current on a main channel with the help of river engineering measures and the partial filling of side channels as well as the extension of the tide water volumes due to the expansion according to the funnel principle. This led to a drastic over shaping of the Lower Weser's morphology. In the 1980s this approach has been advanced further after the 9 meter deepening with the help of an extensive groyne construction program (in particular Weser-km 34 to 62) as well as coastal nourishments and coastal protections upstream Weser-km 40 (WETZEL 1987). Aim of the different deepening (see above) was the adjustment of the water depth of the fairway to the increasing vessel sizes while simultaneously limiting the required maintenance dredging. The material of the 9 meter deepening was mainly relocated to the foreland and tributary waters of the Lower Weser (WETZEL 1987). The profound over shaping can be noticed particularly in the inner estuary where the tidal range has risen from about 0.2 up to ca 4.1 m in Bremen over the last 120 years (SCHUCHARDT 1995). The dredged maintenance volumes in the Weser estuary have decreased after the 9 m deepening from 7.5 mio. m³ in 1979 (back then mainly in the Lower Weser) successively to 1.7 mio. m³ in 1986 (WETZEL 1987).

Outer Weser

Due to its naturally greater depths deepening measures in the Outer Weser were required much later than in the Lower Weser. Up to then, the fairway followed the channel with the greatest flow-through within the multi channel system of the Outer Weser. From 1921 on the fairway was transferred to the so called Fedderwarder Arm. Dredging was accompanied by extensive river engineering measures (training structures and groynes) to further strengthen this channel (WETZEL 1987). Several deepening followed (see above) which further extended the river engineered system but did not change it fundamentally. DIECKMANN & POHL (1991) described the system as low in maintenance. The Outer Weser was last deepened to 14 m below chart datum (14 m deepening) in 1998/1999 (WSV 2010). The currently planned deepening will be able to manage without further river engineering measures.

4.3 Deepening of the fairway

An application has been submitted and approved for further deepening of the Lower and Outer Weser, but proceedings have been instituted against it and are currently pending. Accessibility independent of the tide is envisaged for vessels with a maximum unloading draught of 12.80 m in the port of Brake and for vessels with a maximum unloading draught of 11.10 m in the port of Bremen. For the Bremerhaven container terminal the aim of deepening the Outer Weser is to enable accessibility independent of the tide for large container ships with a maximum unloading draught of 13.50 m (GFL, BIOCONSULT, KÜFOG 2006b). The port-related turning site with an integrated emergency turning site was set up at the location of the container quay at km 70.5 to km 73.25 at the depth level of the 14 m chart datum deepening as a subproject within the scope of the deepening of the Outer Weser back in 2006 (WSV 2010).

Fig. 5 shows the development of the expansion depths of the Lower and Outer Weser fairways.

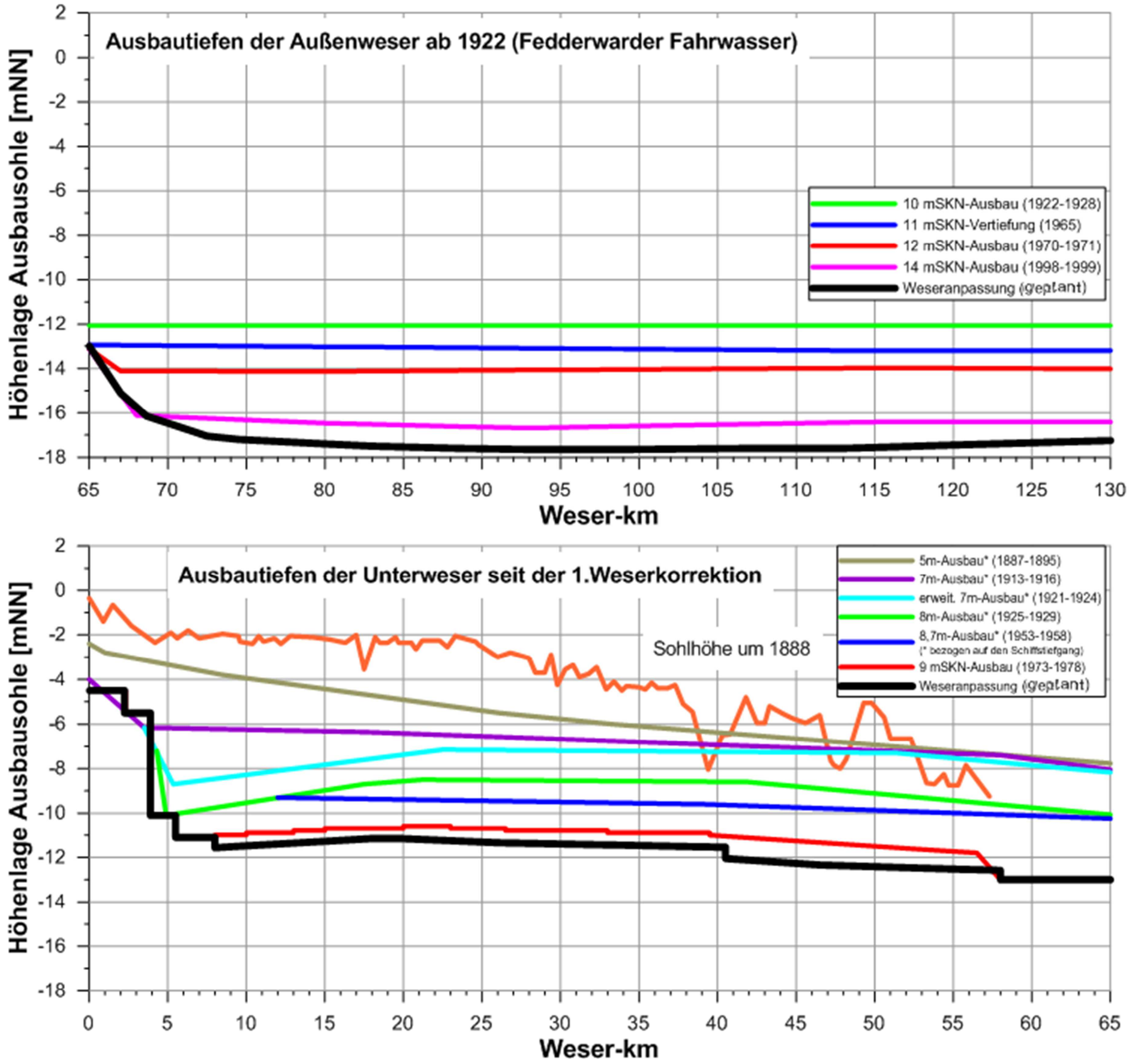


Fig. 5: Longitudinal section of Outer Weser (above) and Lower Weser (below) with expansion depths of the approved Weser deepening (geplant = planned), against which legal proceedings have been instituted, as well as earlier expansion depths (WSÄ BREMERHAVEN & BREMEN).

5. General numbers on dredging and disposal

5.1 Dredging sites and volumes

In the following, dredging conducted within the Weser estuary is presented. Dredging is accomplished in the fairway and the harbours and can be distinguished into maintenance and capital dredging. Dredging volumes are given in m^3.

The officially approved shipping depths are maintained in the Weser estuary by means of various dredging methods. This process involves collecting the sediment and transporting it to another site in the system where it is preferably deposited. This work is primarily carried out using hopper dredgers and additionally, whenever necessary, bucket chain dredgers and pontoon dredgers. Furthermore, water injection (WI) has increasingly been applied in recent years with the aim of reducing dredging operations. In this process the crests of the underwater dunes are mobilized so as to cause the sediment to drift into neighbouring ripple valleys with the current (WSD NW, BP & N PORTS 2011).

The proportions of the dredging volumes of the fairway and the harbours of all the maintenance dredging in the Weser estuary including the sand extractions of third parties and WI in the fairway (no data available for WI in ports) are shown in Fig. 6. While mainly sandy material from the fairway is relocated within the estuary, a part of the muddy sediments found in the harbours is brought on land because of contamination of harmful substances (see section 5.3). The total water area of the ports and fairway within the Weser estuary is displayed in Tab. 3 with dredged material per m^2 in the fairway and ports.

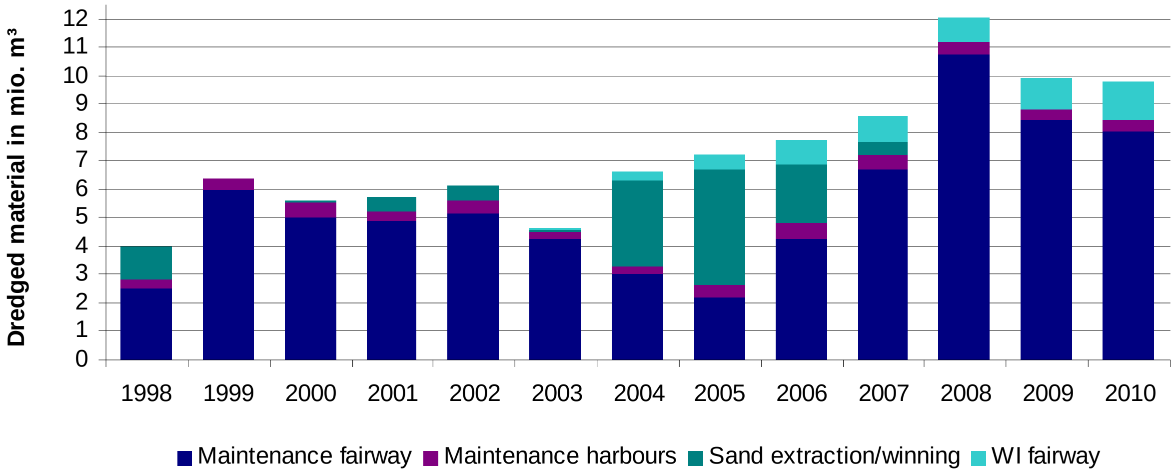


Fig. 6: Total quantities of maintenance dredging in the fairway and harbours ('open' to the estuary and behind locks) as well as maintenance dredging of sand that was delivered to third parties and WI in the fairway (no data available for WI in ports) of the Weser estuary (own figure, data WSA BREMEN and BREMENPORTS).

Tab. 3: Total water area of the fairway and ports ('open' to the estuary and behind locks) in the Weser estuary in hectare with dredged material in m³/m² in the fairway (maintenance dredging, WI and maintenance dredging of sand that was delivered to third parties) and ports (maintenance dredging, no data available for WI, the main maintenance technique in ports) (own table and data, further data SENATOR WUH, BP & HB HAFENAMT 2011; WSD NW, BP & N PORTS 2011; WSA BREMEN; N PORTS and BREMENPORTS).

Area	Total water area [ha]	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
		m³/m²												
Fairway	29,840	0.126	0.201	0.172	0.181	0.191	0.146	0.211	0.225	0.241	0.271	0.389	0.319	0.315
Bremen	280	n.s.	0.102	0.083	0.057	0.032	0.033	0.044	0.021	0.049	0.008	0.004	0.005	n.s.
Brake	20	n.s.	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.175	n.s.
Nordenham	5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Bremerhaven	314	n.s.	0.038	0.078	0.057	0.111	0.066	0.058	0.143	0.131	0.146	0.140	0.113	0.124

5.1.1 Dredging of fairways

Maintenance dredging

The fairway of the Weser estuary has been dredged from the limnetic to polyhaline zone while the euhaline (5.) zone has not to be maintained. Fig. 7. shows the five different salinity zones of the Weser estuary within the TIDE-project and Fig. 8 the volume of dredged material (without WI and sand removal by third parties) in the various zones of the Weser for the period 1999 to 2009. The water area of the fairway for each of the five salinity zones and the dredged material (without WI and sand removal by third parties) in m³/m² within these zones between 1999 and 2009 is displayed in Tab. 4.

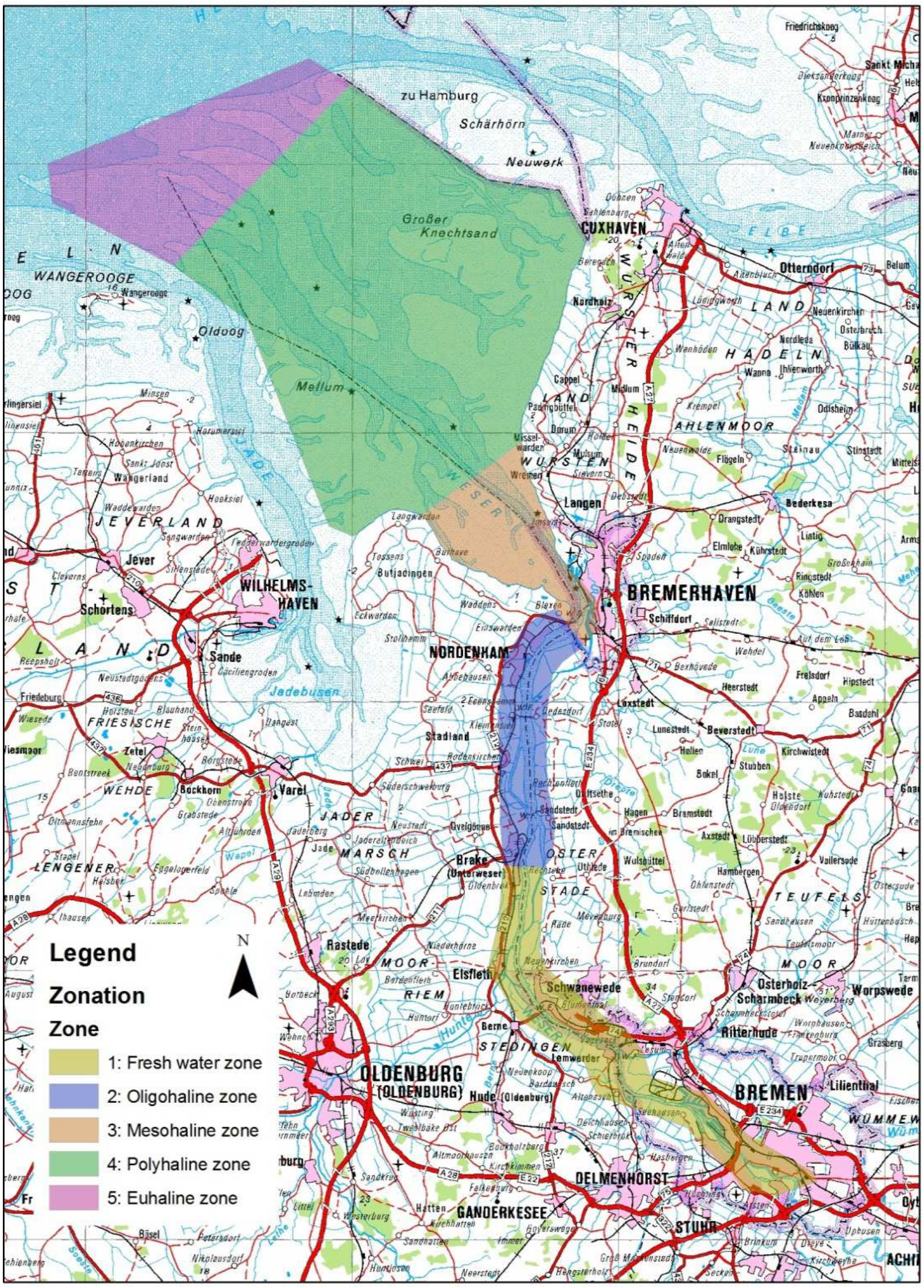


Fig. 7: The five salinity zones along the Weser estuary.

