River Engineering and Sediment Management Concept for the Tidal Elbe River

Task 2: Evaluation of handling contaminated sediments from the perspective of ecology and economic efficiency

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Summary

The Federal Waterways and Shipping Administration (WSV) and the Hamburg Port Authority (HPA) presented a jointly developed "River Engineering and Sediment Management Concept for the Tidal River Elbe" (RESMC) in 2008. The concept contains a number of innovative approaches for which little or no experience is available and parts of it are not easy to implement since interests of third parties are affected. In view of this, external experts have been asked to evaluate the RESMC with respect to its compatibility with the objective of sustainable development of the tidal Elbe. This report focuses on evaluation of the handling of contaminated sediments from the perspective of ecology and economic efficiency.

The objectives of the RESMC are according to our evaluation highly relevant and sensible for the short to middle long-term. The combination of land treatment of the most contaminated sediments, relocation within the river to retain sediments

as natural part of the river system and relocation at sea to break the sediment recirculation cycle are considered sound solutions. The long-term success of the RESMC will depend on contaminant source separation and contaminant source reduction. Methods to separate sources will limit the volume of material to be handled and source reduction decreases the contaminant concentrations in the suspended matter and hence sediments. Sustainable sediment management for the tidal Elbe should encompass flood measures that prevent large amounts of contaminated sediments reaching the Port of Hamburg from the upper reaches of the catchment area.

The primary contaminants that limit sediment management options are: Cd, Hg, PCB, gamma HCH, HCB, DDT and metabolites, with the main sources located in the upper parts of the Elbe catchment. Within the Port of Hamburg, a strong focus on historical contaminants in the harbour of Hamburg as well as source reduction from industry, urban run-off and wastewater has to be given priority to be able to meet the requirements of sustainable sediment management. TBT should be a specific point of attention in relation to harbour activities as this compound has strong implications for relocation of sediments in the marine environment.

A programme of measures to reduce contaminant input from primary and secondary sources in the upper part of the Elbe catchment, as part of the Elbe River Basin Management Plan (RBMP), will eventually reduce contaminant concentrations in suspended and settled matter in the tidal Elbe. However the timetable for such reductions is not yet clear, and it is likely that contaminant content of dredged material will remain a considerable constraint on the cost effective implementation of the RESMC for some time. It is recommended that consideration is given, within the Elbe RBMP, to prioritising those contaminants listed above that limit sediment management options. Also it is recommended that short term measures to reduce contaminants reaching the Hamburg harbour are evaluated.

A number of suggestions are made including interim measures to reduce constraints on sediment management options in the period before contaminant input reductions are fully effective. These include the continuation of sea disposal for some of the material from the Port of Hamburg, the investigation of relocation of the Port's dredged material within the river and capping of some sediments after disposal in regions of the lower river.

Contents

1 Introduction

The Federal Waterways and Shipping Administration (WSV) and the Hamburg Port Authority (HPA) presented a jointly developed "River Engineering and Sediment Management Concept for the Tidal River Elbe" (RESMC) in 2008. The primary source of motivation was the rise in the quantity of sediment to be dredged for the maintenance of the water depth, particularly in the Hamburg area, an altered legal framework as well as the changes in the delta with an unbalanced solids budget.

The concept contains a number of innovative approaches for which little or no experience is available and parts of it are not easy to implement since interests of third parties are affected. On the other hand, it also opens up certain synergies with nature conservation interests. In view of this situation WSV and HPA have decided to arrange for an external evaluation of the concept in order to achieve broader verification and thus acceptance as well as to obtain suggestions for its further development.

The purpose of the project can be outlined as follows. External experts shall analyze and evaluate the targeted practice (which has already been realized in part) presented in the RESMC with respect to its compatibility with the objective of sustainable development of the tidal Elbe. The currently planned deepening of the shipping channel in the Lower and Outer Elbe is not the object of the evaluation.

1.1 Outline of RESMC

On the basis of the overall approach of the RESMC, the long-term and equally weighted objectives of the RESMC as a contribution to sustainable development of the tidal River Elbe can be formulated as follows:

- *Securing the shipping channel depths for the tidal River Elbe according to planning approval*
- *Reducing the dredging quantities and costs*
- *Reducing the environmental impairments related to maintenance*
- *Compatibility with and/or support of the regional objectives of nature conservation and marine protection as well as water resources management*
- *Compatibility with the requirements of European and national water protection, marine protection and nature conservation*
- *Broad social acceptance*

1.2 Evaluation structure

The evaluation process is divided in 5 tasks addressed by different experts:

1. Sediment relocation and river engineering measures of the RESMC from the perspective of effectiveness and economic efficiency.
2. Measures of the RESMC on handling contaminated sediments from the perspective of ecology and economic efficiency.

3. Sediment relocation and river engineering measures of the RESMC from an estuary ecology perspective.
4. The RESMC in view of sediment management strategies at other European estuaries from a morphological perspective.
5. The RESMC in view of sediment management strategies at other European estuaries and European guidelines from an ecological perspective.

This report focuses on task 2: measures of the RESMC for handling contaminated sediments from the perspective of ecology and economic efficiency.

1.3 Outline of task 2

Task 2 focuses on evaluation of the measures described in the RESMC concerning the handling of contaminated sediments from the perspective of ecology and economic efficiency. The following specific questions should be addressed:

Assessment of the situation as of 2005 and with further implementation of the RESMC:

- What is the assessment of the current practice of handling contaminated dredged material on the tidal River Elbe? Are additional options possible beyond that practice?
- What is the assessment of the environmental impact, in particular the ecotoxicological, of the relocation to buoy E3?
- What is the assessment of the objectives described in the RESMC concerning future handling of contaminated dredged material on the tidal River Elbe and in the entire Elbe region (on-shore treatment, relocation, remediation support), also in view of the European regulations and the practice in other estuaries?
- Do the criteria regarding risk assessment of contaminated dredged material conform with the practice in other European countries? What is the assessment of these criteria?
- What requirements have to be met for sustainable sediment management on the tidal River Elbe in the inner part of the catchment area? Are the objectives of FGG-Elbe and IKSE appropriate and realistic for this task?
- What is the assessment of action on the (tidal) River Elbe with respect to the London and OSPAR Conventions as well as the MSFD?

Overall assessment:

- Are the objectives of the RESMC formulated in the work order sensible in your opinion, also in view of the situation in other European estuaries?
- Do the measures outlined in the RESMC (relocation, on-shore treatment and remediation support) represent overall the right way to achieve the objectives?
- Recommendations for the further development of the RESMC.

1.4 Outline of the report

The above mentioned questions will be addressed in this report. A summary of the information used for the evaluation is presented as basis for the observations and conclusions. The report has been build up as follows:

- Contaminant status at present
- Present handling of contaminated sediments
- International experience from other rivers
- Consequences of present day practice
- Future scenarios
- Alternative approaches
- Recommendations and summary of the initial questions

2 Contaminant status at present

2.1 Overview over sediment quality in the various parts of the Elbe

An overview over the quality of the suspended solids in different parts of the Elbe catchment is given in Heise at al. (2005 and 2008a) and FGG (2009). A general overview of the sources in the different parts of the catchment area are shown in figure 1.

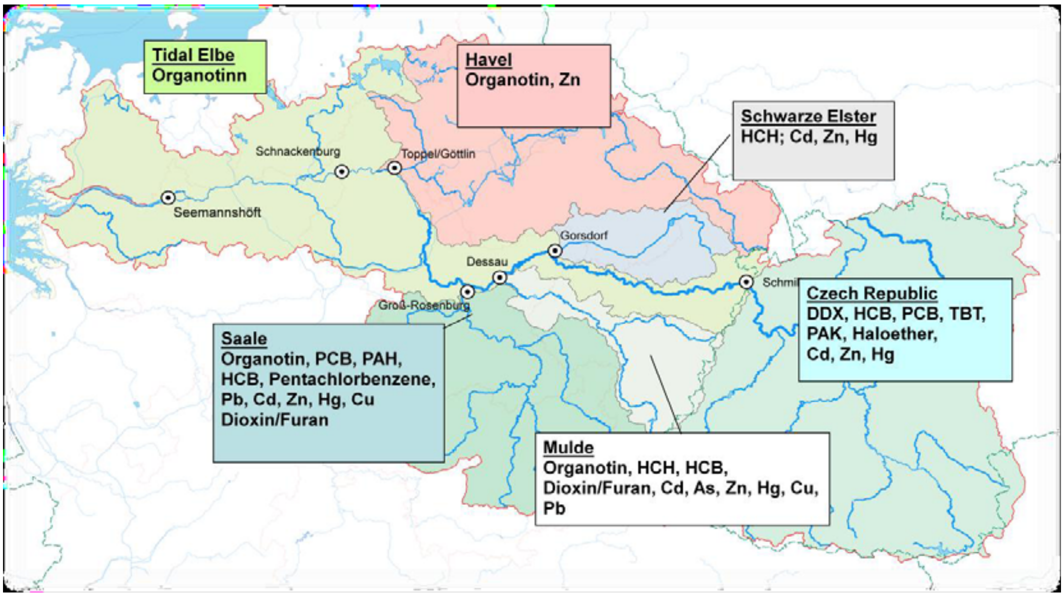
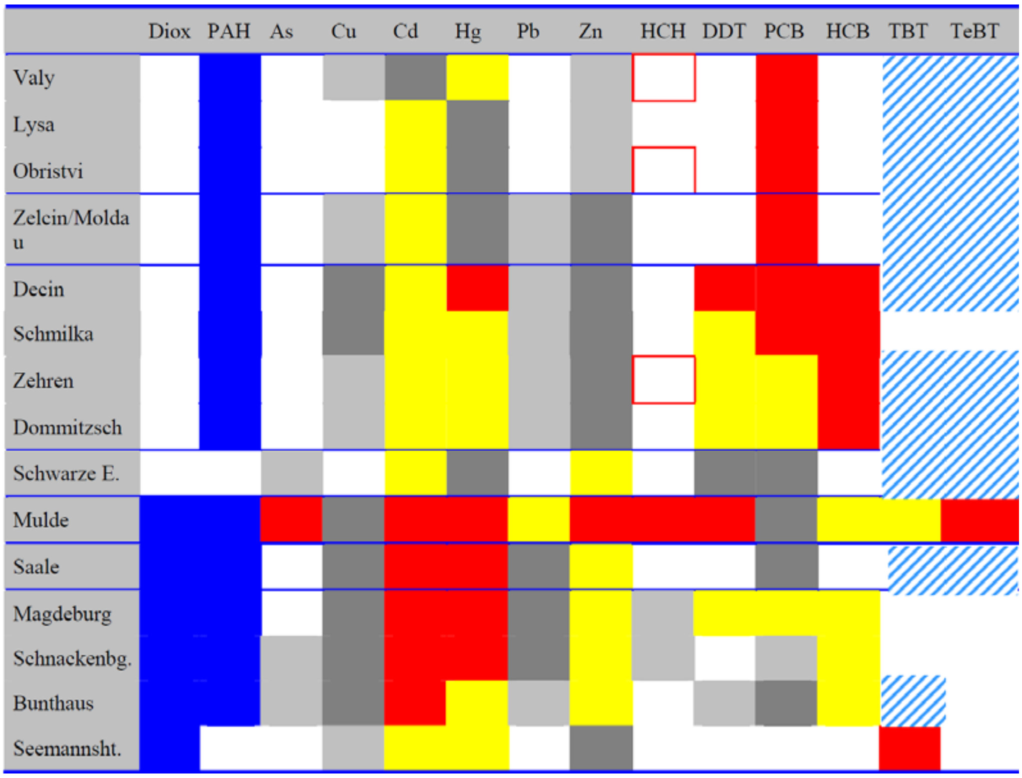


Figure 1. Overview of the critical contaminants in the different parts of the Elbe catchment (from FGG, 2009).

Despite dramatic decreases in the contaminant levels since the early 1990's historic contaminants like persistent chlorinated hydrocarbons and heavy metals are still the dominant pollutants (Table 1). Cd, Hg, DDT, PCB and HCB exceed target values at the border with the Czech Republic (Schmilka). Heavy metals contribute strongly in the Mulde and Saale area. Upstream of Hamburg (Bunthaus), Cd, Hg, Zn and HCB are the main contaminants.

Downstream of the harbour in the tidal part of the Elbe (Seemannshöft) contaminant concentrations reduce rapidly as a result of intermixing with marine sediments (Figure 2). However, Hg, Cd, DDT (including metabolites DDD + DDE), HCB, gamma HCH, PCB and TBT are identified as critical with respect to the handling of dredged material and possibilities for disposal (see chapter 3.2).