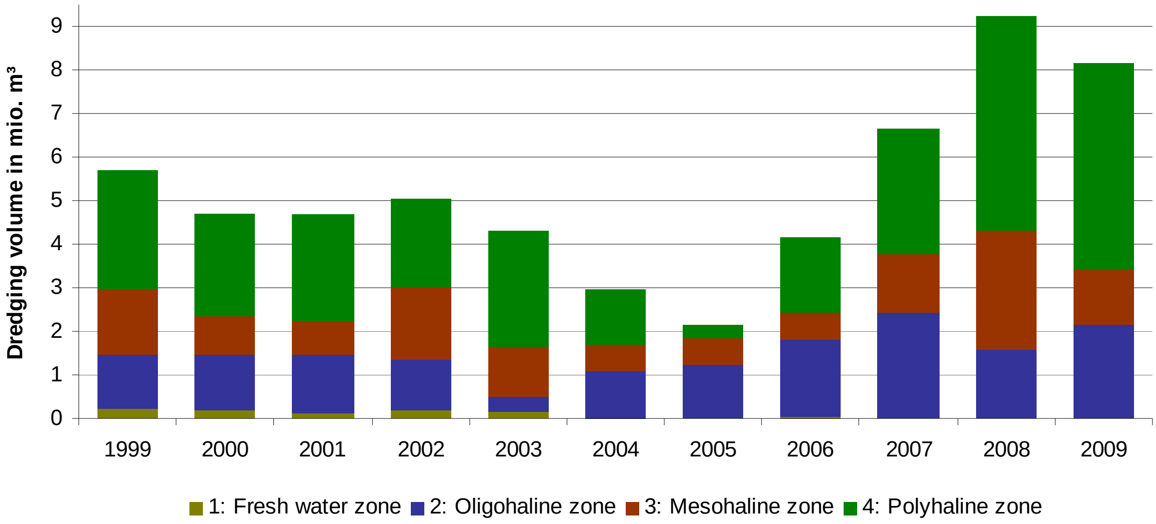


Fig. 8: Quantities of material dredged in the fairway of the Weser estuary (zone 1–4) from 1999 to 2009 in mio. m³ per year without WI and dredging of sand that was delivered to third parties (own figure, data WSA BREMERHAVEN).

Tab. 4: Total water area of the fairway in hectare and the dredged material (without WI and sand removal by third parties) in m³/m² for each of the five salinity zones along the Weser estuary between 1999 and 2009 (own table and data, dredging data WSA BREMERHAVEN).

Zone	Total water area fair-way [ha]	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		m³/m²										
1: Fresh water	700	0.032	0.025	0.014	0.028	0.020	0.001	0.001	0.006	0.000	0.000	0.000
2: Oligohaline	529	0.233	0.242	0.259	0.221	0.068	0.202	0.232	0.334	0.456	0.296	0.407
3: Mesohaline	337	0.443	0.268	0.225	0.481	0.336	0.189	0.177	0.184	0.405	0.818	0.372
4: Polyhaline	1,040	0.262	0.224	0.238	0.197	0.256	0.122	0.030	0.167	0.276	0.472	0.455
5: Euhaline	378	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

WI is applied in the sandy sections of the Lower Weser and – depending on the swell – of the Outer Weser (WSD NW, BP & N PORTS 2011). The extent of the sediment set into motion by WI in the Weser estuary (zone 1 to 4) displays Fig. 9. WI was not applied in zone 5. Additionally, sand removal from the shipping channel for third parties is shown in Fig. 10, it did not take place in the period 2008–2011. The elevated sand removal by third parties between 2004 and 2006 led to lower dredging volumes in the fairway over these years (Fig. 8).

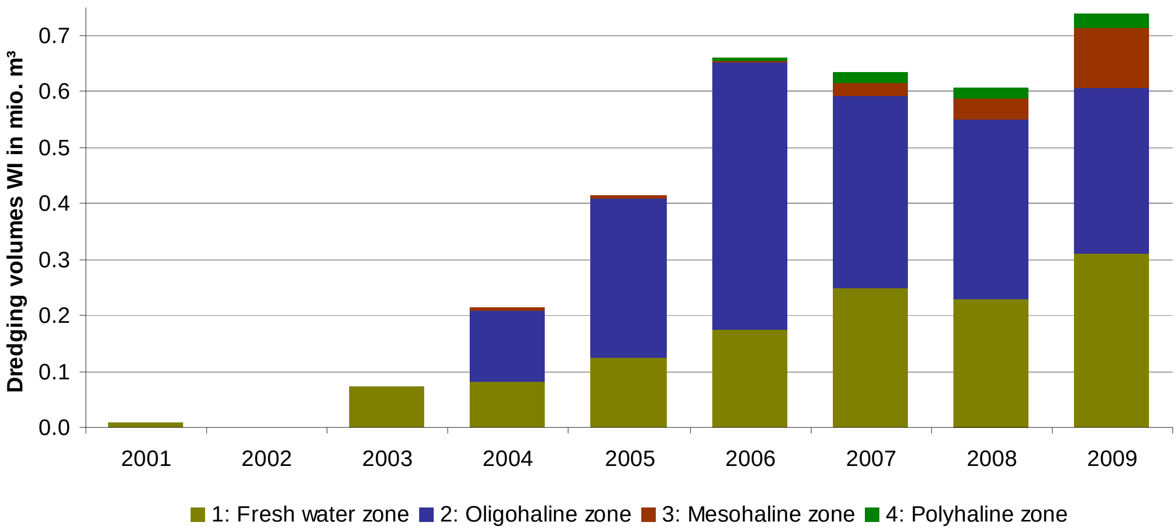


Fig. 9: Dredging volumes of water injection (WI) in the fairway of the Weser estuary (zone 1–4) in mio. m³ per year (own figure, data WSA BREMERHAVEN).

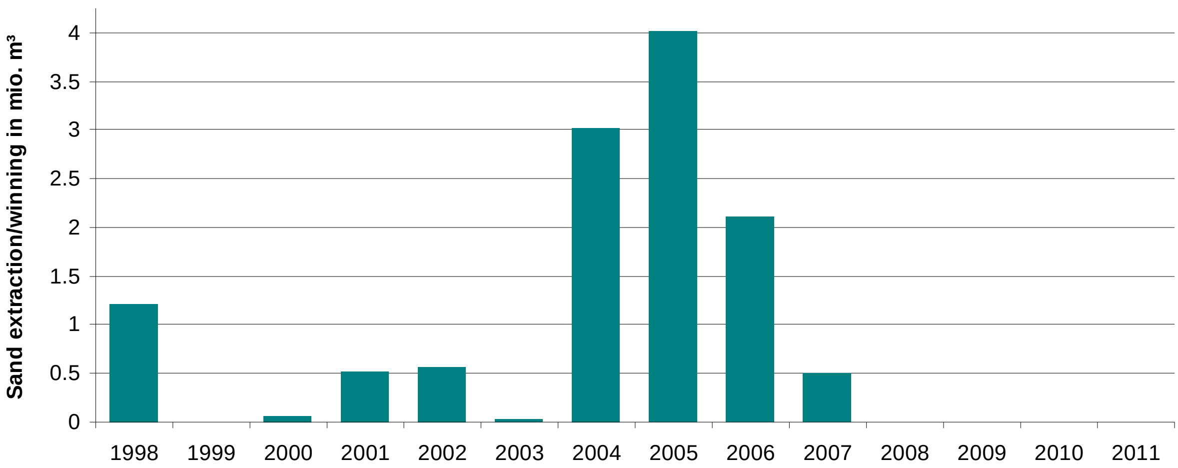


Fig. 10: Maintenance dredging in the fairway of the Weser estuary between 1998 and 2011 with removal of sand that was delivered to third parties for construction purposes (own figure, data WSA BREMEN).

In Fig. 11 the discharge of the Weser as the daily mean value at the gauge in Intschede (Januar 1998 to December 2011) is displayed. A visual comparison of the curve progressions with the ones in Fig. 8, Fig. 9 and Fig. 10 does not exhibit obvious dependencies; a statistical analysis could be expedient. Like this SCHUCHARDT & SCHIRMER (1991) were able to show a clear positive relationship between suspended load concentration, discharge and sedimentation dynamics in the port open to the tide of the City of Bremen.

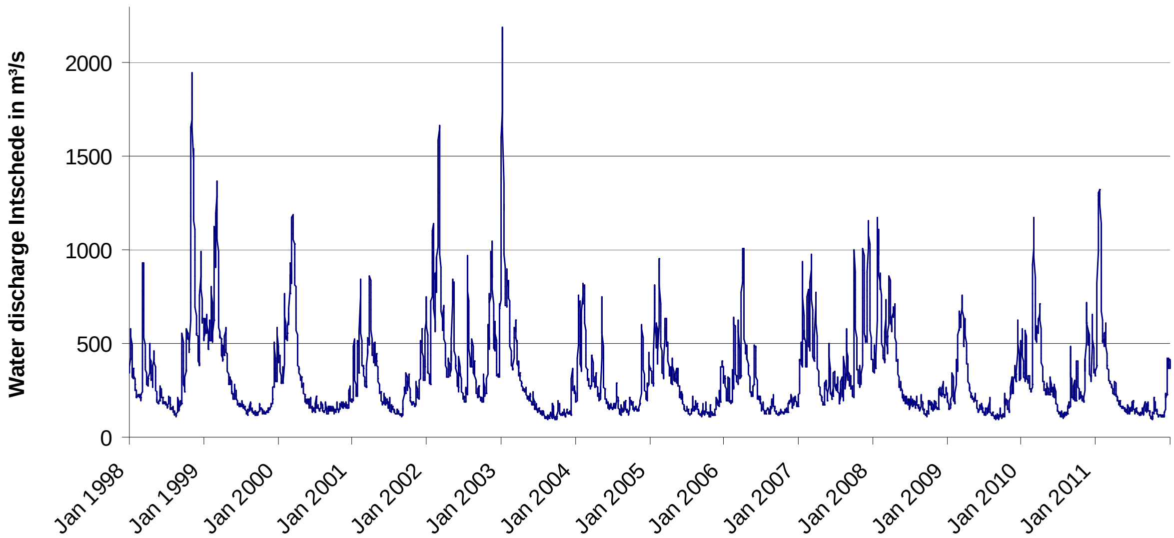


Fig. 11: Daily mean values in m^3/s of the water discharge in Intschede between Januar 1998 and Dezember 2011 (own figure, data WSD Mitte).

Certain sections of the fairway of the Weser estuary are dredged more than others. Fig. 12 and Fig. 13 show the removal of material as a result of maintenance, WI and extraction of third parties of the different parts of the Weser estuary over the years.

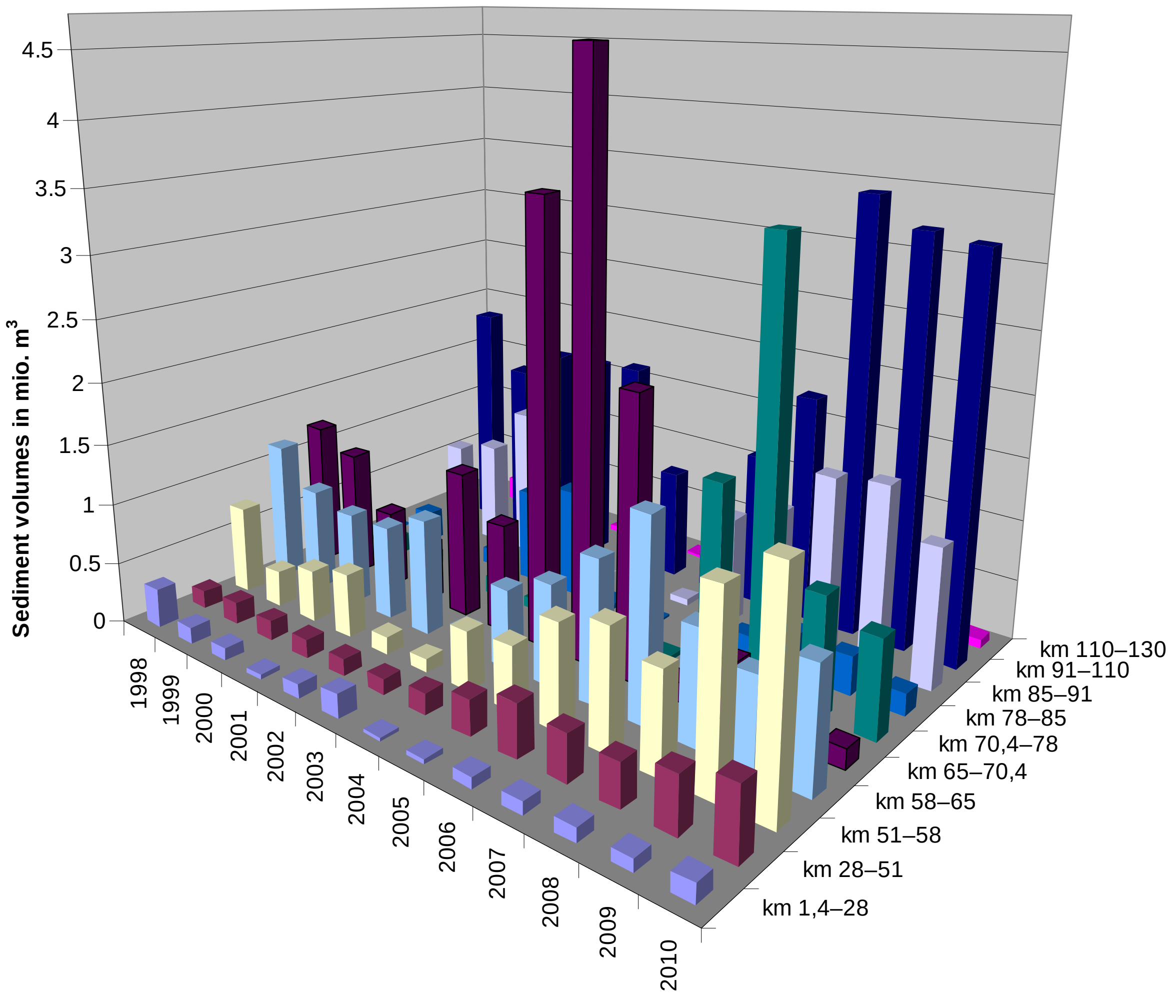


Fig. 12: Volumes of material removed due to maintenance, WI and maintenance dredging of sand for third parties in different sections of the fairway which are varying in length within the Weser estuary between 1998 and 2010 (maintenance dredging of about 50,000 m³ material a year for coastal and construction protection between 2005 and 2010 is not included) (own figure, data WSA BREMEN).

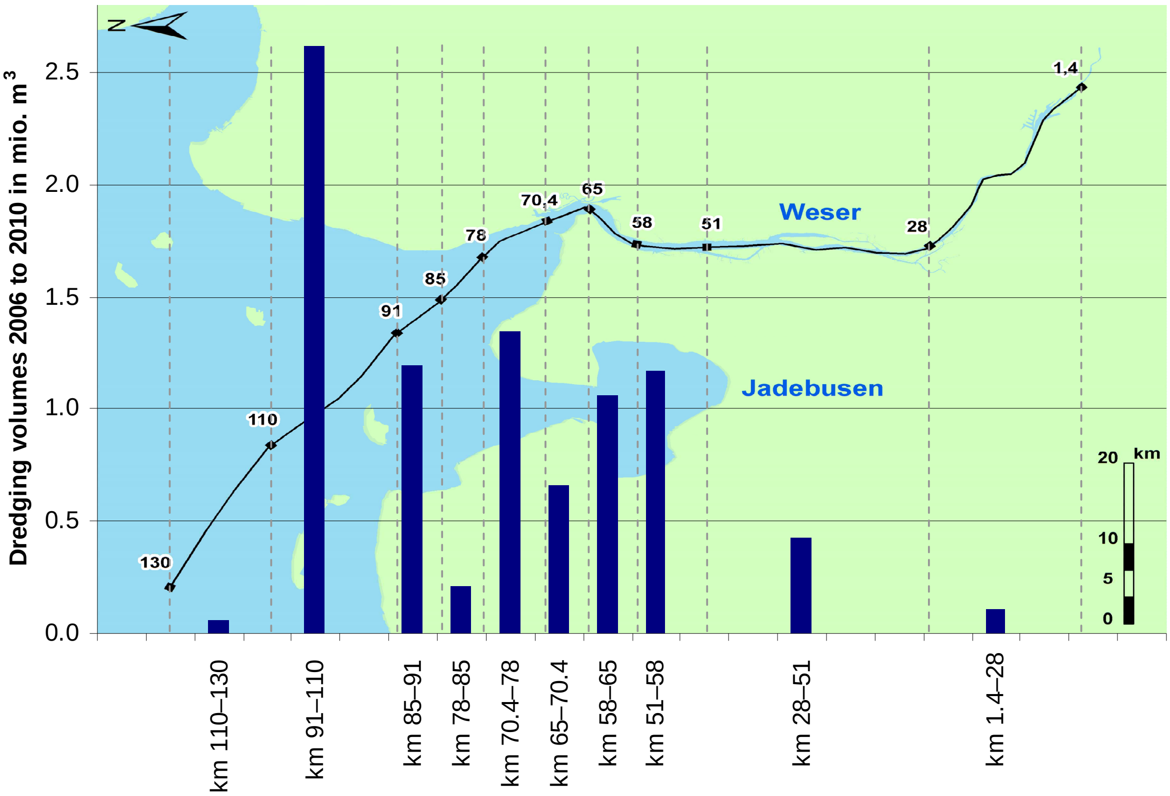


Fig. 13: Mean volumes of maintenance dredging (including WI and maintenance dredging of sand for third parties) within the fairway between 2006 and 2010 in mio. m³ in different sections of the Weser estuary (maintenance dredging of about 50,000 m³ material a year for coastal and construction protection between 2005 and 2010 is not included) (own figure, data WSA BREMEN).

Capital dredging

Capital dredging of the fairway was conducted in the Outer Weser the last time in 1998/99 (see section 4). The respective volumes of more than 7 mio. m^3 are not included in the figures above. The construction of the port-related turning site in Bremerhaven is treated in section 5.1.2.

In the application for further deepening of the Lower and Outer Weser the volumes of capital and subsequent maintenance dredging in the fairway has been stated as indicated in Tab. 5.

Tab. 5: Overview of the volumes for capital and additional maintenance dredging in the fairway of the approved Weser deepening, against which legal proceedings have been instituted; abbreviations: LW = Lower Weser, OW = Outer Weser, NF = tributaries, ST = turning site (GFL, BIOCONSULT, KÜFOG 2006b).

Capital dredging		
Capital dredging (hopper dredgers or bucket chain dredgers) [a]	mio. m^3 solid mass [b]	LW: 0.58 OW: 4.70 + 0.90 (ST) + 0.06 (ST) = 5.66 **Total: 6.24**
Capital dredging WI [a]	mio. m^3 solid mass [b]	LW: **0.3** OW: –
Dumping of capital dredging [a]	mio. m^3 loose mass [b]	LW: – OW: 0.87 + 7.8 + 1.6 (ST) = **10.27**
Maintenance dredging		
Additional maintenance dredging by hopper dredgers in the 1st year after deepening	mio. m^3 loose mass [b]	LW: 2.3 OW: 3.99 **Total: 6.24**
Additional maintenance dredging by hopper dredgers after the 4th and 5th year [c]	mio. m^3 loose mass [b]	LW: 1.55 OW: 2.86 **Total: 4.41**
Additional maintenance dredging by WI in the 1st year after deepening	mio. m^3 solid mass [b]	LW: **1.06** OW: –
Additional maintenance dredging by WI after the 4th and 5th year [c]	mio. m^3 solid mass [b]	LW: **0.23** OW: –
Additional dumping of maintenance dredging in the 1st year after deepening	mio. m^3 loose mass [b]	LW: 0.74 OW: 5.55 **Total: 6.29**
Additional dumping of maintenance dredging after the 4th and 5th year [c]	mio. m^3 loose mass [b]	LW: 0.49 OW: 1.05 + 2.86 = 3.91 **Total: 4.40**

[a] without previous maintenance and (reduced) ongoing maintenance during deepening
[b] the grain composition of the sediments depend on the prevailing hydrological conditions, for the soil loosening during dredging and for dumping an additional 25–50% is estimated (depending on dredging method and sediment characteristics sand/mud)
[c] after the 4 years (LW) and 5 years (OW) lasting subsequent morphological development

5.1.2 Dredging in harbours

Ports of Bremen and Bremerhaven

Maintenance dredging

In the port areas open to the tide as well as in the harbours behind locks in Bremerhaven, the city of Bremen and Lower Saxony the water depths have to be restored regularly in order to maintain shipping operations. Hopper dredgers are primarily used in the harbours open to the estuary like the container terminal in Bremerhaven. In the muddy port areas open to the tide non-consolidated sedimented particulate matter is regularly remobilized by WI, thus reducing maintenance dredging by hopper dredgers with removal. WI has been applied in the lock exit basins in Bremerhaven since 1994. Since then dredging with removal of approx. 300,000 m³ of material a year has no longer been necessary. Maintenance dredging with removal in the Bremen port group has also been reduced by means of WI since 2007 (see Fig. 14 and Fig. 15) (WSD NW, BP & N PORTS 2011; BREMENPORTS pers. comm.). Sediment volumes relocated in the ports with means of WI are not understood and documented as maintenance dredging by bremenports (see section 5.3.1).

Further reduction of maintenance dredging resulted from constructional measures, e.g. for the "Überseehafen" in Bremerhaven a new watering facility ("Freilaufkanal") was designed and constructed (between 2001 and 2003) as it was the best solution to get low-sediment water from upper parts of the water column out of the river Weser that are not influenced by fluid-mud of ground structures. This measure reduced the sedimentation rate in the Überseehafen by half (HAMER & KRESS written notice).

Annual amount of dredged material in the ports of Bremerhaven and Bremen was reduced from more than 1 mio. m^3 in the 1990s (WSD NW, BP & N PORTS 2011) to 400,000 m^3 today. Around 260,000 m^3 of that volume is sandy and little contaminated. This material is transferred to dumping sites in the Weser estuary or used as building material. At the remaining approx. 170,000 m^3 fine-grained material, which is primarily found in the harbour sections behind locks in Bremerhaven, harmful substances can be bonded and concentrated. These sediments require special handling depending on their contamination (see section 5.3.3) (WSD NW, BP & N PORTS 2011, BREMENPORTS written notice).

The annual volume removal of these muddy and contaminated harbour sediments depend on both the requirements of the harbours and the capacity of the landfills and third parties. The integrated dredged material disposal site in Bremen-Seehausen can treat 200,000 m^3 dredged material a year. A higher removal was possible 2006–2008 and 2011 since sediments were transported to the Lower Rhine. In addition, the utilisation of the aquatic Confined Disposal Facility (CDF), the Slufter in Rotterdam, since 2011 allows a higher removal of material (BREMENPORTS pers. comm.).

The anew increase of maintenance dredging of sandy material in Bremerhaven since 2005 (Fig. 14) can be attributed to the construction expansions of Container Terminal IIIa (2001–2003) and Container Terminal IV (2004–2008). WI can only eliminate local shallows at the extended riverside quays (BREMENPORTS pers. comm.).

At the 2006 constructed port-related turning site in Bremerhaven 493,000 m^3 of sandy material was removed. In 2008 maintenance encompassed around 1.5 mio. m^3 and in 2009 and 2010 about 200,000 m^3 sediment that was relocated to placement sites in the Outer Weser (WSA BREMEN written notice).

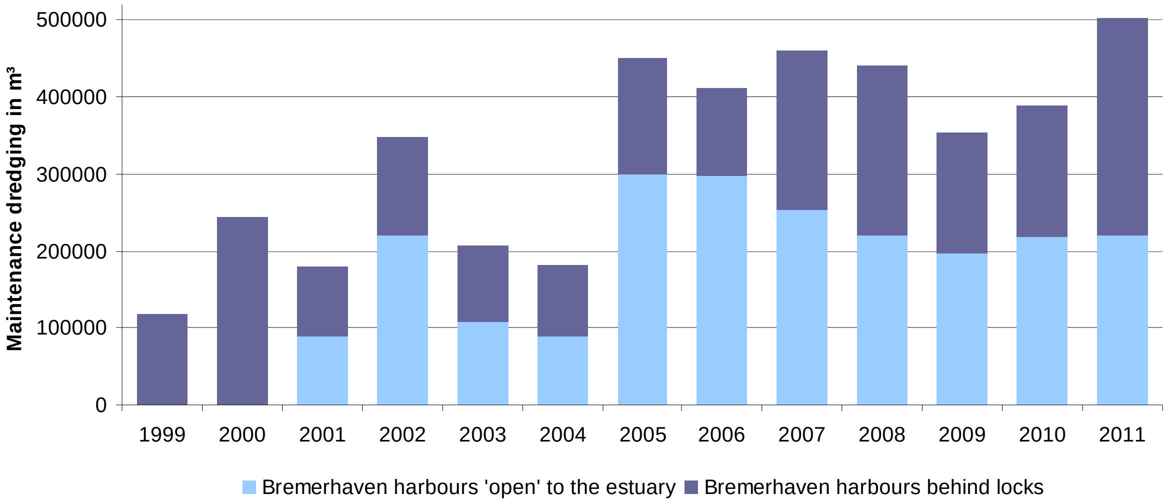


Fig. 14: Maintenance dredging of harbours in Bremerhaven 'open' to the estuary and behind locks (without dredging volumes of the turning area and internal relocations) (own figure, data BREMENPORTS written notice) (without WI).

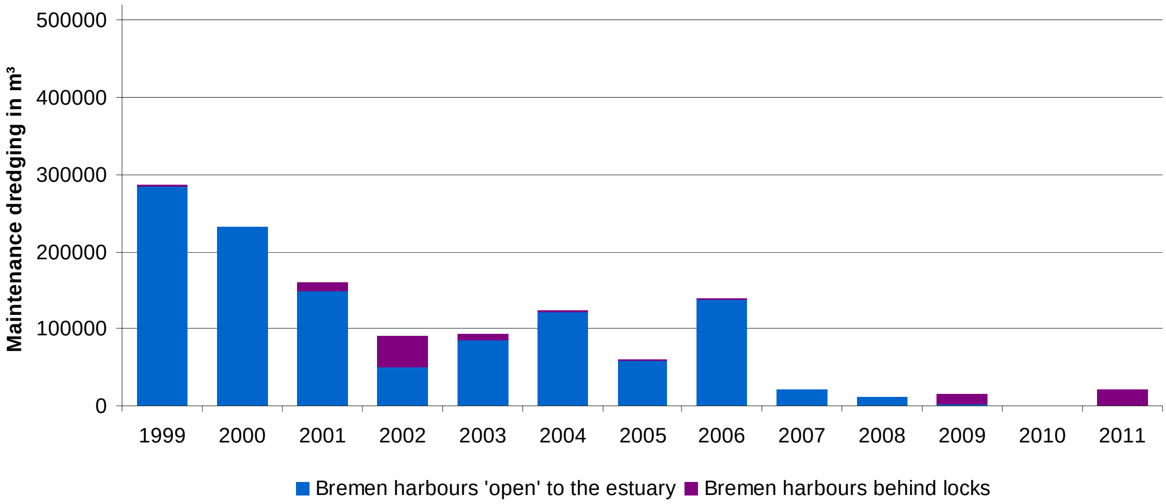


Fig. 15: Maintenance dredging of harbours in Bremen 'open' to the estuary and behind locks (own figure, data BREMENPORTS written notice) (without WI).