Table 1. Exceedance of target values in different parts of the Elbe catchment (from Heise, 2008b)



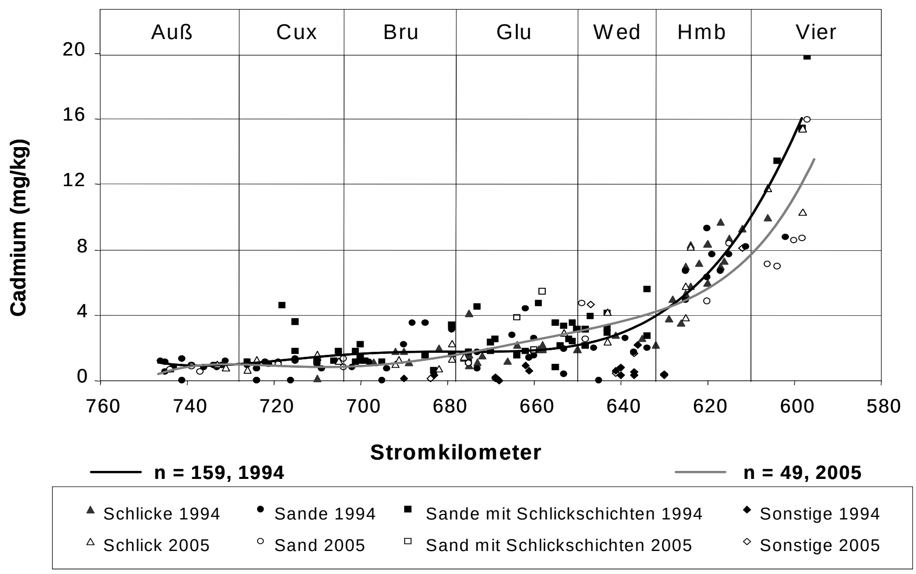


Figure 2 Reduction in the concentration of Cadmium in the sediments downstream of the port of Hamburg (km 620).

2.2 Contaminant loads

The general understanding of the contaminant transport in the tidal Elbe is a net input of contaminants from the upper catchment area which is mixed with contaminants in the harbour area and clean material transported upstream from the estuary (Figure 3). This process will result in lower levels of contaminants in a larger volume of sediments.

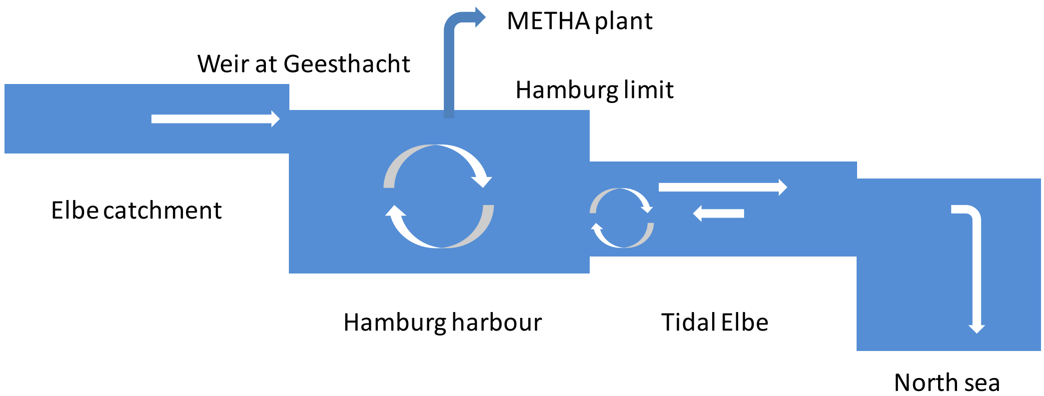


Figure 3 Schematic illustration of contaminant fluxes in the Port of Hamburg.

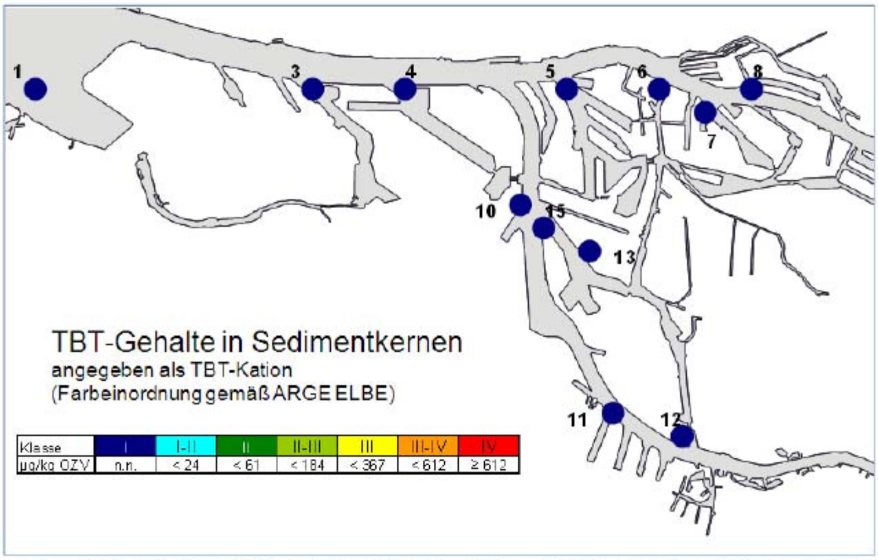
To be able to address the contribution of the various contaminant sources to the contaminants found in the dredged material an overview of contaminant loads for the critical contaminants is presented in table 2. Despite the large uncertainties in the presented numbers, they give a general overview of the potential for contaminant reduction. Unfortunately the data for some critical contaminants in the tidal Elbe like PCB and DDT including metabolites, were not suitable for load calculations. Total adsorbable organic halogen (AOX) gives however an indication of the presences of hydrophobic and persistent chlorinated compounds.

Table 2. Total contaminant loads at monitoring stations along the Elbe river mean values for period 2003-2008 based on the official balancing profiles of the international Elbe commission (IKSE-MKOL, 2010 www.ikse-mkol.org).

Compound	Czech border	Schnackenburg[1]	Seemannshöft[2]
Cd (t/y)	0.8	4.4	2.6
Hg (t/y)	0.2	1.3	1.4
γ-HCH (kg/y)	11	18	19
HCB (kg/y)	15	17	24
AOX (t/y)	272	438	575

[1] Upstream of Port of Hamburg
[2] Downstream of Port of Hamburg

Land treatment of dredged material in the port of Hamburg removes e.g. 2,2 tons of Cd and 1,8 tons of Hg from the river system yearly. Data for the chlorinated organic compounds are not suitable for load calculations. In addition to those contaminants entering the Hamburg port from the non-tidal Elbe, some contaminants are introduced in the Hamburg area. Organotins are of special interest since these anti-foulant compounds are highly toxic and bioaccumulative in aquatic systems and enter the environment through shipping activities, particularly ship maintenance. Although TBT use on ships has been banned in recent years it remains on the hulls of vessels from earlier use, and can enter the harbour sediments during hull cleaning. The presence of TBT in sediments in the port area has been monitored by the HPA, (HPA, 2008, 2009, and 2010).



TBT	Ref 1 Außeneste	Ref 3 Köhlfleet	Ref 4 Parkhafen	Ref 5 Vorhafen	Ref 6 Reiherst.	Ref 7 Hansah.	Ref 8 NE6-Strandh.	Ref 10 Sandauh.	Ref 13 Rethe Bl.2	Ref 15 Rethe Bl.3	Ref 11 Seehaf. 4	Ref 12 ReiV
1997		514	343	759	6610	1280	798	330	[903]	350		
1998	198 *	353	406 *	962 *	3831	896	1207	137	316	176	64	
1999		348	323 *	644 *	3946 *	1224	837 *	274	[590]	335	306	
2000	132 *	301	304 *	428 *	1660	1058 *	419 *	247	353	262 *	149	
2001	228 *	394	360 *	575 *	1856 *	[864 *]	592 *	308 *	311 *	357 *	164	
2002	83	179	103	262	548	607	196 *	122	144	157	88	
2003	132	279	230	250	2301	820	509	164	340	181	201	
2004	92	176	288	259	838	427	331	136	239	131	111	60
2005	116	378	227	203	282	292	203	101	199	133	100	133
2006	104 *	123 *	140 *	180 *	305 *	260	130 *	113 *	155 *	120	134	42
2007	[33]	72 *	103 *	135	158 *	180	82	[51]	120	117 *	135	89
2008	[90]	95 *	83 *	144 *	299 *	152 *	93 *	[49]	115 *	103 *	152	101
2009	[63]	123 *	119 *	256 *	370 *	131	97 *	64	102 *	77	87	56
2010	[25]	137 *	101 *	140 *	740 *	162	110	43	89 *	171 *	59	43

* TBT-Mittelwert aus mehreren Sedimentkernen aus den Gebieten. [ ] Wert nur bedingt vergleichbar aufgrund Sedimentalter bzw. Lage

Figure 4 *TBT levels in sediment samples in the period 1997-2010 in the Port of Hamburg (classification according to ARGE-ELBE).*

The presence of organotins in the harbour sediments constrains the disposal possibilities for dredged material. High concentrations still occur in one area in 2010 suggesting that measures to prevent TBT entering the harbour sediments are not yet fully effective (Figure 4).

3 Present handling of contaminated sediments

3.1 Sediment handling in the Hamburg port

The Hamburg Port Authority dredges approximately 5 to 6 mill m^3 of sediments yearly to maintain operations. Relocation downstream at the border of the Port of Hamburg is the preferred option for the less contaminated material (approximately 4 mill m^3 per year). The more contaminated material mostly from the old parts of the harbour is treated on land by sand separation followed by dewatering (METHA plant) and subsequent safe disposal or beneficial use, accounting for approximately 1 million m^3 per year.

3.1.1 Relocation at Neßsand

Since 1994 HPA has relocated some dredged material to the north of the island of Neßsand some 10km downstream of the port. The river is deep and fast flowing at this point and highly turbid. Studies showed that the dredged material deposited here mixes with the naturally occurring suspended solids and is widely distributed by the action of tides. The amount of material deposited by HPA at Neßsand averaged 2.8 million cubic metres over the period 2006 to 2009. Conditions for disposal have been agreed between HPA and BSU, the administrative body for environmental issues in Hamburg and include technology, natural protection areas, impact assessment regulations and further developments. Relocation is only permitted routinely between November and March (Figure 5). Relocation may be allowed in September and October in agreed situations, in which case oxygen availability, fine matter content of the dredged material, total volume and headwater discharge are additional considerations. The assessment of the dredged material for relocation at Neßsand is made according to the ARGE Elbe sediment assessment scheme (ARGE Elbe, 1996). Detailed figures for sediment relocation at Neßsand are given in the year reports (HPA, 2008, 2009, 2010).

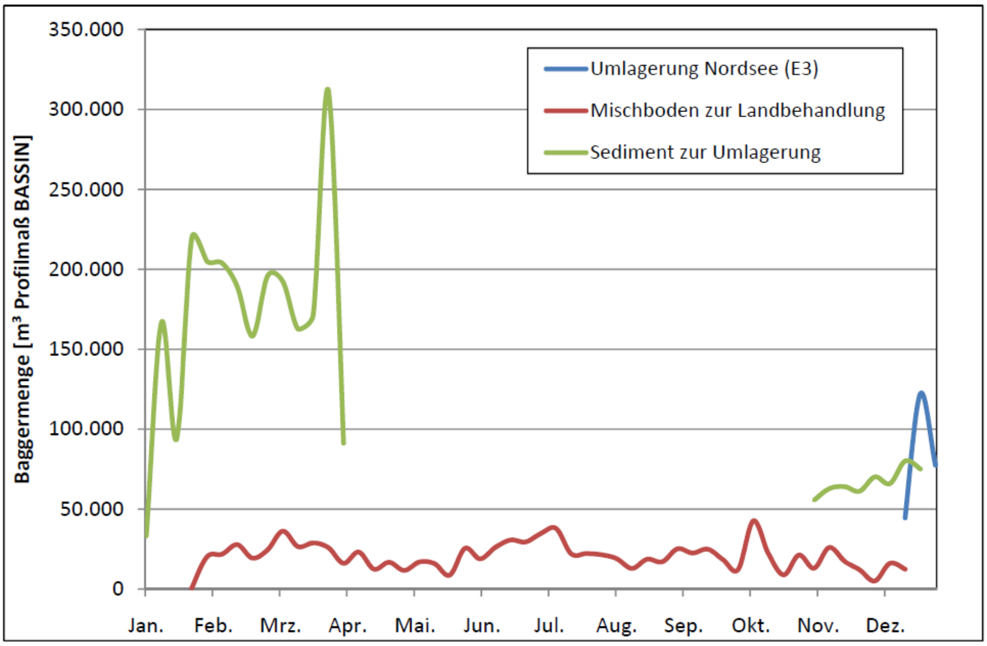


Figure 5 Dredging volumes and disposal methods in 2009, green relocation, red land treatment, blue disposal at sea (HPA, 2010)

Relocation at Neßsand is thought to have resulted in recirculation of sediments and an increase in dredging requirement. Hence sea disposal of material with lower levels of contaminants has been practised since 2005 in an attempt to reduce this recirculation-see section 3.2.

3.1.2 Quality criteria to select disposal option

Different quality criteria are used for assessing suspended solids/sediments in the river and dredged material in the coastal zone.

Table 3 gives an overview of the different criteria for selected compounds that have been shown to be critical for the relocation of dredged material in the tidal Elbe. ARGE Elbe values for fresh water sediments were decided in 1996 by Elbe Länder environmental ministers; they are limit values not to be exceeded. Target values were also set. For coastal disposal HABAK values were replaced in 2009 by the 'Transitional Regulation for the Handling of Dredged Material in Coastal areas', (BfG, 2009); these are guidance values. A further complication is that different grain size fractions are used in different regulations:

ARGE Elbe values: total sample
HABAK: all in < 20µm
Transitional Regulations: heavy metals in < 20µm, organics in < 63 µm

The table clearly indicates that there is a strong contrast between environmental limit values for the fresh and marine aquatic system. The target values are in closer agreement, but still are less stringent for some of the critical organic compounds in the freshwater environment.

Table 3 Assessment criteria for critical contaminants in sediments in the tidal Elbe.

Compound	Guidance fresh water ARGE Elbe		Dredged material in coastal zone since Aug 2009 (Transitional regulations)		HABAK Guidance values dredged material prior to Aug 2009	
	Target value	Limit value	RW1	RW2	GV1	GV2
Cd (mg/kg)	1,2	10	1,5	4,5	2.5	12.5
Hg(mg/kg)	0,8	5	0,7	2,1	1.0	5
PCB_7 (µg/kg)	5	175[1]	13	40	20	60
γ-HCH (µg/kg)	10	50	0,5	1,5	0.2	0.6
HCB (µg/kg)	40	100	1,8	5,5	2	6
DDT (µg/kg)	40	100	1	3	1	3
DDD (µg/kg)	40	100	2	6	3	10
DDE (µg/kg)	40	100	1	3	1	3
Org Sn (µg/kg)	25	150	8[2]	40/120[2]	-	-

[1] 25 µg/kg for each congener
[2] TBT for Wadden Sea/Offshore converted to µg Sn/kg (2,44 µg TBT = 1 µg Sn)

The assessment of the suitability of dredged material for sea or estuary disposal is currently based on the "Transitional Regulation for the Handling of Dredged material in Coastal areas" in force since August 2009, which replaces the earlier HABAK.
An upper (RW2) and lower (RW1) guidance value is specified for each contaminant. The lower value is based on existing data about sediment contaminant content in the German part of the Wadden Sea and the coastal

sediments of the North Sea. The upper value is calculated by multiplying RW1 by 3. Values for metals refer to particle size fraction <20microns, and for organic parameters <63microns. Both refer to dry solids. Metals are measured directly on the given size fraction, organic contaminants on the whole sediment, and normalized to 63microns.

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 a full impact assessment has to be prepared. If needed, go to Case III. Further monitoring is necessary (fish, benthos). Measures for impact minimization need to be considered.

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 (landfilling) and treatment options have to be considered.

Bioassays have to be implemented in Case III. These tests are used to access 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.

Table 4 Ecotoxicological analysis, use of bioassays as defined in Case III

	Level of diluton without effects	pT-value of single tests	Classification
ECOTOXICITY	Original	0	0
	1 : 2	1	I
	1 : 4	2	II
	1 : 8	3	III
	1 : 16	4	IV
	1 : 32	5	V
	1 : 64	→ 6	VI

The pT-value, table 4 is the result of the most sensitive organism within a test series of bioassays on the same level. Bioassays are used besides other criteria in decision making of a disposal option. Toxicity classes 0 – II are considered to be harmless. Higher results have to be considered in the impact prognosis; in these cases the reasons for elevated toxicity require identification

3.2 Permit for sea disposal

3.2.1 2005-2008

During 2004 and 2005 large amounts of sediment were dredged in Hamburg port and it was decided to investigate disposal of dredged material further downstream to reduce the amount apparently re-circulated back to the port from the deposit at Neßsand.
Permission was granted to deposit material at a site outside the estuary in the inner German Bight, near buoy E3. The surrounding area is a natural silt deposit and hence sediments have similar physical characteristics to the dredged material.
The permit allowed the deposit of up to 4.5 million cubic metres of dredged sediments from the Elbe to the North Sea. Assessments of the suitability of the dredged material for sea disposal were made under the German directive HABAK. This directive transposed the requirements of the international conventions LC, OSPAR, HELCOM into German law, see section 4.2.
Monitoring of the impacts of disposal at the site was undertaken from 2005 onwards. By the beginning of 2009 the approved amount had been deposited.

Figure 6 shows the amounts deposited at E3 over the period 2005 to 2010.

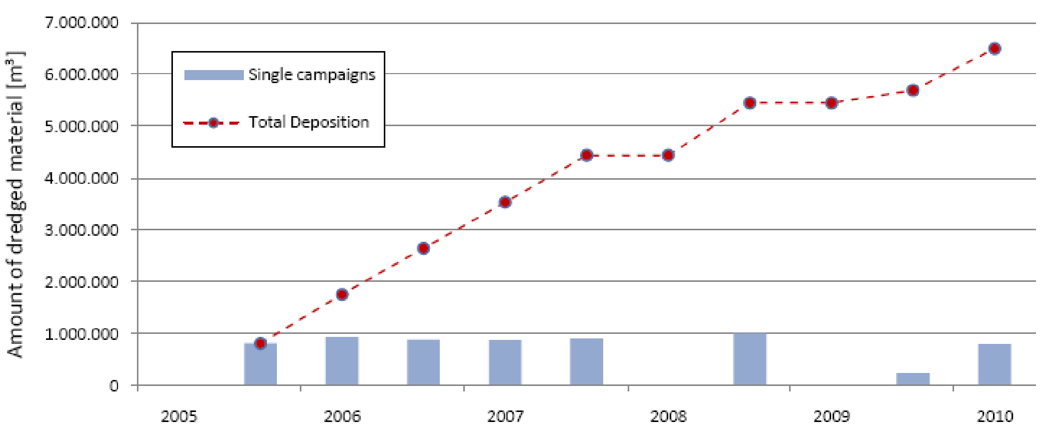


Figure 6 Volumes of dredged material deposited at Buoy E3 by HPA over the period 2005-2010.

3.2.2 2009-2011

A further agreement was reached to transfer another 6.5 million cubic metres to Buoy E3. The agreement was granted subject to additional monitoring requirements and concludes at the end of 2011.The assessment of suitability for sea disposal was based on the “Transitional Regulation for the Handling of Dredged Material in Coastal areas” in force since August 2009 which replaced the earlier HABAK

The dredged material disposed by the Port of Hamburg during this period was freshly deposited sediments in the Federal waterways and was largely classified as Class II or Class III. Class III designations were largely due to organic contaminants and in general heavy metals were Class II.

The issue of disposal permits of dredged material from the Elbe containing contaminant concentrations in excess of national guidelines (Class III) was notified to OSPAR in line with their requirements. The contaminants of concern notified for 2008 were CB180, HCB, gamma HCH, pp-DDT, pp-DDD and pp-DDE (OSPAR, 2010).

3.3 Sediment handling in the lower reaches of the river

3.3.1 Dredged material management in the tidal Elbe, WSV areas

Downstream of the Port of Hamburg, dredging is under the control of the WSA Hamburg to km 689.8 and WSA Cuxhaven downstream of that. In the WSA Hamburg area the highest volumes need to be dredged in the region of the Wedel (km 638.9-644.0) and Juelssand (km 649.5-654.4). The material is mainly silty fine sand and is excavated by hopper dredgers. Downstream of Juelssand, sandy material predominates. In the WSA Cuxhaven controlled area the bed material is mostly sand and substantial amounts of silt only occur in the Osteriff dredging section (km 698.5-709.0). The mouth of the estuary narrows at this point making it one of the most important dredging sites of WSA Cuxhaven. Other key dredging sites occur in front of Cuxhaven (km 717.0-726.0) and at the slip off slope near the eastern central navigation channel (km 732-0-739.0). In 2008 morphological changes occurred and a sandbar (Kratzsand) moved towards the navigation channel and hence dredging volumes in this area increased (km 726.0-732.0). Little other dredging is required in the WSA Cuxhaven area, merely as needed from time to time largely due to ripple/dune formation. All of the hopper dredged material is relocated within the river.

Figure 7 shows the relocation volumes in WSA Hamburg’s area of control.

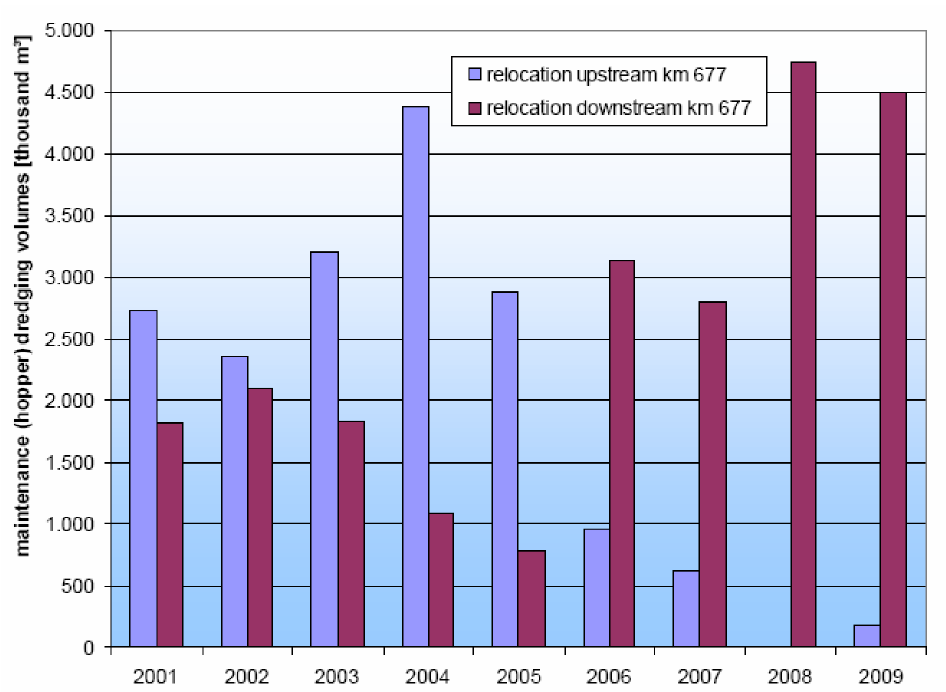


Figure 7 Relocation of maintenance dredging volumes in the WSA Hamburg area.

Since 2006, a changed relocation strategy has been implemented to relocate more of the material downstream, and since 2008 almost all of the material has been relocated to between km 686 and km 690 in the area of the main zone of turbidity maximum in the river (Figure 8). This change was instigated in order to reduce the quantities of sediment being recirculated, the aim being to reduce upstream transport of the relocated material.

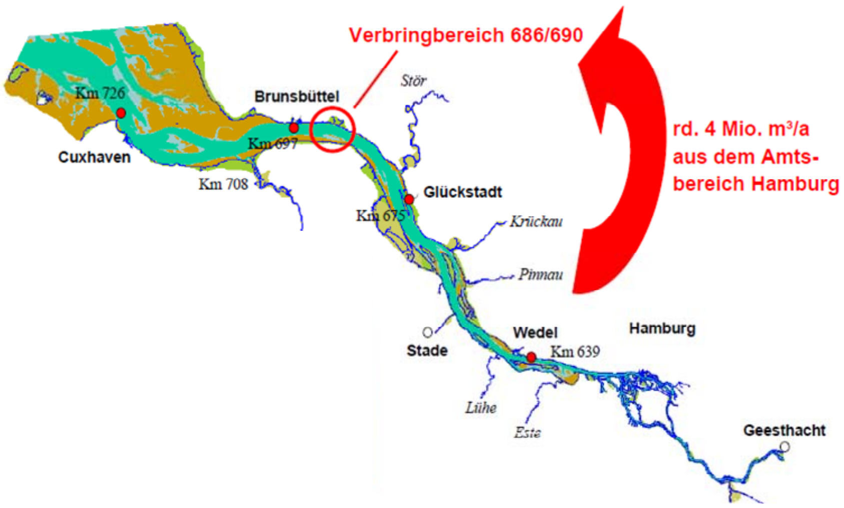


Figure 8 Changed relocation strategy in the tidal Elbe since 2006

A series of investigations into the morphological and ecological impacts of the changed strategy have been commissioned. An impact prognosis in accordance with the Joint Transitional Regulation for the Handling of Dredged Material is expected by BfG in 2011.