Capital dredging

The port-related turning site in Bremerhaven was set up in 2006 in front of the container terminals and at this point the fairway passes through the turning site. The construction involved removal of about 2 mio. m³ of sandy soil and approx. 100,000 m³ of cohesive soil.

The reconstruction of the Kaiserschleuse in Bremerhaven was finished in April 2011. Within the scope of the ground management overall 385,788 m³ material was brought on land and for the building activity a total of 239,309 m³ Sediment was relocated, thereof 26,793 m³ in 2008, 61,133 m³ in 2009, 61,883 m³ in 2010 and 89,500 m³ in 2011 (BREMENPORTS written notice).

Construction of Container Terminal IIIa required transfer of 1.3 mio. m^3 of material in the Outer Weser and Container Terminal IV 10.6 mio. m^3 (Tab. 6).

Tab. 6: Capital dredging at the construction of the Container Terminals IIIa and IV (BREMENPORTS written notice).

Project: CT IIIa	Material	Deposition	Extraction	Volume	Period
Soil replacement	Dredging of cohesive soil	Robbensüdsteert / Robbenplate Nord		350.000 m³	2001
Soil replacement	Refilling with sand		Outer Weser	350.000 m³	2001
Hinterland heightening	Sand accretion		Outer Weser	470.000 m³	2002
Mooring basin dredging	Excavation of mixed soil	Robbensüdsteert / Robbenplate Nord		140.000 m³	2003
Project: CT 4	Material	**Deposition**	**Extraction**	**Volume**	**Period**
Soil replacement	Dredging of cohesive soil	Robbensüdsteert		175.200 m³	2004
Soil replacement	Dredging of cohesive soil	Robbenplate Nord		262.800 m³	2004
Soil replacement	Refilling with sand		Outer Weser	970.000 m³	2004
Hinterland heightening	Sand accretion		Outer Weser/ Jade	8.821.000 m³	2005–2007
Mooring basin dredging	Excavation of mixed soil	Robbensüdsteert/ Robbenplate Nord		350.000 m³	2006–2008

Ports of Lower Saxony

Maintenance dredging

In the past sediment management in the ports of Brake and Nordenham was carried out with relatively little work input. With the exception of a harbour behind locks in Brake, the ports profit from the force that carries away sediment (WSD NW, BP & N PORTS 2011).

In Brake the slow-flow harbour sections are maintained through regular application of WI or by means of a mud harrow. In harbours behind locks maintenance dredging on the order of 10,000 to 20,000 m³ is necessary approx. every 10 years. The mooring basin along the riverside pier is restored in intervals of several years and the dredged volume comes to around 20,000 m³ of fine sand (WSD NW, BP & N PORTS 2011).

In the past the dredged material from Brake was transferred to the dumping sites in the Lower and Outer Weser or deposited in groyne fields. The additional berths resulting from port expansion in 2009 are maintained regularly via WI or by means of mud harrows since they have an unfavourable location in terms of the current and are subject to considerable sedimentation (WSD NW, BP & N PORTS 2011).

The Nordenham port is regularly maintained through application of WI at the necessary depth (WSD NW, BP & N PORTS 2011).

Capital dredging
In the course of the port expansion carried out in Brake in 2009 the dredged material (0.385 mio. m^3) was taken ashore to heighten the new port area (NIEDERSACHSEN PORTS written notice).

5.2 Kind and quality of dredged sediments

5.2.1 Kind of dredged sediments

The main types of sediments in the shipping channel of the Outer Weser are fine to coarse sand, towards the sea their grain sizes tend more to medium and coarse sand. In addition, silt portions can be found in the inner Outer Weser (km 68–70). There may also be small quantities of clay, peat, wood and shell fragments, though they occur on a very small scale. Narrow marl banks occur between Weser km 77 and 77.6 as well as between Weser km 95.4 and 97.3 (WSA BREMERHAVEN 2006).

The Lower Weser can be divided into three sections on the basis of the types of soil found there: section km 58–55, km 55–40 and km 40–8. In the section km 58–55, the mud section before Nordenham (above the port facilities at km 57.5), the fine sand and silt portion with the fraction < 0.2 mm (around 90%) predominate. Only small portions of medium and coarse sand occur, though their quantity increases towards the western side of the channel. In the section km 55–40, the ripple section above Nordenham on the other hand, hardly any silty sediments or fine sand is found. Here the coarser sediments like medium sand with proportions up to 90% and coarse sand (0.2 to 2 mm) predominate. Above Brake (section km 40–8) medium and coarse sand dominates. Larger portions of fine sand and silt and/or fine to coarse gravel can also be found on a small scale (WSÄ BREMERHAVEN & BREMEN 2006).

Silty sediments are present in particular in natural slow flow (anabranches) and artificial (harbour basins) side areas as well as in the mud section before Nordenham (see above).

Assuming that almost all material dredged in the fairway is sandy and all the material dredged in the harbours is silty, Fig. 6 displays that possibly more than 80% of the material dredged and relocated in the Weser estuary is sandy, although directly comparative data is not available.

5.2.2 Contamination of sediments

Sediments in estuaries and harbours are a mirror-image of many activities in the catchment area. In the end, the composition of dredged sediment is the result of both, first the different sedimentation regimes in a river and its harbours, which influence the grain size distribution of the sediments, and second, diffuse and point sources influencing the chemical quality of those sediments. As a consequence, dredged sediments of an estuary are heterogeneous in physical as well as chemical characteristics (HAMER & KRESS written notice).

Even though the heavy metal load in the Weser has dropped considerably since the end of the 1970s (HAARICH 1996), this reduction is reflected in the sediments only to some extent. The contents of heavy metals in the Weser exceed the worldwide mean contents and they are elevated due to former smelting and mining activities in the Harz Mountains since more than 1000 years. That had been shown by analysis of overbank and harbour sediments of the Weser River (MATSCHULLAT et al. 1997; MONNA et al. 2000). Over the time organic components came into focus as well, and further pollutants were identified. Most of the riverine organic contaminants input into the Wadden Sea has decreased, however, compared to background levels present values are still elevated (BAKKER et al. 2009). For tributyltin (TBT), deriving from anti-fouling agents on ships, and its decomposition products a decrease is expected in the long-term because of limitations and the ban of the application (KÜFOG 2011).

Generally, a reduction in the heavy metal contamination, which is significant in some cases, has been found in the Lower Weser towards the Outer Weser (Tab. 7). The pollutants inputted from upstream as well as any depositions from the Bremen region are increasingly diluted as of the brackish water zone via marine sediments that contain little contamination and are transported upstream with the ebb flow (BFG 2006).

Fundamentally a distinction must be made between the more contaminated fine-grained sediments primarily from the port areas and the sandy dredged material primarily from the fairway. The sandy material from the fairway and certain sections in front of the riverside quays with low to very low fine grain portions predominantly has a low level of contamination and can be transferred to water bodies according to the national requirements (see section 5.3.2).

Quality criteria

Different quality criteria are used for assessing suspended solids in the river and dredged material in the coastal zone. The "Regulation for handling dredged material inland" applies to the area of the Weser upstream from Nordenham (km 58) (HABAB) (BFG 2000). The assessment of the suitability of dredged material for sea or estuary disposal is currently based on the new "Joint transitional regulation for the handling of dredged material in coastal areas" GÜBAK (ANONYMUS 2009). It replaced the earlier HABAK ("Regulation for handling dredged material in coastal areas") (BFG 1999) in August 2009, which had already transposed the international regulations of the London Convention (LC), Oslo-Paris Convention (OSPAR) and Helsinki Convention (HELCOM) into a German directive. The HABAB and GÜBAK shall be soon replaced by a new directive, which encompasses the coastal and inland regulations. Waste law provisions according to LAGA (1997) and TASI (1993) shall apply to on-shore placement.

The guiding values (RW) of the GÜBAK (ANONYMUS 2009) are based on sediment contaminant content found in the German part of the Wadden Sea and the coastal sediments of the Northern Sea. The lower value is equivalent to the 90th percentile of the current regional contamination. The upper value is calculated by multiplying the lower value by 3. The only exception is TBT. In assessing the heavy metals, the values measured in the sediment fraction < 20 µm are compared directly with the guiding values. The assessment of the organic contaminants is based on their concentrations in the sediment fraction < 63 µm that were calculated from the analyses in the total sample and the percentage of the sediment fraction < 63 µm. TBT values relate to the total sample.

Three cases are defined when interpreting the sampling analysis:

Case I : Analysis results below RW1: The material complies with the background contamination of the coastal area. Beneficial use/direct use is to be considered, placement has to be carried out under consideration of physical and biological effects.

Case II: Analysis results in between RW1 and RW2: This material has a higher degree of contamination compared to the coastal zones (at least one parameter > RW1, no parameter > RW2). Beneficial use/direct use options need to be verified, and an impact hypothesis as well as a monitoring programme has to be prepared when appropriate. If the impact hypothesis identifies significant or long-lasting impairments of environmental assets to be protected or if significant or lasing accumulation of contaminants in the sediment is to be expected, actions like those of Case III should be taken.

Case III: Analysis results above RW2: This material is significantly higher contaminated compared to sediments in the coastal areas (at least one parameter > RW2). Procedure similar to Case II but additionally the source of contamination needs to be determined and if possible remediated. Safe disposal (landfill) and treatment options have to be considered.

Bioassays have to be implemented in Case III, but partly also in cases of lower contamination. These tests are used to assess the toxicity of the dredged material. Qualified tests are (1) marine algae test (2) luminous bacteria test and the (3) acute toxicity test with amphipods.

Dredged material from the harbours

In Tab. 7 the contents of pollutants in dredged material from the ports of Bremen and Bremerhaven, the fairway as well as suspended sediment from Farge are displayed in comparison with guiding values for assessing contaminants in dredged material by the GÜBAK.

Already 1997 relocation of muddy harbour sediments into the Outer Weser was abandoned mainly because of high tributyltin (TBT) contamination; the material is predominantly taken to a landfill (see section 5.3.3). As displayed in the study of DAEHNE & WATERMANN (2009), a significant reduction of the TBT contamination is not observed until now despite the international ban on the application and regular maintenance dredging in most of the port areas at the German coast. Although, Bremenports reports that the range of the concentration in the main dredging areas in the ports has decreased in the meantime to such an extend that relocation is considered (HAMER written notice).

Tab. 7: Contents of pollutants in dredged material from the ports of Bremen and Bremerhaven (2009–2011, Bremen n = 14–16 and Bremerhaven n = 34; BREMENPORTS written notice), the Lower and Outer Weser and suspended sediment from Farge (all 2005; BFG 2006) compared with guiding values for assessing contaminant concentrations in dredged material (RW1 and RW2) (GÜBAK, ANONYMUS 2009).

Substance	Unit	RW1	RW2	Port of Bremen	Port of Bremer-haven	Farge km 26	Lower Weser-km 55–58	Outer Weser km 65– 120
Heavy metals (particle size fraction < 20 µm, dry mass)								
Arsenic (As)	mg/kg	40	120	15–25		24	25	21
Lead (Pb)	mg/kg	90	270	110–200	58–132	132	108	35
Cadmium (Cd)	mg/kg	1.5	4.5	3.5–8.4		3.1	1.5	< 0.5
Chromium (Cr)	mg/kg	120	360	66–103	84–106	70	79	69
Copper (Cu)	mg/kg	30	90	64–137	34–659	60	33	17
Nickel (Ni)	mg/kg	70	210	38–58		54	40	43
Mercury (Hg)	mg/kg	0.7	2.1	0.29–0.82		0.39	0.63	< 0.15
Zinc (Zn)	mg/kg	300	900	560–2500	247–848	630	341	158
Organic contaminants (particle size fraction < 63 µm, dry mass)								
PCB sum 7	µg/kg	13	40	15–127	4.03–332.9	28	58	< 21
α-HCH (Hexachlorcyclohexane)	µg/kg	0.5	1.5	< BG[1]–0.53		0.1	< 0.9	< 0.6
γ-HCH (Lindane)	µg/kg	0.5	1.5	< BG[1]–1.02		0.6	< 0.8	< 0.6
HBC (Hexachlorbenzene)	µg/kg	1.8	5.5	0.24–2.7		1.3	< 3.0	< 3.0
Pentachlorbenzene	µg/kg	1	3	< BG[1]–1.99		0.4	< 3.0	< 3.0
p,p'-DDT	µg/kg	1	3	< BG[1]–23.57		2.3	< 3.0	< 3.0
p,p'-DDE	µg/kg	1	3	0.52–4.89		2.1	< 3.0	< 3.0
p,p'-DDD	µg/kg	2	6	< BG[1]–6.29		1.9	< 3.0	< 3.0
Hydrocarbons total	mg/kg	200	600	42–760		209	480	< 290
PAH (Polycyclic Aromatic Hydrocarbons) sum 16	mg/kg	1.8	5.5	0.67–9.54				
TBT (tributyltin)	µg/kg	20	300[2]	2–1000	27–38000	69[3]/106[4]	31[3]/200[4]	3.4[3]/26[4]

[1] BG = limit of evidence, [2] TBT for the Wadden Sea National Park RW2: 100 µg/kg, [3] TBT in < 2 mm µg TBT/kg, [4] TBT in < 20 µm µg TBT/kg

Contamination of sediments in the fairway

In the context of the preparation for the current deepening there has been a comprehensive analysis concerning the sediments including surface sediments as well as sediment cores in the Weser estuary by the BFG (2006). The goal was to assess the contaminant loads and the ecotoxological impact. The scope of the analysis was mainly aligned to the standards of HABAB as well as HABAK. Four sections were observed: the ripple section of 8 km to 55 km, the mud section Nordenham between km 55 and km 58, the side arms of the Lower Weser as well as the Outer Weser from km 69 to km 120.

Due to the low contamination loads in sandy sediments of the ripple section from km 8 to km 55 its dredged material is classified mostly as case 1 according to HABAB; in these cases a relocation is possible without any restrictions.