Analyses of pollutant concentrations show that these decrease down the estuary due to mixing with sediment of marine origin. In the WSA Hamburg area, sediments are classified as case II and III according to the HABAK classification (see table 3), and heavy metal concentrations remain the same from Wedel to Pagensand, then decrease in general. Hydrocarbons and PAHs remain fairly uniform throughout the WSA Hamburg area, organochlorine compounds and TBT decrease from Juelssand section. Contaminant data relating to sediments from Brunsbuttle 2007-2009, (BfG, 2010) show most sediments corresponding to Case I or Case II, however a small number of samples exhibit concentrations of DDE and DDT in excess of the guidance values for Case II. The deposit of these sediments within the estuary was notified to OSPAR in 2008 on account of the DDT and DDE values. All of the sediments from the Cuxhaven area were lower in contaminants, with metals mostly below the lowest guidance level, i.e. Case I, except for Cu and occasionally Hg and Zn which fell into Case II. Of the organic contaminants only DDE, DDT and organo-tins were Case II, the others falling below the first action (guidance) level. Details of fine material pollution across all of the WSA Hamburg and Cuxhaven area are contained in BfG, 2010 (Figure 9).

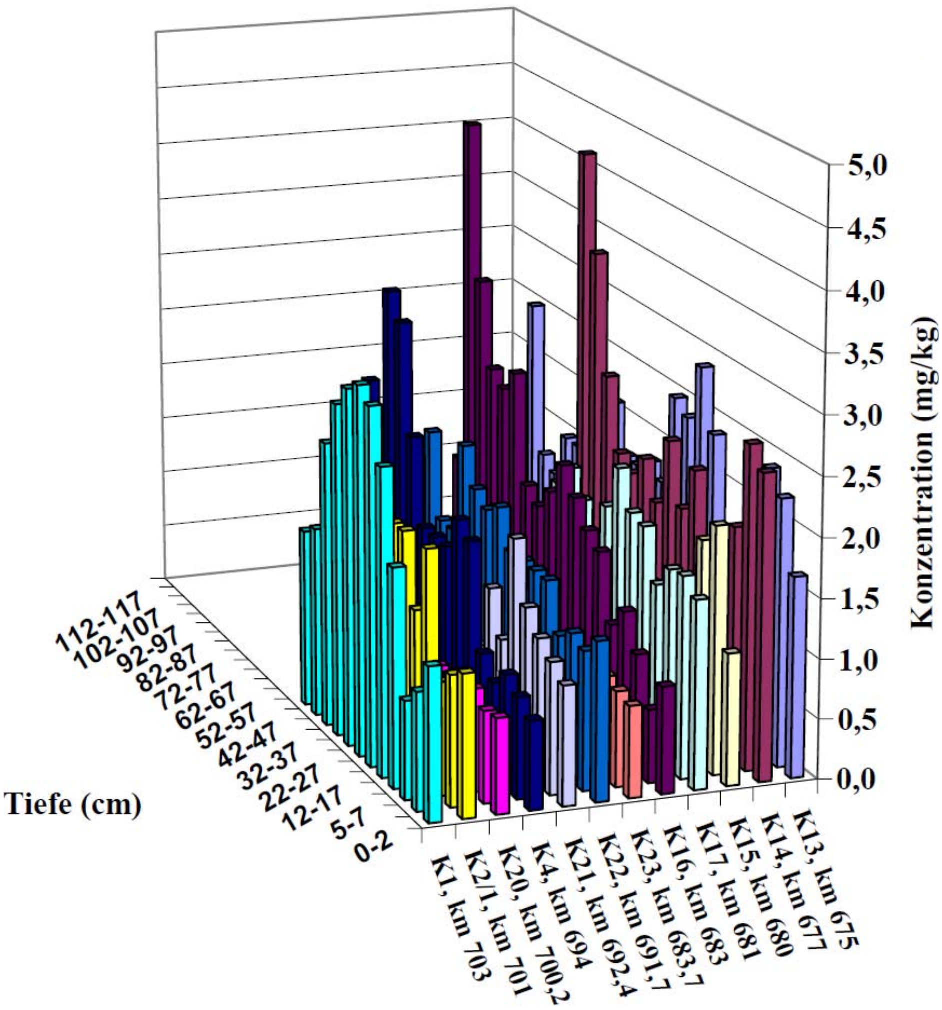


Figure 9 *Cadmium levels in sediment cores upstream and downstream of the disposal site at km 686/690 show that levels are lower in the top layer.*

3.3.2 Water Injection dredging

In the WSA areas Water Injection (WI) dredging is mainly used to eliminate sand ripples in the navigation channel from km 638.9 to km 726.0, and in the silty fine-sand outside the navigation channel. Analyses of contaminants in the sediments where WI dredgers are used show that over 70% of those in the main channel are of marine origin, and in the downstream side channels where these are deployed it has been assumed the proportion of marine sediments is higher. Hence contamination is not likely to be a major issue in the areas where WI is currently used.

In the HPA area, WI is used to supplement hopper dredging and relocation and its use is restricted to between high tide and two hours before low tide

3.4 International Conventions and European Directives

A number of international conventions are concerned with the placement of materials in the sea and are relevant to the disposal or use of dredged material in marine systems. The relevant conventions for Germany are the global London

Convention (LC), the Oslo-Paris (OSPAR) convention which covers the North-east Atlantic and North Sea, and the Helsinki (HELCOM) convention for Baltic countries. The format of each of these conventions is similar in that they require that disposal must take place only under permit, and they specify considerations which must be made before that permit is granted. Two European Directives particularly relevant in the consideration of sea and estuarine placement of dredged material are the Marine Strategy Framework Directive, and the Water Framework Directive. All of these regulatory mechanisms have at their core the reduction and ultimately the elimination of pollution by the reduction of contaminants at source, of naturally occurring substances down to background and man-made substances down to zero. They target those substances which are toxic, persistent and bio-accumulative and hence provide the greatest environmental risk.

3.4.1 OSPAR

Comparison shows that most OSPAR signatory countries use a system of two action levels to assess chemical contamination, below Action Level 1 (AL1) contamination is sufficiently low to allow a disposal or use unrestricted by the contaminant content, and Action Level 2 (AL2) at which disposal into the marine or estuarine environment is not usually permitted. Between AL1 and AL2 additional risk assessment is required which can result in modification of disposal proposals e.g. by removal of pockets of contamination prior to disposal of the remaining sediments. Exceptionally sediments with contaminant levels in excess of AL2 are disposed. These require separate notification to the OSPAR commission, and are usually seen as an interim arrangement while changes to reduce contamination are effected. Figure 10 and 11 show the disposal sites for dredged material used by Germany in 2008 (OSPAR, 2010).

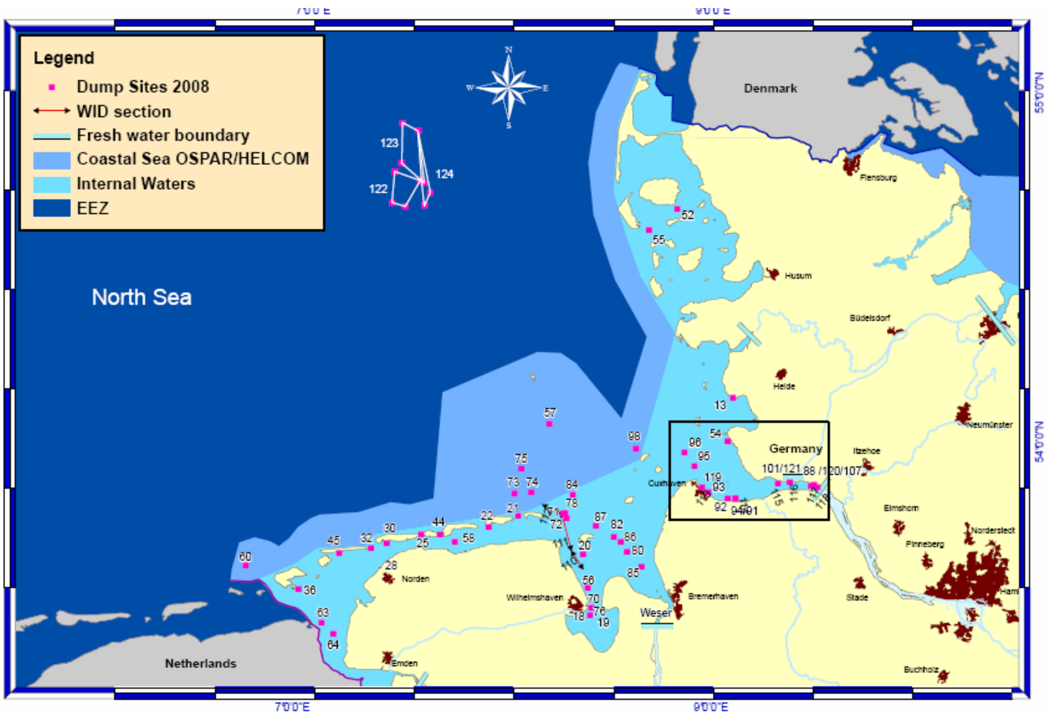


Figure 10 Dredged material placement sites used by Germany in 2008

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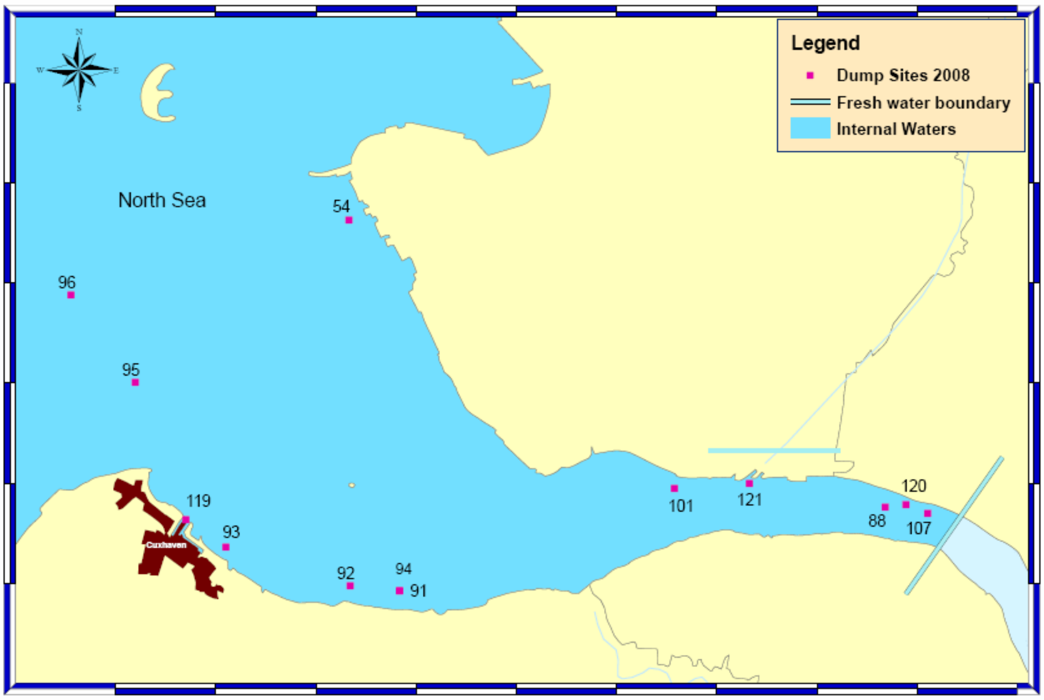

Figure 11 Dredged material disposal sites in Elbe Estuary used in 2008

Material which exceeds national limits was notified (Table 5). The Elbe sediments disposed at Buoy E3 and at 5 points in the Elbe Estuary were so notified in 2008.

Table 5 Overview of German notification to OSPAR commission in 2008

Placement site	Source of material	Contaminants of concern
D/57 (E3)	Hamburg Port	CB180, HCB, gamma HCH, pp-DDT, pp-DDD, pp-DDE
D/88	Elbe km 638-717	HCB, pp-DDT, pp-DDD, pp-DDE
D/101	Outer part of lock and inner part of Kiel canal	pp-DDD, pp-DDE
D/107	Elbe Wedel km 638.9-670	HCB, pp-DDT, pp-DDD, pp-DDE
D/120	Sediment trap	HCB, pp-DDT, pp-DDD, pp-DDE
D/121	Inner part of lock at Brunsbuttel and inner Kiel canal	pp-DDD, pp-DDE

3.4.2 Water Framework Directive

The Water Framework Directive (WFD) establishes a legal framework across Europe to protect and restore clean water across Europe and ensure its long-term sustainable use. It establishes an approach to water management based on river basins rather than country boundaries, observing natural and hydrological units, and sets specific deadlines for Member States to achieve ambitious environmental objectives. The Directive addresses inland surface waters, transitional (estuarine) waters, coastal waters and groundwaters and aims to ensure the good chemical status of these water bodies. For surface waters this goal is defined by limits on the concentration of specific pollutants of EU relevance. These are known as **priority hazardous substances** and to date 33 have been identified. A new Directive (2008/105/EC) published in December 2008 establishes limits, known as Environmental Quality Standards (EQS) for these substances and for an additional 8 substances regulated under previous legislation. While the WFD deals with water quality, this is relevant for sediment management, since many water contaminants are adsorbed onto sediments, and hence upstream discharges of polluting chemicals are responsible for the contamination of sediments moving downstream. Measures taken under the River Basin Management Plan for the Elbe, established in line with the WFD, should provide a powerful mechanism for managing the quality of sediments which enter the tidal Elbe from the upper and middle Elbe since the WFD aims for priority hazardous substances to be phased out completely within 20 years. The WFD also calls for surface waters to reach good ecological status, and hence Member States may need to ensure additional pollutants of national relevance are controlled.

3.4.3 Elbe River Basin Management Plan

The international Elbe River Basin Management Plan was published in December 2009 and is available at www.ikse-mkol.org. The national plan for the German part of the Elbe river basin is at www.fgg-elbe.de.
According to the criteria of the WFD, more than 88% of the surface water bodies of the Elbe River Basin are in good chemical status, but only 10% in good ecological status. This is despite substantial reduction in point source inputs in the last 20 years. The unsatisfactory status is caused by hydromorphological alterations to rivers, water flow regulation and non point sources of pollution such as agriculture and old environmental loads derived from earlier discharges and retained in the sediments. Ground waters are particularly impacted by inputs of nitrates, previous discharges, and earlier mining activities.
In order to achieve the objectives of the WFD, measures need to be taken in numerous water bodies (FGG ELBE 2009). The causes for the deficient status of a water body may lie directly in the water body or in its catchment area. Downstream environmental objectives can only be achieved if the levels of pollution in the whole river basin are reduced or eliminated. The contaminant content of the sediments in the tidal Elbe is largely (but not wholly) sourced from upstream. This contaminant content constrains the use or disposal of material dredged to maintain the navigable waterways in the tidal Elbe. Hence further reductions in the contaminant content of the sediment is required to safeguard the navigable waterways and Port of Hamburg, which in turn requires measures to reduce contaminant loads entering the tidal Elbe from upstream.

3.4.4 Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) extends EU water legislation to the marine environment. It follows an approach similar to the WFD and aims to ensure good environmental status of all Europe's marine regions. It cites four existing conventions for the protection of Europe's regional seas including OSPAR and HELCOM relevant to Germany, and expects these to provide the framework for co-operation with neighbouring non-EU countries. It

requires Member States to make a preliminary assessment of Europe's seas, identifying targets and indicators to be achieved and setting up monitoring programmes by 2012.
The authority for MSFD in Germany is in the process of being set up, and it is likely that from the perspective of the RESMC, observation of the provisions of the WFD, OSPAR and current national legislation will be of more immediate relevance, and provide a robust basis for any future implementation of the MSFD.

3.5 Quality criteria in other European countries

Quality criteria and guidance values for contaminants in sediments vary considerably between the different European countries. A compilation was written by Röper and Netzband (2011). A selection of guidance values for some European countries is presented in table 6. Comparing the different value sets shows reasonable consistence for many compounds. However the German RW2 values for PCB7, HCB and DDT/DDE/DDD seem to be low compared to the other countries guideline values in table 6. For TBT there is a large variation in guideline values spanning almost 2 orders of magnitude. However, direct comparison of numeric concentrations is difficult since different countries have used different particle sizes for analysis or normalisation. In Norway organic contaminant levels are normalised on organic carbon content (1% TOC). Such numbers are at least in part a reflection of the differing underlying geologies and the 'base level' of the substance in clean sediments. Ignoring the geology can lead to unachievable objectives and even the setting of action levels which are below natural geological concentrations.

Table 6 Overview over sediment quality criteria and guidance values for selected compounds in European countries (different particle size/ normalisations are used, see Röper and Netzband, 2011)

Compound	Germany	NL	UK	NO
	RW2	Marine material	AL2	Class III
Cd (mg/kg)	4,5	4	5	2,6-15
Hg(mg/kg)	2,1	1,2	3	0,63-0,86
PCB_7 (µg/kg)	40	100	200[3]	17-190
γ-HCH (µg/kg)	1,5	-	-	1,1-2,2
HCB (µg/kg)	5,5	20	-	17-61
DDT (µg/kg)	3	20	-	20-490
DDD (µg/kg)	6			
DDE (µg/kg)	3			
Org Sn (µg/kg)	40/120[2]	115	400[2]	2-8[2]

[1] 25 µg/kg for each congener
[2] TBT converted to µg Sn/kg
[3] sum 25 PCB congeners

Absolute standards for international use are not necessarily achievable and each country needs to consider its own situation, and how the conventions and directives apply in its particular circumstances.

3.6 Experience in UK

Some 30-40 million cubic metres of dredged material per annum is deposited in coastal and estuarine waters in the UK. The assessment of the suitability of material for disposal, and the selection of disposal sites follows practice in the OSPAR and London Conventions. An assessment is made of the likely physical, chemical and biological impacts of the disposal. It is accepted that disposal of dredged material gives rise to local physical impacts in the immediate area of disposal. This impact is one of settlement of some or all of the material to the seabed, which can give rise to local smothering of the benthic flora and fauna. Such impacts can be short lived if only small amounts of material are deposited, and the disposal area is dispersive. In other locations the material may mound on the seabed. Observations show that such disposal areas are not sterile areas of seabed, but may be recolonised by benthic organisms, to a greater or lesser extent depending on the physical nature of the deposited material and the characteristics of the disposal site. An assessment of the chemical status of the dredged material is carried out by undertaking prior chemical analyses of representative samples of the material. The number of samples is based on the OSPAR guidance, as a minimum, but more samples may be requested where there is the possibility of different concentrations of contaminants within the area for example in berths in a port. The analyses are carried out on the whole (<2mm) fraction. The assessment is carried out by reference to Action Levels (AL). Where contaminants are below AL1 sea disposal is permitted, and where they are above AL2, they are usually not permitted for sea disposal except in special circumstances. Between AL1 and AL2 further detailed consideration is given to the nature of the material, and the conditions of disposal as well as the alternative options available for dealing with the dredged material. Where some samples contain concentrations higher than AL2, the distribution of contamination is considered, and the contaminated areas usually excluded from the sea disposal permit. Direct testing of dredged sediments for ecotoxicity is not used routinely in the assessment-see section 3.8.1

3.7 Experience in Norway

In Norway sediment management is a rather new field. The Norwegian coast is dominated by deep fjords and sedimentation rates are generally low, in the order of millimetres per year. This has limited the need for navigational dredging in the coastal zone. Historically, the sediments have been a sink for the contaminant input from rivers, urban and industrial activity.

Small maintenance dredging operations in harbours and shipping lanes are regulated by the Counties. Relocation in deeper parts of the fjord has historically been practised. Permits are given after individual evaluation. Contaminants levels should not exceed Class III (Table 6). For large scale dredging operations and more contaminated sediments the Norwegian climate and pollution agency (Klif) is the regulating authority. After decades of reducing direct discharges from industry to the fjords, the Norwegian climate and pollution agency (Klif) has, during recent years, focused on the importance of the historic contaminant layer at the bottom of the fjords. These sediments might become a secondary source of contaminants to the fjord system. A main driving force has been the food advisories that exist in many fjords. Sediment management in Norway is therefore primarily driven by sediment quality issues resulting in a strong focus

on sediment quality criteria (Bakke et al., 2010). County based remediation plans have been prepared for 17 fjord- and harbour areas (Klif/SFT, 2007).
Remediation methods that might improve the environmental quality in vast areas (several km^2) are required for fjord remediation. Cost-effectiveness and use of the local natural conditions are therefore key issues to be considered. For disposal of dredged material three main options are preferred:

- Controlled subaqueous disposal (CAD) in deeper parts of the fjord with subsequent capping following newly released guidelines (Klif, 2010)
- Near shore disposal (CDF) for land reclamation
- Capping of contaminated sediments with sand, clay or other fine mineral fractions from tunnelling or quarries. This method is applied for deeper parts of the fjords or where commercial harbours activities are terminated.

Land disposal has only been applied for limited amounts of highly contaminated sediments. Special landfill requirements have to be fulfilled including, impermeable bottom liner and top capping as well as monitoring of leachate. The national controlled disposal site for chemical waste (NOAH) has been used for sediment disposal in a limited number of cases.

Establishment of central storage facilities for contaminated sediments in abandoned quarries and mines has been discussed, but these do not exist at the moment.

3.8 International use of ecotoxicology and bioaccumulation tests

The PIANC Envicom report of WG-8, 2006 gathered evidence from experts in a number of countries on the use of bioassays in dredged material characterisation. This guidance describes the use of biological tests of dredged material to distinguish sediments that pose minimal hazards from those that will require special handling or treatment. Some countries, such as USA and Canada, make extensive use of such methods to determine if dredged material can be placed at sea, others may use them periodically to provide supplementary information for the risk assessment process. The guidance suggests that the use of a battery of tests is good practice, since the results from individual assays may be difficult to interpret. Experience from UK and Norway shows that the use of single bioassay tests in a pass/fail situation can be problematic. Ecotoxicity testing has been found useful as supplementary information to chemical analysis to assess suitability of dredged material for disposal.
Spain uses ecotoxicity testing in addition to chemical analyses in some situations. For example, the OSPAR Report on dumping in 2008 notes that dredged material from the port of Aviles was subject to bioassays using *Chlorella vulgaris* and Microtox (*Vibrio fischeri)* in addition to chemical characterisation.

3.8.1 Experience in UK

A programme of ecotoxicity testing of a range of dredged material from England and Wales in conjunction with chemical analyses was carried out by Cefas over a period of several years. Currently ecotoxicity tests are not used routinely for dredged material characterisation but tests can be carried out where these are thought useful to provide additional information about the sediment, for example if some contaminants concentrations are close to, or over AL2, and other options for disposal of the dredged material are limited. Such tests have also been used in support of monitoring of dredged material disposal sites, usually in response to specific concerns about contaminant burden. The test battery includes acute tests using the polychaete *Arenicola marina* and the amphipod *Corophium volutator*, and a chronic test using the amphipod *Leptocheirus plumulosus.*

3.8.2 Experience in Norway

Ecotoxicity test are integrated in the system for risk assessment of contaminated sediment (Klif/SFT, 2008). This system is primarily meant to evaluate the quality of coastal sediments and consider the need for remedial action. The system consists of three stages (tier I-III):

- Tier I General guideline values to assess risk to sediment ecosystem (class II), includes acute toxicity tests on porewater and sediment extract using the marine algae *Skeletonema costatum* as well as the DR-Calux test on extracts to test for dioxin like response.
- Tier II Risk of spreading/transport, risk to human health and local ecosystem, includes whole sediment toxcicity test using *Arenicola marina* or *Corophium volutator*.
- Tier III Site specific characterisation of risk, based on local conditions and can include studies of biodiversity and bioaccumulation.

Requirements for ecotoxicity testing are not included in the permits for maintenance dredging.

4 Consequences of present day practice

4.1 Land disposal

Approximately 1 mill m^3 of contaminated sediments is yearly treated by land disposal. The METHA plant is used for sand/silt separation and dewatering of silt, which allows reuse of parts of the sediments. After dewatering the sediments are disposed in two landfills (Francop and Feldhofe). This approach is evaluated as a good environmental practice with respect to isolating contaminants from the environment. However, separation and land disposal are energy intensive and have limited capacity. In a long-term perspective new landfill sites have to be developed to store the dewatered sediments. To use the present capacity in an optimal land disposal should be limited to the strongly polluted sediments from old parts of the harbour. This should mean that the need for land disposal should reduce over time as remediation of historically contaminated sediments progresses. Source control from industry and urban run-off to the harbour is a prerequisite to achieve a better sediment quality in the future.