Also, the contamination loads of the surface sediments as well as of the sediment cores from the Outer Weser are regarded to as low. Because of the TBT-load dredge material taken from the Outer Weser has to be regarded to as case 2 according to HABAK, its ecotoxicological impact, however, as case 1. Since the placement sites display a similar contamination load like the dredged material due to their high sediment dynamic, relocating the material is thoroughly possible.

In contrast, the Lower Weser from km 55 to km 58 (mud section Nordenham) displays a strong contamination load. The deeper sediment layers from about 50 cm downwards, show to some extent clearly higher contamination loads than the surface sediments, particularly for the heavy metals lead, cadmium, mercury and zinc as well as for the PAHs, PCBs and TBT. Obviously, deeper sediments in this area have settled at end of the 1980s and earlier. According to HABAK the contamination load of dredge material in the mud section has to be classified as case 2 and the ecotoxicological impact as case 1. The relocation of dredged material is only possible after a prior intensified examination. Elevated contamination loads were also partly found in surface sediments of the side arms of the Lower Weser but mainly in some deeper sediment layers.

5.3 Placement options

5.3.1 Procedures

Prior to the placement of dredged material in water bodies the options of use, treatment, re-use or the need of confined disposal have to be reviewed, taking technical, economical and ecological aspects into consideration (see Fig. 16). This is accomplished by a set of investigations according to different directives. For sea or estuary disposal of dredged material the "Joint transitional regulation for the handling of dredged material in coastal areas" is in charge (GÜBAK) (ANONYMUS 2009). The "Regulation for handling dredged material inland" applies to the area of the Weser upstream from Nordenham (km 58) (HABAB) (BFG 2000). Relocation of dredged material from ports at WSV placement sites has to be approved by NLWKN Lüneburg (Department for Water, Coastal and Nature Conservation in Lower Saxony), water authority, in the form of a licence issued under water law and by the WSA Bremerhaven in the form of shipping and river police approval. In addition, other authorities may be involved in placement of the dredged material in the Outer Weser (HAMER & KRESS written notice).

The question if water injection should be treated as a relocation method or not is seen differently. According to GÜBAK and HABAB WI is defined as a relocation method. However, according to SENATOR WUH, BP & HB HAFENAMT (2011) the application of WI is not seen as a relocation method and WI is operated in the ports without prior contaminant assessments (BREMENPORTS pers. comm.). The HABAB and GÜBAK shall be soon replaced by a new directive, which encompasses the coastal and inland regulations; how WI will be defined in this new regulation remains to be seen.

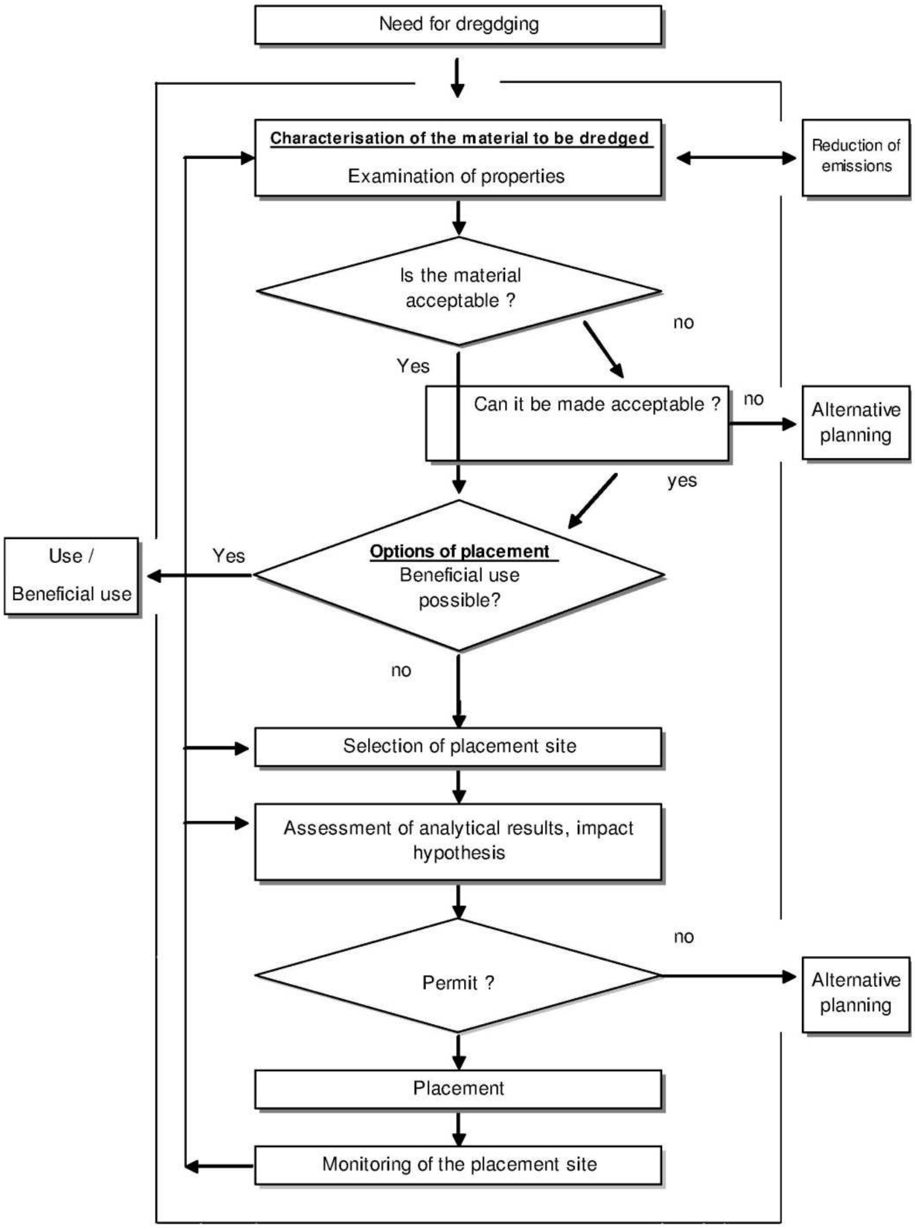


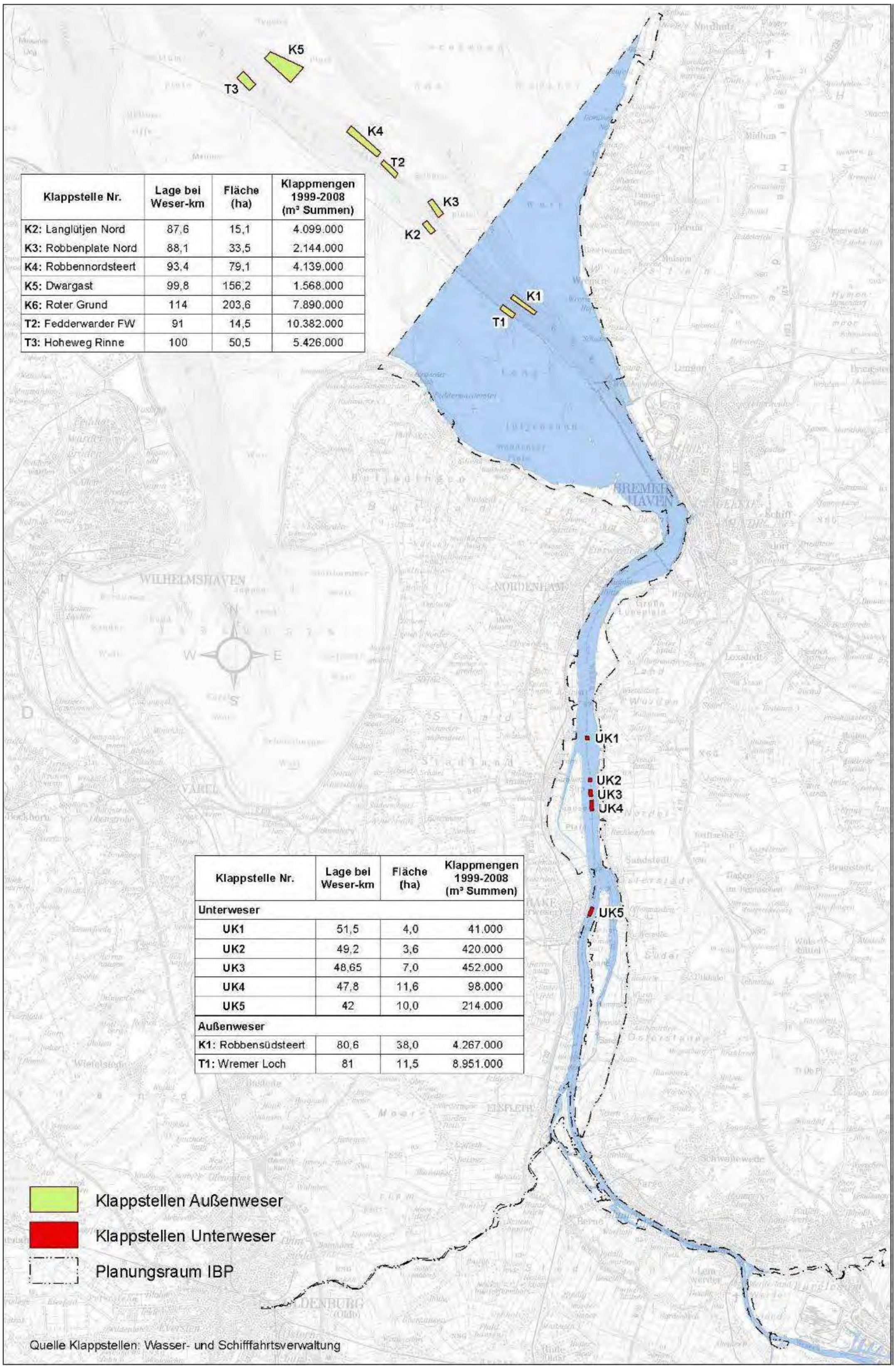
Fig. 16: Flow chart of dredged material assessment (ANONYMUS 2009).

5.3.2 Placement sites within the Weser estuary

The dredged material from the Lower and Outer Weser is taken to various placement sites, as long as it is not contaminated and deposited on land. A total of nine placement sites (placement sites K1–K6 and T1–T3) are permitted in the Outer Weser (see Fig. 17). They include the deepwater placement sites Wremer Loch (T1), Fedderward fairway (T2) and Hoheweg Rinne (T3) as well as the placement sites Robbensüdsteert (K1), Langlütjensand Nord (K2), Robbenplate Nord (K3), Robbennordsteert (K4), Dwarsgat (K5) and Roter Grund (K6). Sandy material can be dumped at all placement sites, except for K3, while muddy soil is placed at K1 and K3 as well as T1 and T2 (Tab. 8). In the Lower Weser there are five other placement sites (Weser km 42.0; 47.8; 48.6; 49.2 and

51.5) (see Fig. 17), for which only sandy dredged material from the Lower Weser is permitted (WSV 2010). The tables of Fig. 17 show the location of the placement sites, their size in area as well as the maintenance and placement volumes of the years 1999–2008. Yearly placement volumes of all placement sites are displayed in Fig. 18.

In the Hunte and Lesum maintenance dredging is carried out to a lesser extent. This sandy dredged material is used for sand nourishment on banks prone to erosion or deposited in over-depths of the Lower Weser (WSD NW, BP & N PORTS 2011). In 2005 217,100 m^3 of sediment from the deepening of the Hunte was additionally placed in the Weser between km 31.5 and 33 (WSA BREMEN written notice).



Klappstelle Nr.	Lage bei Weser-km	Fläche (ha)	Klappmengen 1999-2008 (m³ Summen)
K2: Langlütjen Nord	87,6	15,1	4.099.000
K3: Robbenplate Nord	88,1	33,5	2.144.000
K4: Robbennordsteert	93,4	79,1	4.139.000
K5: Dwargast	99,8	156,2	1.568.000
K6: Roter Grund	114	203,6	7.890.000
T2: Fedderwarder FW	91	14,5	10.382.000
T3: Hoheweg Rinne	100	50,5	5.426.000

Klappstelle Nr.	Lage bei Weser-km	Fläche (ha)	Klappmengen 1999-2008 (m³ Summen)
Unterweser			
UK1	51,5	4,0	41.000
UK2	49,2	3,6	420.000
UK3	48,65	7,0	452.000
UK4	47,8	11,6	98.000
UK5	42	10,0	214.000
Außenweser			
K1: Robbensüdsteert	80,6	38,0	4.267.000
T1: Wremer Loch	81	11,5	8.951.000

Fig. 17: Placement sites K1–K5 (K6 lies out of map) and T1–T3 in the Outer Weser and UK1–UK5 in the Lower Weser with tables of position within the estuary, area of placement site and volumes of placed material (WSD NW, BP & N PORTS 2011).

Tab. 8: Overview of placement sites in the Outer Weser and their present use (GFL, BIOCONSULT, KÜFOG 2006b).

Placement site		Allowed type of soil and tide phases for placement			
		Sandy		Cohesive	
		Flood tide	Ebb tide	Flood tide	Ebb tide
K1 *	Robbensüdsteert	No	Yes	No	Yes
K2	Langlütjensand Nord	Yes	No	No	No
K3 *	Robbenplate Nord	No	No	Yes	No
K4	Robbennordsteert	No	Yes	No	No
K5 **	Dwarsgat	Yes	Yes	No	No
K6	Roter Grund	Yes	Yes	No	No
T1 *	Wremer Loch	Yes	Yes	No	Yes
T2	Fedderwarder Fahrwasser	Yes	Yes	Yes	Yes
T3	Hoheweg Rinne	Yes	Yes	No	No

* Utilisation above all for dredged material from the Outer Weser.
** This placement site is hardly used in practice since it only permits low draughts.

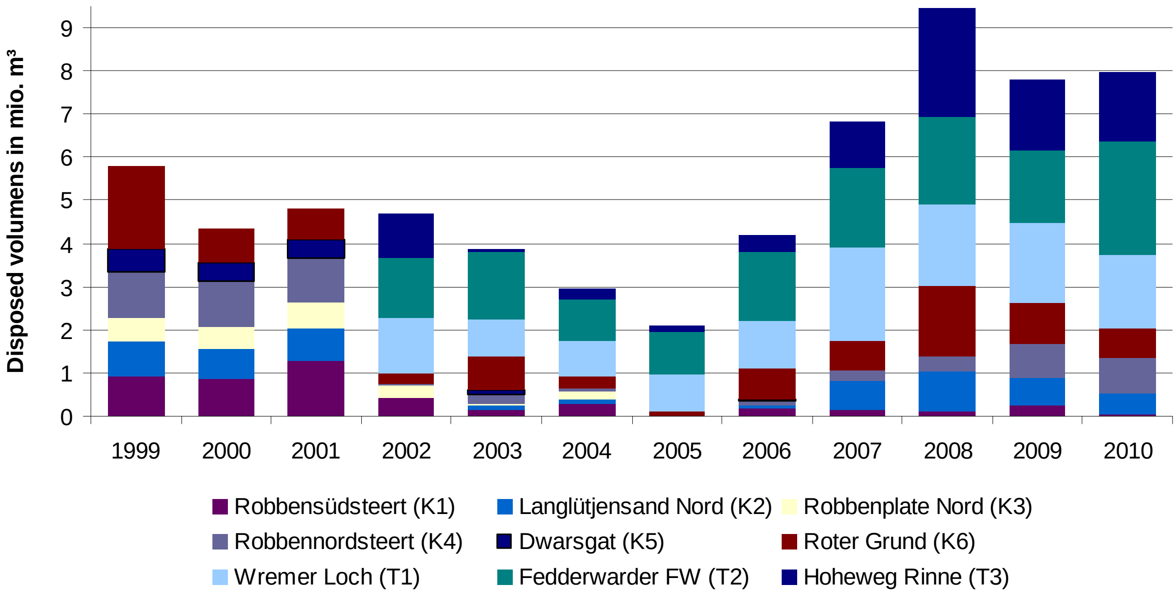


Fig. 18: Disposed volumes of dredged material from the different placement sites a year (own figure, data WSA BREMEN).

The volume of dredged material relocated from the federal waterway and port of Bremerhaven within the Weser estuary is shown in Fig. 19 from the year 1999 to 2009. Sediment from the port of Bremen was not relocated to these placement sites.

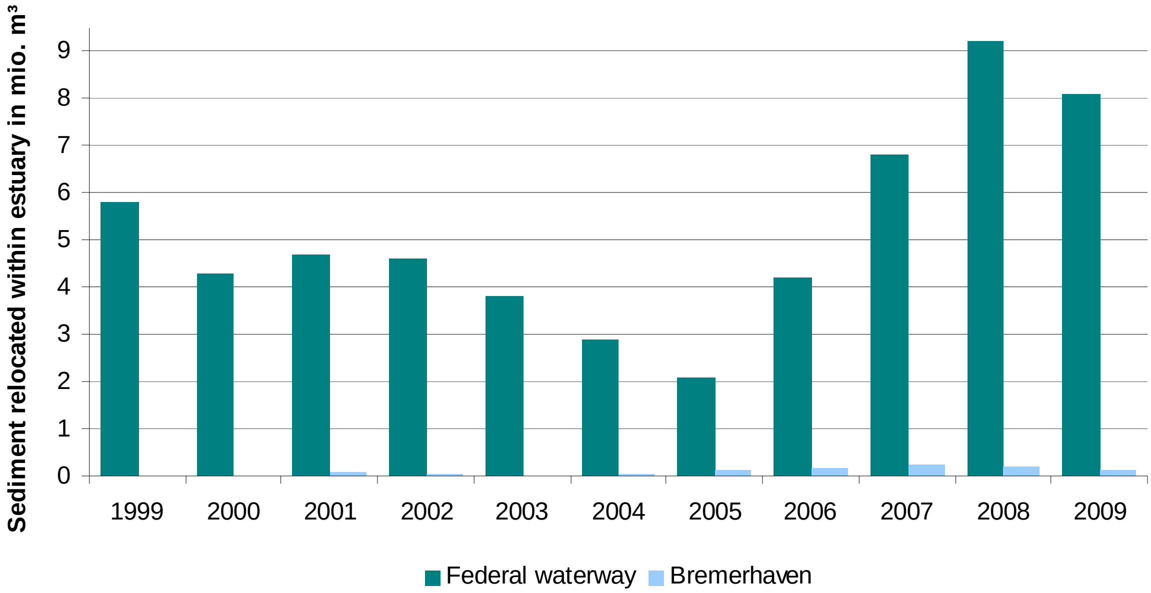


Fig. 19: Sediment relocated within the Weser estuary from the federal waterway and the port of Bremerhaven a year (own figure, data WSA BREMERHAVEN and BREMENPORTS).

In 2004 to 2006 large volumes from maintenance dredging were given to third parties, primarily in the framework of construction work (see Fig. 10). This is presumably one of the reasons for the low volumes of relocated material during these years. Causes of the increase in the last years seem to be among others large-scale morphological developments e.g. within the range of Hohe Weg (WSV & BFG written notice). Further causes should also be considered in our opinion. Within the development of the upcoming integrated river engineering concept an in-depth analysis is planned.

Within the framework of maintenance sand nourishment takes place at intervals of several years in non-reinforced shore sections exposed to the current in the main stream in order to secure the banks (GFL, BIOCONSULT, KÜFOG 2006b).

In recent years water injection (WI) has also been employed in the sandy sections of the Weser estuary to reduce dredging.

5.3.3 Land deposition and/or treatment of sediments

Deposition of dredged material on land is carried out with hardly contaminated sandy material for construction purposes. Muddy contaminated material not qualified for relocation is taken on land and deposited (up to the 1990s) or treated (nowadays); assessment criteria are given by national guidelines.

To confine the dredged material one option is to construct a flushing field on dry land; the other is to build a facility similar to a landfill and to use this to dispose dewatered sediment. Such a landfill operates in Bremen-Seehausen and allows to manage about 200,000 m^3 of sediment annually (BREMENPORTS pers. comm.).

Harbour sediment from the city of Bremen has been deposited at the integrated dredged material disposal site in Bremen-Seehausen since 1994 and also from Bremerhaven since 2001. Until that time contaminated material was deposited on disposal sites on land and on a placement site in the Wurster Arm. Furthermore, sediments were transported to the Lower Rhine (see section 5.3.4).

The only in-situ approach to be applied in real scale is capping contaminated sediments. Despite capping is the most commonly used in-situ option in some countries (HAMER et al. 2006), Bremen considered this option only theoretically (HAMER & KARIUS 2005). However, in spring 2011 dredged material of Bremerhaven was taken to a Confined Disposal Facility (CDF), the Slufter in Rotterdam, for the first time. Only highly contaminated material (limit value > Z 2, see Tab. 10) is allowed in the CDF. So far 71,327 m³ was handled in the Slufter (BREMENPORTS written notice). The yearly volume of sediment deposited on land and partly treated is displayed in Fig. 20 for the years 1999 to 2009. Sandy sediment – low in contamination – removed from the federal waterway was used for construction purposes and silty material from the ports – high in contamination – was deposited, treated and when possible re-used.

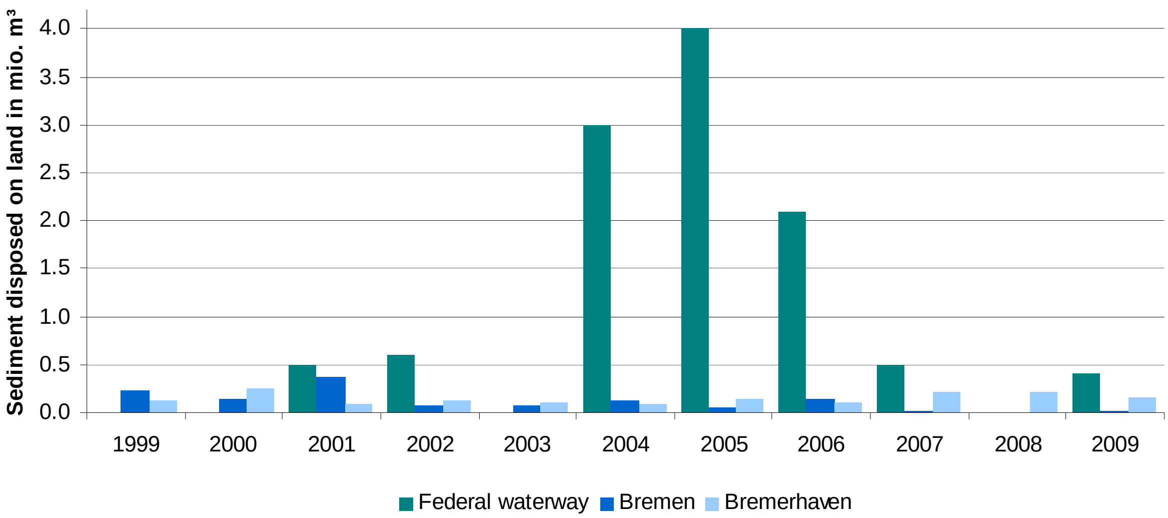


Fig. 20: Volumes of sediment removed from the Weser estuary between 1999 and 2009 from the federal waterway and the twin ports of Bremen and Bremerhaven (own figure, data WSA BREMERHAVEN and BREMENPORTS).

At the integrated dredged material disposal site in Bremen-Seehausen the mud-water mix is pumped onto 16 drainage fields with a total size of 36 ha and dried for about one year (Fig. 21). In the course of such treatment, stones, timber and other extraneous substances enclosed in the dredged material are removed. After the drying process the material is built in the deposit hill (32 ha) which has been equipped with downward and upper protection layers for which selected dredged sediment could be used as well (HAMER & KRESS written notice). The contaminated water is pumped into a drain water reservoir measuring 2.6 ha. In a plant-growth sewage plant following the drain water reservoir (1.6 ha) surplus water is purified and subsequently discharged into the Weser. Apart from the dredged material landfill, the drainage fields drain water reservoir and the plan-growth sewage plant are equipped with sealing systems because of the contaminants (BREMENPORTS 2003).

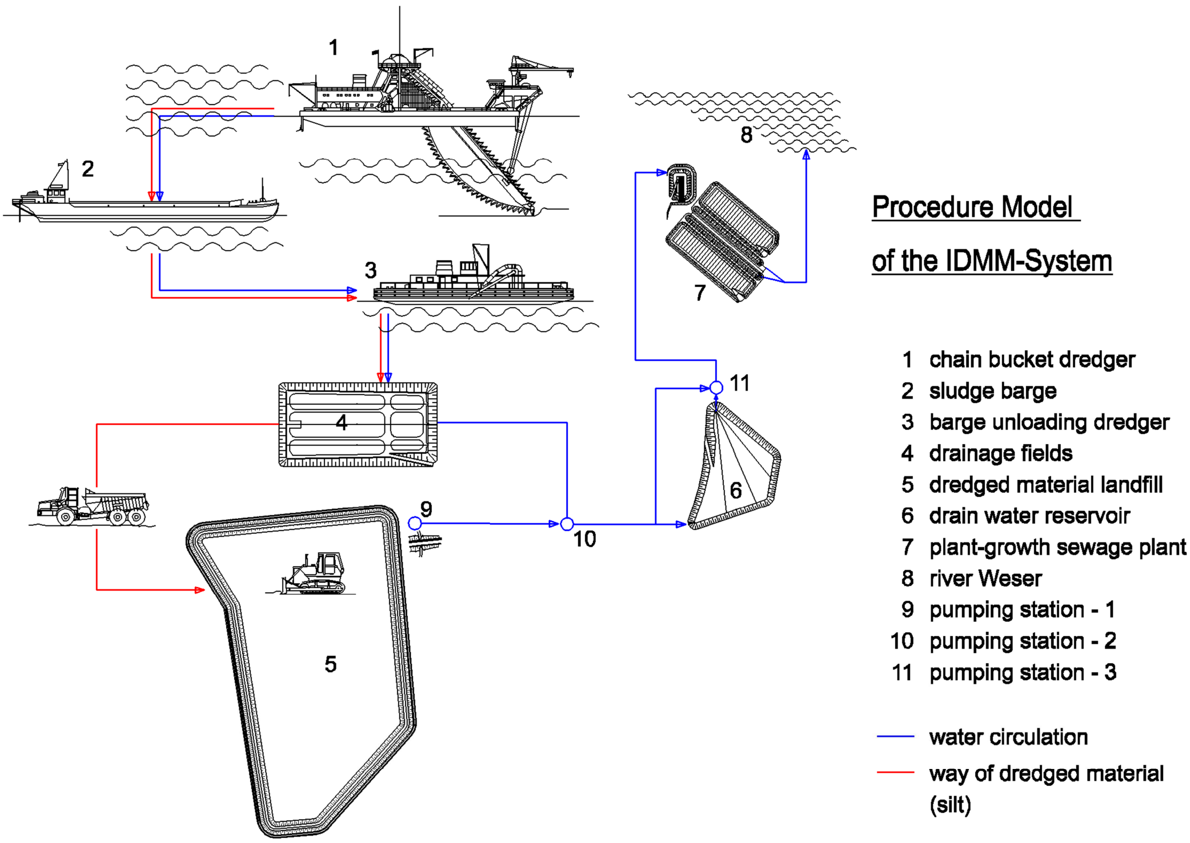


Fig. 21: Flow chart of the IDMM-System (Integrated Dredged Material Management) in Bremen-Seehausen (BREMENPORTS written notice).

5.3.4 Alternative utilisation of sediments

Uncontaminated sandy dredged material is utilised for construction purposes, in most cases to increase and prepare the subsoil of industry and infrastructure facilities. Fig. 10 shows the volumes removed in past years. In this case sand that would have been dredged anyway within the scope of maintenance (or during deepening projects) is generally used. However, the material is thus removed from the estuary as a morphodynamic system with impacts that can be assessed only to a restricted degree. Therefore, the volumes as of 2013 are to be limited (PIECHOTTA; DUNKER pers. comm.).

Utilisation of cohesive material is made difficult by the fact that it is usually contaminated. Use in agriculture, which used to be customary, is therefore currently not possible at all or only to a limited extent. If further reduction of contamination took place, this might become an option again in the long term, however.