4.2 Relocation in the river

4.2.1 Hamburg harbour

Disposal of dredged material from Hamburg Port to Neßsand is described in section 3.1.1. Studies have demonstrated that fine grained material mixes rapidly with the naturally occurring suspended sediments and is distributed over a wide area through the action of tides. Impacts of disposal, particularly those related to oxygen depletion and spawning grounds and juvenile fish, are restricted by discharge into an ebb tide, avoiding periods of low head water discharge, and limiting to the winter months only. Acute chemical contaminant effects would be similarly restricted by this control.
While the mixing of the contaminated material from the port with cleaner marine derived sediments results in apparent lower levels of contaminants in the sediment, this does not bring about a reduction in contaminant load. Effectively the same load of contaminant is contained within a larger volume. It is thought likely that the disposal at Neßsand has resulted in increased volumes of sediment being moved upstream and deposited in the port and hence increased the need for dredging. This recycling of sediments is evaluated to be non-sustainable in a long-term perspective. It was to break this cycle that sea disposal was introduced for material from the Port of Hamburg, and it is recommended that this could be continued in the short to medium term, see section 5.3. Relocation within the river is in itself a good solution as it retains the fine sediments as part of the river ecosystem, and it is considered that relocation in the lower reaches of the river should be evaluated. Also more permanent relocation options inside the reaches of the river should be considered. Capping with coarser material will be able to reduce the availability of the contaminants and thereby reduce the contaminant load reaching the estuary and could provide a useful interim measure in the period before contaminant inputs are fully reduced (see section 5.3.1).

4.2.2 Lower reaches of the tidal Elbe

Dredged material handling in the tidal Elbe under the WSA competence, is described in section 3.3.1. In the Hamburg WSA area the highest volumes to be dredged are in the Wedel and Juelssand areas, both comprising of silty fine sand and this material is subject to some contamination. Material from the Wedel area and the sediment trap was notified to OSPAR on account of levels of HCB and DDT and its metabolites exceeding national guidelines. An further impact prognosis is expected from BfG in 2011. Most of the silty materials are classified as Case II or Case III according to HABAK. The likely impacts of this disposal are similar to that of disposal in the sea with the proviso that the background concentrations of contaminants in sediments in the river are higher here than in the sea, so effectively the material is being distributed in an area already subject to some contamination. Consequently chemical effects of such disposals may not be distinguishable. The changed strategy since 2006 of relocation further downstream to break sediment recirculation is not evaluated as a problem in relation to contaminants. In general, dredging and relocation of sediments in the lower reaches of the tidal Elbe is a good solution as it retains sediments as part of the river system. Contaminant levels in the fine and medium sands which form the bulk of the material downstream of Juelssand are relatively low, and therefore do not restrict relocation as a management option.

All of the sediments from the Cuxhaven area are sufficiently low in contaminant levels to not restrict sediment management options.

4.3 Monitoring data at sea disposal site

Since 2005, the Hamburg Port Authority has deposited some of its dredged material at a sea disposal site, E3, located in the inner German Bight. A comprehensive monitoring programme has been conducted, and is on-going, to determine the impacts of the disposal on the marine environment. The results of monitoring in the period 2005-2009 were reported by Hentschke et al. (2009) and presented in a poster to SedNet. The monitoring included chemical, biological, ecotoxicological and sedimentological investigations and by August 2009, data from 10 monitoring campaigns were available.

ADCP surveys were employed to track the sediment plume immediately after release from the dredger. These studies showed a classic pattern of the majority of the material (95-98%) falling rapidly to the seabed in the area of the disposal site. Turbidity plumes could be detected for up to 5 hours reaching an extension of 8km with the concentrations of particulate matter in the decaying plume rapidly decreasing to below the background concentration. Bathymetric surveys using multi-beam and sediment echo-sounder demonstrated the presence of the material on the seabed. The disposal of approximately 5.5 million cubic metres of dredged material between 2005 and the beginning of 2009 resulted in a seabed elevation of about 2.8 m near the centre of the site. Numerical modelling studies using a 3-D model of the North Sea were conducted to study the movement of sediments from the site. Initial dispersion is along the tidal axes, roughly North-West and South-East, with a net particulate movement towards the north. At the end of the simulation, 2 weeks after placing the last batch of material, the model predicts an increase of about 0.4mg/l. Such low concentration increases would not be observable in the field, and are set against background concentrations of some 10-25mg/l. In other words there would be no detectable increase in suspended sediment concentrations a few kilometres from the site. The observed dispersion of sediments is in line with these simulations.

Investigations showed that the dredged material influences sediment composition and contaminant concentrations in a limited range up to 1 km from the centre. Contaminants are accumulated in the fine fraction near the centre of the site, and concentrations vary from one sampling campaign to another depending on the composition of the material dredged and disposed from different regions of the Elbe system. Within the 1km circle concentrations of some contaminants in sediments were elevated in 2009 compared to the baseline surveys in 2005. These included mercury, copper, cadmium and zinc and the organic contaminants alpha-hexachlorocyclohexane, DDX, TBT and its metabolites, PCBs and PAHs. No influences of the disposal were detected further than 1km from the centre of the site.

Ecotoxicity tests were also conducted on samples taken from in and around the disposal site using a battery of tests (marine algae test, pore water and eluate (MAT), marine bioluminescence assay (MLBT), pore water and eluate, corophium test). The results of the algae and marine bioluminescence assay entail the pT-class categorisation, whereby the worst result of the four test methods will define the classification. In general ecotoxicological responses were low over the period 2005-2009 with most sediments throughout the survey area classified as no toxicity, or very low toxicity. In April and August 2010

some higher toxicity classes were determined, but these results were not repeatable, and a disruption of parts of the test battery by the high incidence of dead organisms in these samples was possible. Individual toxicity tests are notoriously hard to interpret, hence the good practice of using a battery of tests which provides more comprehensive information. Overall, no ecotoxicological deterioration in the area of the disposal site has been demonstrated.
Investigations of bio-accumulation were carried out by collecting samples of the common whelk (*Buccinum undatum*) and the tellin (*Abra abra*). In 2008 and 2009, higher concentrations of MBT and DBT were found in the whelks from the 1km circle compared to the reference sites, suggesting bio-accumulation of these compounds, see figure 12 below.

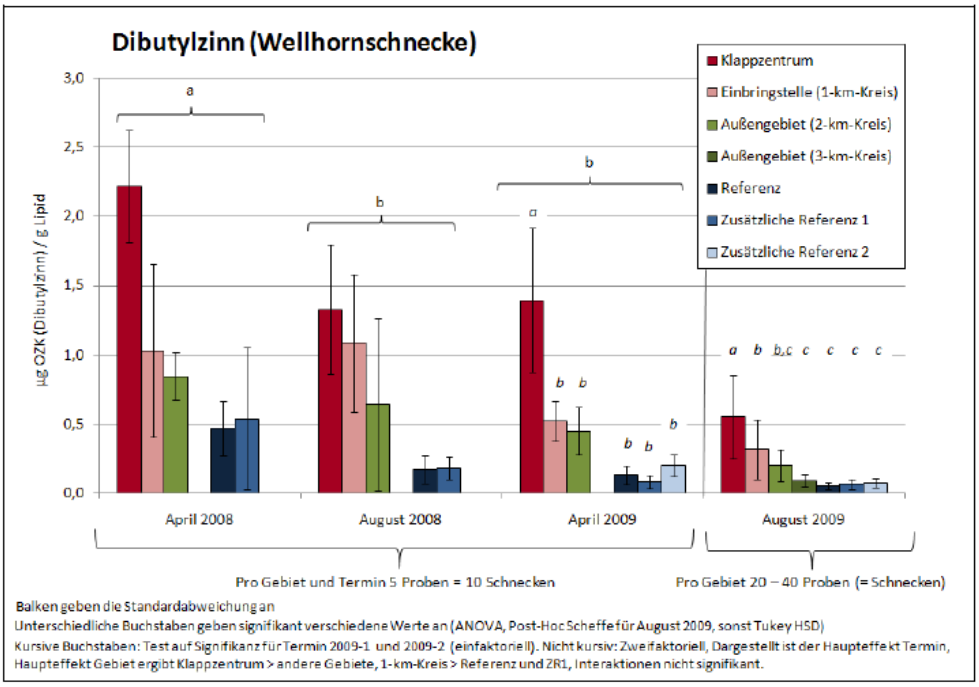

Figure 12 *Concentration of dibutyltin in 2008 and 2009 (values normalised on a lipid basis) (bars indicate the different areas: red=disposal centre, pink=placement site, green=2-km, dark green=3 km, dark blue=reference area, blue and light blue=additional reference areas)*

Accumulation of pp-DDE, pp-DDD and op-DDD was also noted in 2008. Interestingly heavy metal and PCB concentrations in these animals tended to be higher in the reference areas than in the disposal site.
The common whelk is particularly sensitive to TBT and androgenisation of the female whelk, the so-called imposex effect, can be induced by exposure. The monitoring programme was widened in 2007 to include the imposex rate. There was some evidence of class C imposex values in all areas at different times, suggesting probable exposure to organotin concentrations above the assessment criteria developed by OSPAR, but this was independent of the closeness to the disposal site. Hence there was no observation of imposex which can be attributed to dredged material disposal.
Sediment samples were taken to examine the macrobenthos community simultaneously with the samples for chemical and ecotoxicological analyses.

The analyses produced the expected range of species for the Nucula-nitodosa community typical of this part of the North Sea. During the baseline survey, prior to disposal, there was no indication that the placement site was of special importance to the macrobenthos community. Even after the sixth placement campaign the macrobenthos community in the centre showed no signs of strong deterioration, although there were reductions in the number of species, diversity and to some extent population density. These disposal induced impacts remained relatively constant over the course of the monitoring surveys.

Additional monitoring in fish was also conducted. The species range found was typical of this part of the North Sea including European plaice, armed bullhead, flounder and common dab as the dominant species, together with solenette, scaldfish, whiting and common dragonet. Samples of common dab were taken from the placement site, outer area, first and third reference areas for analysis. No significant increases in contaminants were determined for the samples collected in the placement site compared with those of other area.

Fish disease studies were also conducted in 2009. No differences could be detected that were related to the disposal activities.

4.4 Evaluation of E3 monitoring, an international perspective

A very extensive monitoring programme has been undertaken, and is continuing, at and around the placement site at E3 in the inner German Bight. A baseline assessment was carried out in 2005 prior to disposal, and subsequently a series of campaigns have been undertaken with the results of some 10 surveys available to date. The surveys have employed a range of techniques well suited to describe the parameters under investigation. Early studies included ADCP measurements to study the plume generated when the dredged material was placed, as well as multi-beam and sediment echo-sounding. The results from these investigations have allowed comparison with computer modelling predictions for the fate of the disposed material which have confirmed that water column effects are short lived and that accumulations of some of the sediment occur at and around the centre of the placement site. These investigations suggest that impacts of the disposals would not be expected on more distant areas, like the Island of Helgoland or the Wadden Sea.

Furthermore investigations have been made, on repeated surveys, into the levels of chemical contamination of the sediments, and comparisons made with samples taken at increasing distances from the placement site, and from reference sites chosen to be of similar characteristics to the placement site but at sufficient distance to be remote from any effects of disposal. The macrobenthos have been studied and animals have been collected for assessment of bioaccumulation. Samples have also been collected for ecotoxicological assessment. Assessment methodology proposed by OSPAR has been used (OSPAR, 2008) to assess the survey results.

Where difficulties have arisen in the interpretation of results of some parts of the programme, for example the ecotoxicological tests in 2009, good practice has been followed by repeat testing, and in some cases by repeat surveying. Results have been carefully examined, and any unexplained changes, for example systematic series differences (HCB, gamma-HCH in tellin) or methodological problems have been identified and are subject to clarification with the laboratories concerned. In all cases a thorough examination of the issues is evident. Bioaccumulation studies in fish have been added to the programme, as have fish disease surveys. While no differences in fish disease in the areas close to the disposal site are evident, it is acknowledged that the comparisons with total numbers of fish affected by a disease (all fish species, all symptoms) is based on limited comparability since databases for the North Sea are still not very comprehensive.

Overall the results of the monitoring programme from 2005 to 2009 can be summarised as:

- Impacts are restricted to the disposal site or areas immediately adjacent and comprise:
    - sediment accumulation,
    - time-limited impacts on the number of species and diversity of the macrobenthos population
    - increased concentrations of some heavy metals and organic substances in sediments within the 1km ring,
    - bioaccumulation of DDT and metabolites, and DBT and MBT in common whelk at direct disposal centre.

- There is no evidence for disposal induced:
    - eco-toxicological deterioration around placement site
    - imposex in common whelk,
    - bioaccumulation in fish
    - strong deterioration of macrobenthos community,
    - continuous degradation of fish fauna,
    - fish disease

The extensive nature of the monitoring programme, the number of surveys, and the use of international assessment methodologies gives confidence in the main findings of the monitoring programme. This has shown that while there are impacts from the disposal of dredged material, these are limited in nature and extent, and to date have been confined to an area within 1km of the placement site.
Good monitoring programmes are adaptive. If disposals are continued at E3, adaptation of the monitoring strategy to concentrate on those elements known to be changing, or where longer term effects might be anticipated should form the focus of the surveys. Since the dredged material from areas of the Hamburg port does at the moment contain concentrations of certain contaminants in excess of national action level 2, it will be important to continue to monitor these contaminants in sediments and biota in the placement area and at reference sites. The number of stations might be capable of reduction, providing that some stations are maintained in the direction of any sensitive sites, such as those important for nature conservation. Sampling in clean reference sites to provide comparative data should be continued.

5 Future scenarios

Dramatic decreases in contaminant levels have been observed in the Elbe catchment due to removal of direct discharges from industry and waste water. Despite this improvement a lot of "secondary" sources remain, like contaminated soil, sediments and groundwater as well as run-off from mining areas. This has reduced the rate of improvement in recent years. In addition will flooding events contribute to remobilising historic contaminants. Through national and international coordination further reduction in contaminant levels is expected. However, the time frame of this improvement is quite unclear. Based on this, different scenarios for the contaminant situation in the future can be envisioned. This includes the potential impact of climate change.

5.1 Constant input from upper reaches of Elbe

Assuming continued input from the upper reaches of the river one can foresee a continuous need for land treatment and disposal of material dredged from the port of Hamburg. While sea disposal of some of the less contaminated material could contribute to breaking the circle of recirculation of sediments in the tidal part of the river, it would need to be tied to a programme of contaminant reduction to meet national and international requirements. Separation of the contaminated suspended solids transported downstream and the clean sediments transport upstream in the tidal part, would be crucial to reduce the volume of sediments that has to be treated and disposed.

5.2 Reduction of contaminant input

Reduction of the contaminant input from the upper reaches of the river will have an immediate positive effect on the possibilities to manage dredged material. Measures to reduce contaminant transport are central themes in the international Elbe commission (IKSE) and FGG, and are required to meet water quality objectives under the Water Framework Directive. Measures in the Hamburg port should be considered to ensure TBT does not continue to be released to the port sediments. Once lower contaminant levels are reached, land treatment will be limited to a one-time removal of historic contaminants. For newly formed sediments a more flexible regime of relocation in the reaches of the river would be achievable. Contaminant related constraints on the RESMC would be removed and sediments could be managed cost effectively to achieve flood protection and nature conservation benefits as well as sustaining navigation.

5.3 Impact of climate change

Climate change will impact the tidal Elbe and its future management in a number of ways, and the RESMC needs to be adaptable to such changes. Most likely scenarios include increased storminess, increased flooding within the catchment, and continued sea level rise leading to 'coastal squeeze' and loss of intertidal habitat. From a contaminant viewpoint the implications of these changes are that the storminess could lead to increased suspension of sedimentary material, hence increased contaminant transport within the Estuary. Increased flooding may mobilise more contaminants from the Elbe catchment towards the tidal Elbe. Coastal squeeze will reduce the intertidal areas which act as permanent or temporary sinks for contaminants. Hence, the overall effect of climate change is likely to result in more rapid transport of contaminants from the Elbe catchment to the North sea.

6 Alternative approaches to sediment management

6.1 Resumed sea disposal

While impacts have been observed for the disposal of dredged material at the sea disposal site, E3 in the German Bight, these impacts have been confined to the immediate area around the disposal site, within a circle of approximately 1 km diameter. Such impacts are to be expected from the disposal, and we concur with the conclusion that far field impacts are not likely to occur while disposals are confined to those sediments which contain concentrations of contaminants similar to those in earlier disposals. Resumed disposal at E3, together with a comprehensive monitoring programme to ensure the continued absence of far field effects would seem to be one future option for the short to medium term. To comply with national and international obligations to reduce the environmental input of persistent, toxic and bioaccumulative substances, this disposal should be tied to an urgent programme to reduce inputs to the tidal Elbe from upstream as well as the reduction of inputs directly into the Hamburg Port and tidal Elbe from its surrounding area.

6.2 Capping

Other short to medium term measures to dispose of the contaminated port sediments could include consideration of capping after disposal within the estuary. International experience suggests that disposal and capping operations are more successful when carried out in less dispersive areas, preferably following excavation of the site. Dredged material is placed in the excavated site and capped with clean material to retain it. Disadvantages of using capping for dealing with persistent contaminants include the need to monitor to ensure there is no loss of contaminant from the site, and to check if remedial action is required. Such methodology may be most suited for geologically stable areas, removing the possibility of re-exposure through erosional processes at some point in the future. There is considerable experience of using capping in the United States, and the PIANC publication Working Group PEC1: Management of aquatic disposal of dredged material (1998) touches on this topic. See (www.pianc-aipcn.org) for a range of publications dealing with dredged material management. Difficulties of capping include the identification and selection of suitable sites which will not cause interference with other uses and users of the area.

6.3 Intervention upstream

Contaminants in the dredged sediments of the tidal Elbe represent a major constraint of the subsequent placement of the dredged material in the lower reaches of the Elbe. This is particularly the case in the Port of Hamburg which acts as a settlement basin for fine sediments from the polluted upstream areas. It is now accepted good practice to retain sediments within the water courses from which they were dredged, where possible, in order to reduce the drawdown of sediments from the sides of the river system which can occur if dredged material is removed entirely from the system.

Some inputs from primary sources such as industrial discharges to the upper and middle Elbe have already been reduced from historic highs, however secondary sources such as discharges from early mining activity, and agricultural run-off, remain an issue. The programme of measures to reduce pollutant concentrations being undertaken by FGG Elbe in connection with the Elbe River Basin Management Plan, under WFD, will undoubtedly result in reductions in the contaminant load reaching the tidal Elbe, however this will take time to achieve. To effect a more rapid reduction in contaminant content, intervention upstream to capture the contaminated fine sediment before it reaches Hamburg Port could be considered. This would require the creation of a settling basin large enough to allow settlement of the fine-grained particulate matter where much of the contaminant load is situated. If the settlement areas require dredging to maintain settlement capability then disposal of these contaminated sediments would require treatment and land disposal sites similar to those required for the contaminated material from the port of Hamburg. However the contaminants in such settlement basins would be more highly concentrated i.e. in smaller volumes to remove a given contaminant load.

6.4 Disposal in the lower reaches of the Elbe

Disposal of the dredged material into the lower reaches of the Tidal Elbe could be considered as an alternative to sea disposal for the material from the Port of Hamburg. This would entail selection of a site where water flows are ebb-dominant, so that initial dispersion at least is towards the sea. Predicted environmental impacts of such disposal would be similar to those experienced at the North Sea disposal site, although the extent to which the material would settle to the bed, and hence confine most impacts to the immediate area, would depend on the characteristics of the chosen site. While dispersion has advantages in spreading the material, it does make monitoring of the impacts of the disposal more difficult. Pre-disposal and post disposal monitoring would be required to ensure that impacts were in line with predictions. Limitations on site selection would include that it should be remote from other uses, such as nature conservation areas. In practice this might be difficult to realise. The North Sea site has already been impacted, and while contamination is present in the dredged material, there is an argument for continuing to use this same well-characterised site rather than impacting an additional area. Sites within the estuary currently used by WSV might also be suitable for the material from Hamburg. Following further reduction of contaminant levels in the sediments, the potential for chemical and ecotoxicological effects is reduced, and placement into the tidal Elbe could be a preferred option on the grounds of reduced distance for the dredgers to travel and hence economic benefit. This also has the benefit of retaining sedimentary material within the estuary.

6.5 Uses of dredged material

There are numerous ways in which dredged material can be used. Where possible dredged material should be replaced in the water course from which it was dredged, in line with ARGE recommendations, but where this is not possible there are other options. Uses can be broadly classified into engineering uses and environmental enhancement. The PIANC report 'Dredged material as a resource: Options and constraints'(PIANC 2009) describes many such uses and worldwide examples.

In the tidal Elbe, the majority of sediments downstream of Hamburg are sufficiently low in contaminants to permit relocation within the Elbe river and estuary. Efforts to reduce volumes of dredged material which is contaminated through the use of sediment traps for example, are focussed on minimising the volume of sediments for which other disposal routes are required. Hence it is the sediments dredged in the Port of Hamburg and those just downstream for which alternatives are sought.

The presence of contaminants in the dredged material reduces the options available for use without prior clean-up, and it is likely that engineering uses will be more relevant on the short-term than environmental ones.

Engineering uses cited in the PIANC report include:

- Construction including landfill and foundation materials
- Isolation
- Flood and Coastal protection
- Land improvement
- Placement on river banks

In order to use dredged material on land, dewatering is often required, and sometimes some type of separation process or more complex treatment. Complex treatment techniques such as stabilisation (mixing with cement or other additive) and ceramic processes may be used to transform dredged material into construction material. Hamburg already has extensive experience of treatment via the METHA plant, of sand separation for use, and of product creation. Other construction uses of silty dredged material such as road fill, isolation, for example, rehabilitation of brownfield sites should be considered, but again may be constrained by the contaminant content, and may require the use of cleaner sandier material as a final layer. Incorporation of dredged sediment within constructions, following mixing with cement, could be worthy of consideration. Use of material for flood and coast protection purposes within the Elbe basin is a possibility. The more contaminated finer sediments might be used beneath cleaner sandier ones in such situations.

7 Recommendations and summary of the initial questions

7.1 Evaluation of RESMC objectives

The RESMC has stated very clear objectives for the tidal Elbe:

On the basis of the overall approach of the RESMC, the long-term and equally weighted objectives of the RESMC as a contribution to sustainable development of the tidal River Elbe can be formulated as follows:

1. *Securing the shipping channel depths for the tidal River Elbe according to planning approval*
2. *Reducing the dredging quantities and costs*
3. *Reducing the environmental impairments related to maintenance*

4. *Compatibility with and/or support of the regional objectives of nature conservation and marine protection as well as water resources management*
5. *Compatibility with the requirements of European and national water protection, marine protection and nature conservation*
6. *Broad social acceptance*

We have evaluated these objectives from the perspective of contaminant transport and their environmental impact as well as a general sustainable environmental perspective. Balancing the economic interest of increased shipping and harbour activities with required sediment management is complicated. The objective of reducing dredging quantities is both an economic question as well as a question of sustainable environmental development and reduction of resource consumption. Protection and improvement of nature quality on land as well as in the marine and intertidal zone are clearly stated and directly related to both the physical as well as the chemical nature of the sediments and suspended solids in the river system.
We feel that the objectives of the RESMC are well defined and focus on the critical points for long-term sustainable development of the tidal Elbe.

7.2 Summary of initial questions

The following questions were asked:
:

- *What is the assessment of the current practice of handling contaminated dredged material on the tidal River Elbe? Are additional options possible beyond that practice?*

The most contaminated dredged material occurs in the older parts of the Hamburg port area, and is disposed on land with or without prior sand separation. Constraints on the volume that can be disposed or recycled following treatment in the METHA plant, or in drying fields, mean that the policy of using this route for the most contaminated of the materials remains key. Other options for dealing with this highly contaminated material are limited, although options for use of the material within local construction projects, after fixing with cement for example, should continue to be explored. The practice of separating sand for use is a good one and should be continued, but it is recognised that the majority of this highly contaminated material is fine particulate matter.
The more recently deposited sediments in the port are lower in contaminant levels, but contamination still remains a considerable restraint on their relocation within the estuary or placement out to sea. There is urgency to reduce the levels of contaminants reaching the port from upstream. The programme of measures within the Elbe River basin management plan (section 3.4) will make an important contribution to this, but it will take a long time to realise the benefits in terms of acceptable levels of contaminants in port sediments. Direct intervention upstream of the port, such as that described in section 6.3 should be considered.
Interventions to reduce the quantities of dredged and relocated sediment being recycled back to the port area and hence reduce the volume of contaminated material for disposal by HPA, are attractive. Whether such interventions can be

physically achieved will be subject to comment by the experts of the other task groups.
The sea disposal of some 6.5 million tonnes of dredged material at Buoy E3 has been subject to careful monitoring. Impacts are encountered, (section 4.3) but confined to the immediate area surrounding the placement site. Continued sea disposal, tied in to a contaminant reduction programme, would be feasible for this material (section 6.1)
The relocation within the estuary of material dredged in the WSA Hamburg and Cuxhaven areas of competence awaits a further impact prognosis by BfG in accordance with the Joint Transitional Regulation for the Handling of Dredged Material and is expected in 2011.The most contaminated sediments here will also benefit from the Elbe RBMP measures. The practice of placing the sandier material in areas which may benefit such as scour holes should be continued. In selecting sites for relocation consideration should be given to whether any nature conservation or other benefit can be derived.