Re-use scenarios of contaminated sediments may combine bio-remediation, chemical extraction or stabilisation in order to reclaim the treated sediments for civil engineering construction such as liner in landfill constructions (TRESSELT et al. 1998, DETZNER & KNIES 2004; BIENER et al. 2003), noise embankments or dikes (ARNING & HAMER 2005; GRÖNGRÖFT et al. 2005). Another alternative is to substitute natural clay with dredged sediments to produce bricks (HAMER & KARIUS 2002), lightweight aggregates (LWA) (DETZNER & KNIES 2004) or concrete (STERN 2007). All of the techniques mentioned were tested in different scales with different partners at the Weser and some have been applied at an industrial scale. However, most effective is the application in the field of civil engineering (Tab. 9).

Tab. 9: Re-use of dredged material by the ports of Bremen and Bremerhaven (HAMER & KRESS written notice).

Year	Volume of dredged material m^3 in situ	Application	Where
1999–2008	1,100,000	Different layers in the landfill Bremen Seehausen	Bremen
2006–2009	230,000	Recultivation of gravel/clay pits	North Rhine-Westphalia
2005–2010	> 400,000	Dike construction and maintenance	Along the Weser, Weser estuary

According to the recommended threshold limits regarding the content of pollutants in mineral recycling material (LAGA 2004), the dredged sediments of Bremen can be used as raw material for LWA production (Tab. 10). The installation classes 0 (non-restrictive utilisation), 1 (restrictive open placement) and 2 (restrictive placement with defined technical safeguarding measures) are distinguished (LAGA 2004). Material exceeding these threshold limit values would be suggested to be deposited in a landfill. Placement of dredged material in dikes thus requires previous approval by the responsible water authority.

Tab. 10: Contents of pollutants in dredged material from the ports of Bremen and Bremerhaven treated in Bremen-Seehausen compared with recommended limit values (Z values: ≤ Z 0: non-restrictive utilisation, ≤ Z 1: restrictive open placement and ≤ Z 2: restrictive placement with defined technical safeguarding measures) for re-use (LAGA 2004) (mg/kg dry substance, data relate to total sediment) (HAMER & KRESS written notice).

Pollutant	Z 0	Z 1	Z 2	Mean value dredged material 1997–2003	Port of Bremen 1996–2001	Port of Bremerhaven 1996–2001
Cadmium (Cd)	1	3	10	3	1.1–3.8	0.9–1.2
Lead (Pb)	70	210	700	99	53–110	88–98
Chromium (Cr)	60	180	600	75	41–93	100–130
Copper (Cu)	40	120	400	57	31–73	39–45
Mercury (Hg)	0.5	1.5	5	< 1	0.2–0.41	0.4–0.46
Nickel (Ni)	50	150	500	36	24–41	41–49
Zinc (Zn)	150	450	1500	477	260–590	300–390
Arsenic (As)	15	45	150	14	11–17	22–29
Thallium (Tl)	0.7	2.1	7	< 0.9	< 0.5–0.9	–
Cyanide		3	10	No value	< 0.5	–
∑ PAH according to EPA	1	3	30	2.3	0.61–4.43[a]	0.71–1.56
∑ PCB congenere (DIN 51527)	0.05	0.15	0.5	0.03	0.004–0.0266[a]	0.0026–0.0047
BTEX (aromatic hydrocarbons)	1	1	1	< 0.01	< 0.01	–
LHKW (lightly volatile halogenated hydrocarbons)	1	1	1	< 0.015	< 0.015	–
Hydrocarbons	100	600	2000	221	50–370[a]	58–93
EOX (extractable halogens in organic bonding)	1	3	15	0.33	0.33	–
MBT(mercaptobenzothiazole)				0.024	0.005–0.5	
DBT(dibutyltin)				0.035	0.005–0.035	
TBT(tributyltin)				0.148	0.004–0.028	

[a] respective concentration Naphthaline and Benzo-(a)-Pyrene < 1.0

Of course further treatment methods are constantly being developed, but are not ready for industrial use (HAMER & KRESS written notice).

Bremen is working on the assessment of treatment products. While products are being used, circumstances can change so that formerly stable pollutants are mobilised again. Methods used to investigate potential emissions have to consider the whole life-cycle of the product including the phases of storage, use, potential re-use under different boundary conditions and finally disposal (HAMER & KRESS written notice). This approach is implemented in the Dutch Building Material Decree enacted in 1999 and considered in German regulation as well (DIBT 2009).

6. Sediment management strategies

Current sediment management in the Weser estuary has developed historically and constantly adapted itself to the respective requirements. At present there is no written strategy, either for the entire estuary or for specific parts. Currently, the Federal Institute of Hydrology is developing a sediment management concept in cooperation with the WSV that will presumably be submitted in draft form in spring 2013. River engineering is not part of this sediment management concept. This aspect along with sediment management will be incorporated into an integrated river engineering concept as of 2015. Extensive investigations will be carried out for this purpose. Development of an integrated river engineering concept is one of the measures specified in the Integrated Management Plan (IMP) according to the Habitats Directive.

The following presentation is based on available literature and reports, talks with various players and our own experience and assessments. A distinction must be made in particular between deepening and maintenance of the fairway by the Federal Waterways and Shipping Administration and the maintenance of the ports by the federal states of Bremen and Lower Saxony.

Sediment management can only be understood if at the same time the conditions in the natural space, the river engineering measures of the past and present and the relocation of sediment are given consideration since all aspects are directly linked to one another.

6.1 Capital dredging of fairways

The Weser estuary has been adapted to developments in shipping traffic for more than 100 years. The last time the Lower Weser was deepened to a depth of 9 m below chart datum (9 m deepening) between 1973 and 1978 and the Outer Weser was deepened to a depth of 14 m below chart datum (14 m deepening) in 1998/1999. At present further deepening measures in the Lower and Outer Weser have been approved, but proceedings instituted against them are currently pending (see section 3).

Between Bremen and Brake (km 8 to 40) the fairway will be lowered by approx. 0.4 to 0.6 m by cutting off the ripple crests in this ripple section through water injection. This section of the Lower Weser is already currently maintained by means of water injection. Deepening of the fairway between Brake and Nordenham (km 40 to 55) will be carried out using the same method. A deepening of approx. 0.8 to 1.0 m is envisaged in this section. Before Nordenham, in the area of the so-called „mud section" (km 55 to 58) the necessary lowering of the fairway bottom by approx. 0.7 to 0.8 m will be carried out by means of hopper dredgers. The dredged material will be deposited at placement sites in the Outer Weser.

In the Outer Weser the fairway between km 65 and 120 will be deepened by approx. 1.2 m. Hopper dredgers will primarily remove sandy sediments and relocate them at placement sites in the Outer Weser (respective volumes see section 5.1.1). Between km 99 and 130 the fairway will be widened from 300 to 380 m. In addition, the turning site that was set up by bremenports in front of the Bremerhaven container terminal in 2006 will be deepened.

There are no plans to alter the river engineering structures extensively built in the past (see section 4.1). In two areas (Blexer Bogen km 58 to 65 and km 99 to 110) diversions of the fairway are envisaged in areas of greater natural water depth in order to reduce the future maintenance effort (WSV 2010).

The principles of the previous deepening are continued with the current planned deepening measures in the Outer Weser constitutively (establishing the depths by hopper dredgers; relocation of material to placement sites; river engineering measures to restrict maintenance dredging; relocation of the fairway to naturally deeper areas where possible). In the Lower Weser the use of hopper dredgers is largely substituted by WI; this is a change of a constitutive past deepening principle with the goal to reduce costs and impairments of the environment. Measures to reduce the rise of the tidal range like in the current deepening of the Elbe estuary are not part of the planning.

Official planning approval as the conclusion of the approval procedure stipulates extensive preservation of evidence, particularly concerning the rise of the tidal range, the expected upstream shift of the brackish water zone and the possible consequences for the anadromous migratory fish species twaite shad. Environmental organizations question the need, fear pronounced impairment and point out the increase in impairments connected with every deepening measure.

In the application documents a significant increase in maintenance dredging volumes is expected after the deepening (see Tab. 5). A substantial rise in the maintenance volumes, which was considerably above that expected in the application documents for the approval procedure, also took place after the last deepening of the Outer Weser (14 m deepening in 1999). An in-depth analysis of the reasons is planned in the framework of development of an integrated river engineering concept in the coming years (DUNKER, WSA BREMERHAVEN pers. comm.).

6.2 Maintenance dredging of fairways

Maintenance of the fairway is carried out, on the one hand, through maintenance of the existing river engineering structures and possibly through their adaptation to altered boundary conditions and, on the other hand, through relocation of sediments. The two approaches mutually influence each other.

6.2.1 River engineering in the Weser estuary

The basic principles of river engineering measures in the Lower and Outer Weser are outlined in section 4.2. Concerning the Lower Weser they go back to Ludwig Franzius (first deepening about 1890). They have been developed further and adjusted to the respective situation in the following years, regarding further deepening as well as maintenance. The river engineering situation in the Outer Weser was comprehensively analysed by HOVERS (1973) and DIECKMANN & POHL (1991). Essentially, river engineering measures aim to limit maintenance dredging, however, on the other hand dredging material is used to support river engineering constructions.

Currently, no adjustments of the basic river engineering principles are planned (PIECHOTTA; DUNKER pers. comm.). From 2015 on an integrated river engineering concept shall be developed on the basis of extensive analysis by the Federal Waterways Engineering and Research Institute.

6.2.2 Maintenance dredging

Maintenance dredging in the fairway is carried out between Bremen and Nordenham (km 8 to 55) by means of water injection (see section 5.1.1). The sandy ripple crests are mobilized such that they drift into the ripple valleys. The ripples form again within weeks to months, depending in particular on the head water, so that cutting off the crests has to be repeated. This procedure has been applied since 2003/2004 as it is less expensive than the use of hopper dredgers. It is also applied in certain parts of the Outer Weser, wherever technically feasible. One of the main limiting factors in this area is the heavier swell. The impacts on the environment have been assessed within the scope of the environmental impact assessment for the current deepening (GFL, BIOCONSULT, KÜFOG 2006b). The impairment of the benthos appears to be relatively minor compared to hopper dredging due to the existing species-poor community adapted to the dynamic conditions.

In the area encompassing the so-called "mud stretch" (km 55 to 58) before Nordenham the muddy sediment is collected with hopper dredgers and taken to special placement sites in the Outer Weser. The mud stretch is associated with the estuarine turbidity zone (turbidity maximum).

The fairway in the Outer Weser seaward of the mud stretch is maintained up to approx. km 120 by means of hopper dredgers. Mainly sandy sediments are removed and relocated to placement sites in the Outer Weser.

The objective of the WSV is to secure the officially approved water depths via minimal maintenance dredging. The primary motivation is cost reduction and, to an increasing extent, reduction of the ecological impacts related to maintenance (WSD NW, BP & N PORTS 2011). Limitation of maintenance dredging takes place through a number of measures, in particular:

- definition of a main channel and concentration of the force of the current on the latter (especially historically)
- river engineering measures (primarily training walls and groynes)
- adaptation of the location of the fairway to the current morphological situation
- avoidance of cyclical dredging via appropriate location of placement sites
- application of water injection dredging

For the long-term development of maintenance volumes in the Weser estuary no consistent data set is available. Between 1979 and 1986 the relocated volumes dropped from 7.5 to 1.7 million/m^3 (WETZEL 1987). WETZEL (1987) primarily specifies the last phases of morphological development subsequent to the last deepening of the Lower Weser and further river engineering measures (building of groynes and training structures) as reasons for this. The volumes in the Outer Weser rose significantly after the 14 m deepening (detailed information is only partly available so far). The river engineering situation created up to that time with relatively low maintenance volumes changed due to the 14 m deepening, though the reasons for this have not been completely understood as yet.

After the 9 m deepening there appeared to be a sediment deficit in the Lower Weser (main channel) that can be regarded as a result of the dredging work for the 9 m deepening, sand removal for measures by third parties and perhaps also increased flow speeds and mainly affected the section from km 40 to 65 (MÜLLER 2002). The sometimes large sediment volumes removed within a short time, such as for dike construction work in the Hunte area, were completely removed from the system and the river was not able to compensate for them. Since the mid-1980s sand removal has been discontinued in the Lower Weser. The river bed has been stabilized since then and erosion processes have not been observed (GFL, BIOCONSULT, KÜFOG 2006b). Today there is no discernible sediment deficit in the Weser estuary. Large quantities of sediment may be removed only for construction work requiring special application and as of 2013 the volume will be limited (PIECHOTTA; DUNKER pers. comm.).

Upstream transport of certain sediment fractions in the Weser estuary by virtue of tidal pumping does not takes place to an extent that would lead to additional maintenance dredging (PIECHOTTA; DUNKER pers. comm.).

Contamination of the dredged material relocated in the fairway remains below the relevant limit values in the Weser estuary due to the reduced deposition of harmful substances in past years and because of the predominantly very low fine grain fraction so that there are no restrictions for sediment management in the fairway in terms of contamination.

So far there have been no general temporal restrictions on performance of the maintenance. Possible impairment of the environment are looked at in the framework of the licence issue under water law prior to placement of fine-grained sediments from port maintenance. The official approval for the current deepening measure stipulates avoidance of the reproduction phase of the twaite shad in connection with use of water injection and hopper dredgers mainly during capital dredging, to the extent compatible with nautical concerns. During maintenance restrictions are foreseen, if monitoring gives evidence for impact.

Implementation of current EU guidelines, such as the Habitats Directive, Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD), has substantially extended the requirements of sediment management, especially in deepening projects, but also for regular maintenance. Keywords include increased public participation, appropriate assessment, joint development of the Integrated Management Plan (IMP) for the Weser estuary by various players and monitoring.

Outlook

A significant change in the maintenance strategy, particularly in the Lower Weser, took place in 2003/2004 through the changeover from hopper dredger to water injection. There were no other fundamental changes. Currently the Federal Institute of Hydrology is developing a sediment management concept in cooperation with the WSV. It is not yet foreseeable whether this will lead to changes in current practice. The rise in maintenance volumes in the Outer Weser after the last deepening will be analyzed in detail primarily within the framework of the planned river engineering concept as of 2015.

The possible impacts of climate change on the Weser estuary and its use are assessed in SCHUCHARDT & SCHIRMER (2005). At present a large-scale research project in which various institutions of the Federal Transport Ministry are examining the possible consequences for the waterways and shipping in Germany, including the estuaries (www.kliwas.de). Possible consequences for practical action in connection with sediment management will be discussed after completion of the project in 2014 (PIECHOTTA; DUNKER pers. comm.).