- *What is the assessment of the environmental impact, in particular the ecotoxicological, of the relocation to buoy E3?*

The environmental impact has been described in section 4.3. In summary the main impacts are accumulation of sediment at the seabed, time limited impacts on the number of species and diversity of the macrobenthos in the area of the disposal site and a limited increase in the concentrations of some heavy metals and organic contaminants in sediments within an area around the disposal site. Bio-accumulation of DDT and metabolites, as well as DBT and MBT is found in the common whelk at somewhat elevated levels compared to the reference site in the German Bight, although differences are small These effects are confined to the disposal site and the area immediately surrounding it. There is no clear evidence of ecotoxicological impact of the disposal on the placement site or areas around it.

- *What is the assessment of the objectives described in the RESMC concerning future handling of contaminated dredged material on the tidal River Elbe and in the entire Elbe region (on-shore treatment, relocation, remediation support), also in view of the European regulations and the practice in other estuaries?*

The presence of contaminants within the dredged material from the upper parts of the tidal Elbe constrains the achievement of the RESMC objectives. Measures to reduce the contaminant content of dredged material are therefore key to allowing the most cost effective and most environmentally acceptable means of dredging and disposal. In this regard the Port of Hamburg and WSA Hamburg and Cuxhaven are reliant on measures taken by other bodies, both national and international. In particular the work of FGG Elbe is important in establishing trans-regional objectives and programme of measures for reduction of contaminants under the Elbe River Basin Management Plan. Close links have been established between those bodies working to implement this programme of measures and the HPA and WSA Hamburg and Cuxhaven who are directly impacted. These close links are essential for the success of the RESMC.

In terms of relocation in the lower estuary or the sea, concentrations of some contaminants currently exceed national limits and particular attention should be paid to these: (PCB 180, HCB, HCH, DDT and its metabolites). Organotins are also of concern since bioaccumulation has been demonstrated in biota at the sea placement site. TBT and its metabolites require careful assessment and reduction should be given priority. Compatibility with the requirements of European and national water protection, marine protection and nature conservation will require considerable progress in reducing contaminants (see sections 3.4). In a long-term perspective land treatment and disposal is not considered a sustainable sediment management practice, as sediments should remain as an important compartment of the river system. It should therefore be a long-term goal to reduce land disposal. This requires that historically contaminated sites are remediated.

- *Do the criteria regarding risk assessment of contaminated dredged material conform with the practice in other European countries? What is the assessment of these criteria?*

In general, in European countries, assessments of the suitability of the dredged material for aquatic disposal are based on chemical analysis of selected hazardous substances, the toxic effects of the sediment on organisms, (assessed either by consideration of the known chemical contaminants or by direct toxicity testing), and through monitoring of the field impact of the disposal. In chapter 3.5 the criteria for risk assessment and environmental quality in various European countries are discussed. It is clear that differences in chemical quality criteria exist. These differences are partly based on differences in geological/sedimentological conditions in the various countries as well as the basis for defining environmental quality (e.g. particle size normalisation of guideline values). Nevertheless, there is a consistent approach of those countries that are contracting parties to OSPAR of developing national criteria for assessment, of issuing permits for disposal only after assessing the suitability of the material for disposal and of notifying any permits issued where average concentrations exceed the national guidance levels. In countries with large maintenance dredging needs a pragmatic approach is preferred as long as impacts as demonstrated by monitoring are limited to the disposal area, and the contaminant inputs to the river and sea are reduced in the longer term. This is primarily illustrated by the assessment levels for TBT in various European countries.

- *What requirements have to be met for sustainable sediment management on the tidal River Elbe in the inner part of the catchment area? Are the objectives of FGG-Elbe and IKSE appropriate and realistic for this task?*

As stated earlier reduction of contaminant levels in the suspended matter from the upper reaches of the Elbe should be given utmost priority. This is clearly stated in the objectives of FGG-Elbe and IKSE.
The programme of reduction of contaminants is complex in that it needs to deal with diffuse and secondary inputs, not merely point sources. Hence there is a concern that the timetable for reduction of inputs in the non-tidal Elbe may be too slow to effect a necessary improvement in sediment quality in the sediments reaching the tidal Elbe. It will be important that the programme of measures

targets those contaminants of particular concern in the tidal Elbe at an early stage. We have identified these critical contaminants in table 3. Additionally, it may be necessary to consider additional interventions to reduce the contaminant load reaching the tidal Elbe as described in 6.3. A strong focus on historical contaminants in the harbour of Hamburg as well as source reduction from industry, urban run-off and wastewater has to be given priority to be able to meet the requirements of sustainable sediment management. TBT should be a specific point of attention in relation to harbour activities.

- *What is the assessment of action on the (tidal) River Elbe with respect to the London and OSPAR Conventions as well as the MSFD?*

The relocations within the tidal river Elbe and the placement of dredged material at the Buoy E3 in the inner German Bight are compliant with the guidance of London and OSPAR conventions, in the short term.(See section 3.4). However, the aspirations of these Conventions and of the Water Framework Directive and Marine Strategy Framework Directive are the reduction and ultimately elimination of pollution by the reduction of contaminants at source, of naturally occurring substances down to background and man-made substances to zero. Hence while a permit has been granted for sea disposal of some dredged material containing substances at concentrations greater than the national limits, such permissions are notified directly to OSPAR as special permits, and would be expected to be linked to special management measures such as measures to bring down concentrations below national limits. In 2008, OSPAR reports show that there were special permits granted for placement at 5 sites within the tidal Elbe and at Buoy E3. These special permits are linked to the development of the strategy for sediment management. As explained above particular attention will need to be paid to those contaminants which currently exceed national limits (PCB 180, HCB, HCH, DDT and its metabolites) as well as organotins. In addition to the national and international measures under the Elbe RBMP, other interventions may be worth considering to ensure more rapid reductions in the dredged sediments. (See chapter 6).
The Marine Strategy Framework Directive (MSFD) is linked to the regional conventions. National measures to implement this Directive are still at an early stage (section 3.4). In our opinion, the provisions of WFD, OSPAR and current national legislation are of more immediate importance for the contaminant related issues in the RESMC, and will provide a robust basis for meeting the requirements of MSFD in due course.

7.3 Overall assessment of RESMC

As evaluators we were asked to give a general appraisal of the RESMC according to the following questions:

- *Are the objectives of the RESMC formulated in the work order sensible in your opinion, also in view of the situation in other European estuaries?*

The objectives of the RESMC are according to our evaluation highly relevant and sensible for the short to middle long-term, as stated in detail in this report specifically chapters 7.1. The long-term success of the RESMC will depend on contaminant source separation and contaminant source reduction. This should be the long-term goal. It is recognised that contaminant source reduction is largely in the remit of third parties. In the short term the RESMC has to accommodate to the constraints caused by sediment contamination, but the responsibilities of third parties to bring about the necessary reductions is key.

- *Do the measures outlined in the RESMC (relocation, on-shore treatment and remediation support) represent overall the right way to achieve the objectives?*

The measures outlined are the right way to achieve the objectives on the short to middle long-term. Methods to separate sources thereby limiting the volume of material to be handled and source reduction reducing the concentrations should be given priority to achieve sustainable sediment management for the tidal Elbe. This encompasses flood measures that prevent large amounts of contaminated sediments to reach the Port of Hamburg from the upper reaches of the catchment area.

7.4 Recommendations for the further development of the RESMC.

There is an impressive amount of detailed studies and monitoring data available for the Elbe river. Within the time frame available for this evaluation we have tried to generalize our observations in this report and would like to suggest some ways to further develop the RESMC:

- Encourage third party and local measures to reduce contaminant input, as these provide a constraint on sediment management. In particular the contaminants Cd, Hg, PCB, gamma HCH, HCB, DDT, DDE and organotins should be targeted.
- Detailed identification and reduction of TBT sources in the Port of Hamburg.
- Consider upstream interventions to bring about more rapid reductions in critical contaminants and limit effect of flooding events.
- Continue use of sea disposal site E3 as an interim measure to break the recirculation of sediments. This to be contingent on continuing monitoring which ensures that impacts are limited and restricted to the disposal site and its immediate surroundings.
- Investigate the development of subaqueous disposal sites in existing or dredged depressions in the river bottom to reduce contaminant loads.
- Consider relocation of material from port of Hamburg within the lower reaches of the river.

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Appendix A: CVs of evaluators

Curriculum Vitae: Lindsay A. Murray

Date of Birth: 02 May 1949

Nationality: British

Position: Environmental Consultant, Swift Impact Ltd

Education: B.Sc 1970, Chemical Oceanography, University of Liverpool, UK.

Ph.D 1975, Department of Oceanography, University of Liverpool, UK.

Key work areas
- Navigation dredging and disposal/use of dredged material,
- Offshore windfarm construction,
- Marine aggregate extraction,
- Marine licensing and marine spatial planning
- Marine climate change adaptation.

Recent work experience has included:
2007-2009: Director of Environment and Ecosystems Division at Cefas, the UK Government's Marine Science Agency. Member of the senior management team as well as leading a group of 150 staff undertaking research and advisory work on a range of environmental issues related to the marine environment.
2009-2010: Seconded to the UK's Marine Fisheries Agency to help set up the Marine Management Organisation which licenses all marine activities for England.

Professional Activities:
- Chair PIANC Permanent Environmental Commission's international working group on 'The Use of Dredged Material: Options and Constraints'.
- Member of PIANC working groups on 'Dredged Material Management' and on 'The Use of Ecotoxicological tests in Dredged Material Assessment'.
- Vice-Chair of CEDA Environment Commission
- Member CEDA UK Committee

Publications:
Author co/author of a range of technical papers in scientific journals and international conferences on marine environmental management and related issues.

Recent positions held:

2009-2010	Director of Business Continuity at Marine Fisheries Agency, UK.
2007-2009	Director of Environment and Ecosystems Division, Cefas, UK
2000-2007	Head of Environmental Management, Cefas, UK
1995-2000	Team Leader, Regulatory Assessments Team, Cefas, UK

Curriculum Vitae: Gijs D. Breedveld

Date of Birth: 15 June 1962

Nationality: Dutch

Position: - Technical Expert, and discipline manager for Environmental Engineering, Norwegian Geotechnical Institute (NGI)
- Associate Professor, Environmental Geochemistry, Department of Geosciences, University of Oslo

Education: B.Sc 1985, Environmental Sciences, Wageningen University, Netherlands
M.Sc. 1987, Environmental Sciences, Wageningen University, Netherlands
Ph.D. 1997, Department of Geology, University of Oslo, Norway

Key Qualifications:
Gijs D. Breedveld is coordinating R&D activities in the field of environmental engineering and leading large R&D projects. He has a background from soil and environmental chemistry and focusses on research, teaching and consulting on soil, sediment and groundwater pollution problems, with emphasis on risk reduction and development of remediation technologies.

Major fields of work have been related to:
- Remediation of contaminated sediments
- Risk assessment in soil and sediments.
- Contaminant transport and mobility.
- Natural attenuation/biodegradation processes.
- Site investigation and field studies.
- In situ remediation methods. • Modelling of fate and transport
- Monitoring methods for organic contaminants
- Bioavailability and biodegradability studies
- Capping of contaminated sediment

Previous Positions:
2006-present Technical Expert and Discipline Leader for Environmental Engineering, , Norwegian Geotechnical Institute, Oslo, Norway
Associate Professor, Environmental Geochemistry, Department of Geosciences, University of Oslo.

1998–2005 Deputy Department Head, Environmental Engineering, Norwegian Geotechnical Institute, Oslo, Norway
Assistant Professor, Environmental Geochemistry, Department of Geosciences, University of Oslo.

1993-1998 Head of Environmental Laboratory, Norwegian Geotechnical Institute, Oslo.

1991-1997 PhD student at the Department of Geology, University of Oslo (part-time).

1988-1992 Project Engineer, Norwegian Geotechnical Institute, Oslo.

1988 Project Engineer, Department of Soil Sanitation, Province of Zuid-Holland, Den Haag, the Netherlands.

Professional Societies:
Member of:

- Society of Environmental Toxicology and Chemistry
- European Federation of Biotechnology, section of Environmental Biotechnology
- European Association for Geochemistry
- The Norwegian Water Society
- The Norwegian Geotechnical Society

Professional Activities:

- Editor Journal of Soils and Sediments
- Steering committee member European Sediment Network (SedNet)
- Appointed to the Sediment Committee of the Norwegian Environmental Protection Agency

Publications:
Author/co-author of more than 100 technical papers in scientific journals and international conferences (publication list available upon request).