6.3 Maintenance dredging of harbours

The port areas open to the tide (as well as the harbours behind locks) in Bremerhaven, the city of Bremen, Brake and Nordenham have to be maintained. Hopper dredgers are primarily used to remove the predominantly sandy material in the harbours open to the estuary, such as at the container terminal in Bremerhaven and the riverside quays in Brake and Nordenham. In the muddy port areas open to the tide non-consolidated sedimented particulate matter is regularly remobilized by means of water injection processes, in addition to removal by means of hopper dredgers, thus reducing maintenance dredging with removal. Water injection has been applied in the lock exit basins in Bremerhaven since 1994. Since then dredging with removal of approx. 300,000 m³ of material a year has no longer been necessary. Maintenance dredging with removal in the Bremen port group was also reduced by means of water injection (WSD NW, BP & N PORTS 2011).

In the case of the dredged material removed from the ports open to the tide, a fundamental distinction must be made between sandy and fine-grained material (mud). While the sandy material is hardly contaminated, the muddy material is still contaminated to such an extent that it cannot be placed back in the water body according to the applicable limit values despite of the general reduction in contaminant inputs and contamination of the dredged material. This material is primarily deposited at the integrated dredged material disposal site in Bremen-Seehausen and treated there (see section 5.3.3). Until the 1980s dredged material from the ports of Bremen city was washed up on land. The material from the ports of Bremerhaven could still be relocated at that time in the outer Weser estuary. This ended 1997 for the silt material from the ports of Bremerhaven which were situated behind locks because of high values of TBT (HAMER & KRESS written notice).

In the ports of Bremen/Bremerhaven a sustainable water-depth-management has been established with four principles (HAMER & KRESS written notice):

1. Avoid sedimentation
2. Return of any uncontaminated sediments back to the estuary (particularly sand)
3. Re-use
4. Disposal of contaminated dredged material

Though not explicitly mentioned, this also includes efforts to reduce the contamination of the sediments (see section 5.2.2).

Avoid sedimentation

To avoid sedimentation in the locked harbours renewal of certain constructions, new manuals for lock-operation and low-sediment-watering by the lock channels had been important innovations to reduce water loss and sediment inflow in the locked harbours. For the "Überseehafen" in Bremerhaven a new watering facility ("Freilaufkanal") was designed and constructed as it was the best solution to get low-sediment water from upper parts of the water column out of the river Weser that are not influenced by fluid-mud of ground structures (HAMER & KRESS written notice). This measure alone reduces the sedimention rate in the Überseehafen by half.

One of the river engineering measures to reduce sedimentation in Neustädter Hafen was the closing of the Lankenauer Höft/Weserinsel passage, thus avoiding the formation of eddies in the harbour basin with increased sedimentation in the centre of the eddy.

Overall, the natural force of the current is utilised extensively in comparison to other ports due to the high proportion of quays open to the estuary in the Lower Weser in Lower Saxony and, in particular, in Bremerhaven. In addition, the high proportion of harbours behind locks reduces sedimentation compared to harbour basins open to the tide. Presumably, this represents a very effective measure for avoiding sedimentation although quantitative assessments in this connection are not available.

Return of any uncontaminated sediments back to the estuary

If it is not possible to avoid dredging there is a further second principle to return the uncontaminated materials back into the estuary. By this the aim is followed to keep the sediments in the system. Therefore permission is necessary that estimates the effects on environment. Today this is the practice for sandy materials; fine materials are still too much contaminated referred to national assessment criteria. To keep the sediments in the system is on one hand good for the ecological system and the system depends on sediments if it shall be resilient against future challenges like sea level rise. On the other hand it is economically sensible, because it is much more expensive to deposit or treat the sediments on land (HAMER & KRESS written notice).

In the water body it is possible to relocate, in particular, the sandy material that accumulates in the area around the quays open to the estuary and the material from the exit basins of the locks, which in some cases has a higher proportion of mud. The material is primarily mobilized by means of water injection and then carried away by the tidal flow. In Bremerhaven, for example, it has been possible to dispense with maintenance dredging, including removal in the exit basins, completely since deployment of water injection equipment. Prior to the application of this technology, an annual volume of approx. 300,000 m³ was dredged in the exit basins and relocated (HAMER & KRESS written notice).

However, muddy material, too, is increasingly relocated via water injection. In the port of Bremen the efforts to refrain from carrying out conventional maintenance dredging of muddy material in the ports open to the tide were successful for the first time in 2010 thanks to intensive use of water injection. The water depths were maintained solely through water injection.

Water injection is operated in the ports without prior contaminant assessments (BREMENPORTS pers. comm.) since the process is not defined as dredging according to SENATOR WUH, BP & HB HAFENAMT (2011). Although, to this different conceptions exist (see section 5.3.1).

Re-use

Re-use of cohesive dredged material has been extensively studied in Bremen, particularly in the 1990s. Although many ideas have been analyzed, only use of material conditioned via integrated disposal of dredged material is economically feasible up to now (see section 5.3). A further reduction in the contamination of the sediments is necessary for more extensive use.

Disposal of contaminated dredged material

Since 1994 contaminated harbour mud from the city of Bremen and since 2001 also from Bremerhaven has been placed at the integrated disposal site for dredged material in Bremen-Seehausen. Until that time contaminated material was deposited on disposal sites on land and on a placement site in the Wurster Arm (Outer Weser).

Despite of progress in reducing the contamination of the sediments and cutting back the relocated volumes, it remains impossible to relocate all sediments in the water body. The more highly contaminated sediments still have to be disposed on land or treated prior to re-use. The methods are undergoing continuous optimization. Especially use of dredged material after treatment as landfill building material and as dike construction material has proven effective.

Reduction of contamination

By taking measures in the catchment area and in the port and shipping areas, it has been possible to significantly reduce the contamination of the sediments (section 5.2.2).

The primary substances of concern in the ports of the Weser estuary were and are some heavy metals and tributyltin (TBT), which was used as an anti-fouling agent up to 2008. Since 1999 all shipbuilding companies in Bremen and Bremerhaven have been required to set up and operate wastewater treatment facilities to reduce deposition in the water body. Also by 1999 the licence under water law introduced (and has in the meantime implemented) the requirement for pleasure craft clubs and marinas to purify wastewater from the washing of leisure crafts prior to discharge into water bodies. However, up to now there is no reduction of TBT in the sediments.

Contamination with heavy metals does not predominantly derive from current point sources (which are easier to close), but from historical mining, which led to large-scale soil pollution in the catchment area. This contamination can therefore be reduced only to a limited extent.

For a number of parameters the concentrations in cohesive dredged material are still considerably too high so that part of the dredged material has to be disposed of on land. Further reduction in contamination is thus a basic prerequisite for sediment management without disposal of dredged material on land.

For this purpose it is necessary, in particular, to further reduce deposition into the water body in the entire catchment area. In the Weser system, however, this is possible only to a limited degree because of historical mining in the catchment area.

6.4 Relocation of sediments

Handling of dredged material from maintenance and capital dredging has changed elementary throughout the last decades, especially in the Lower Weser.

Up to the 1970s sandy dredged material had been spaciously placed on the foreland (especially in the Lower Weser). This was accomplished mainly to remove it from the system, to positively change the geometry of the Lower Weser in terms of hydraulic engineering, to increase the size of agricultural useful areas and for building purposes. Particularly since the end of the 1980s this has changed significantly. Sandy material is practically not taken from the Lower Weser anymore. Instead the material is largely relocated by WI within the water body or brought into overdepths. Smaller amounts are being used for coastal nourishments to compensate erosions and to be able to dispense with the building of coastal protections.

In the Outer Weser sandy material was and still is mainly deposited on approved placement sites (see section 5.3.2). With appropriate positioning of the placement sites it is tried to secure river engineering structures with the deposited material (e.g. erosion at training walls) and to support their effect as well as to avoid cyclical dredging. Larger quantities have also consistently been taken for building purposes. These volumes will be restricted from 2013 on (DUNKER pers. comm.) to prevent sediment deficits. Placements sites are intended according to their task as transit or accumulation placement site. On the transit placement sites the deposited dredged material does not remain permanently but is distributed already while placing the material because of the local situation of the current or through resuspension. In this process the current is transporting a part of the material to particular target location, like eroding edges of tidal flats. At the accumulation placement sites material is deposited in such a way into the water body that it partly remains stable and, if applicable, it develops a desired river engineering effect. Utilisation of dredged material for a targeted creation of habitats has to our knowledge not been taken place in the Weser estuary until now. However, coastal nourishments in the Lower Weser can be partly understood as such.

Before approving new placement sites an extensive assessment programme according to GÜBAK (ANONYMUS 2009) has to be accomplished (see section 5.3). It has to take into account impairments of benthos as well as water and sediment quality.

6.5 Land treatments, confined disposal facility (CDF) and alternative utilisation

6.5.1 Land treatments and CDF

In 1991 the Senate of Bremen decided to establish the concept of an integrated treatment of dredged material to lower the landscape consumption and to install an environmentally friendly disposal system. Apart from measures for reduction of the dredged material this system entails a long-term and safe on land disposal on the disposal site Bremen-Seehausen. It was put into service in 1994 for the treatment of dredged material from the ports of Bremen city. This kind of hill-disposal reduced land-consumption in comparison to former large-scale land disposal. A long-term monitoring proves that the interests of the public are not harmed. From 2001 onwards also contaminated fine material from Bremerhaven harbours has been able to deposit in Bremen-Seehausen (HAMER & KRESS written notice).

Beginning of 2011 sediments of the ports of Bremerhaven were for the first time put at the Slufter in Rotterdam. 71,327 m³ material was handled there (BREMENPORTS written notice). After the pilot test in 2011 the placement of contaminated material to the CDF in Rotterdam will continue, to be able to dredge more sediments from the ports behind locks (BREMENPORTS pers. comm.).

6.5.2 Alternative utilisation

Details regarding these aspects can be found in section 5.3.4 and shall not be repeated here. Provision is made for raising the portion of usable dredged material in the future further to be able to utilise the space in the integrated dredged material disposal site in Bremen-Seehausen longer (HAMER & KRESS written notice).

6.6 Sediment management and the environment

While relocation of sediment was formerly managed mainly by economical and river engineering aspects in the past years to decades aspects of nature and environmental conservation have increasingly gained relevance.

Contamination of dredged material

From about the 1980s on contamination of estuarine sediments has gradually been recognized as a environmentally relevant problem when relocating dredged material. It has led to series of laws and regulations for relocation within the water body as well as deposition on land with the aim to reduce the risk for the environment. In this process efforts have been undertaken to reduce the inputs of contaminants as well as their release during relocation through appropriate treatment and deposition on land (see section 5.3.3).

However, the contamination of cohesive sediments, especially from port areas, has not been able to be reduced as appropriate to be relocated completely within the water body. Despite of the world wide ban of TBT as an anti-fouling agent contamination loads of the sediments are still too high.

Further reduction of inputs from upstream is also necessary to relocate dredged material within the water body to its full extend. Here, the European Water Framework Directive (WFD) targets at additional reduction. However, consequences of WI on fine grained (possibly contaminated) sediments should be critically checked.

In the long run land treatment and disposal is not a sustainable sediment management practice since sediment should be preserved as an important component of the river system. Thus, reduction of land disposal should be a long term goal. This requires the decontamination of historically polluted places.

Ecological impact of dredging and disposal

Relocation of sediment within the water body leads at the dredging areas as well as at the placement sites to impairment of the benthic population and, at least with cohesive sediment, possibly to temporary impairment of the water quality (oxygen depletion, turbidity et cetera). On the other hand it is expedient to leave sediments, if possible, within the water body and to provide it for the natural dynamic. But also disposal on land is often related with impairments of the environment.

Thus, there is a conflict also between various environmental aspects and it is always necessary to consider different aspects. Therefore it is reasonable and essential to consider in time and adequately the aspects of environmental and nature conservation when developing an integrated river engineering and sediment management concept. This includes an compatibility assessment of the river engineering and sediment management concept according to the European directives like the Habitats Directive, Birds Directive, WFD and at present MSFD.

7. Conclusion and recommendations

Current sediment management in the Weser estuary has developed historically and constantly adapted itself to the respective requirements. At present there is no written strategy, either for the entire estuary or for specific parts. Currently, the Federal Institute of Hydrology is developing a sediment management concept in cooperation with the WSV that will presumably be submitted in draft form in spring 2013. River engineering is not part of this sediment management concept. This aspect along with sediment management will be incorporated into an integrated river engineering concept as of 2015.

In the Weser estuary, which has been morphologically modified to a great extent in the past 120 years, a close interaction between river engineering and sediment management exists. This should be adequately considered in the forthcoming integrated river engineering concept.

While there have been almost no fundamental changes in the formal principles of river engineering (in particular determination of the main channel by training walls and groynes and the concentration of the force of the current towards these) since the first deepening at the end of the 19th century the sediment management with regard to maintenance dredging has altered more. Clear modifications in the past years to decades are the extensive abandonment of land deposition of (non-contaminated) dredged material, the limitation of quantities that can be removed for building purposes, the proper disposal of contaminated dredged material on land and its partial re-use, the increased relocation within the water body without removal by water injection, the decrease of contamination of sediments and the increasing consideration of nature and environmental conservation aspects within the sediment management.

Overall, the natural force of the current is utilised extensively in comparison to other ports due to the high proportion of quays open to the estuary in the Lower Weser in Lower Saxony and, in particular, in Bremerhaven. In addition, the high proportion of harbours behind locks reduces sedimentation compared to harbour basins open to the tides. Presumably, this represents a very effective measure for avoiding sedimentation although quantitative assessments in this connection are not available.

However, at the same time measures were conducted and are planned that led and will lead to a clear increase of maintenance dredging (particularly deepening of the Outer Weser 1998/99, turning site in Bremerhaven, new riverside quays in Brake, planned deepening of the Weser). In the planned integrated river engineering concept it should be verified if a restriction of the rising quantities is achievable through river engineering measures since it is fundamental that increasing maintenance dredging involves greater ecological impairments and costs. Also, the results from the KLIWAS project that will be present by that time with the expected impacts of climate change can be considered then.

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