# Evaluation of "River Engineering and Sediment Management Concept for the Tidal River Elbe" by WSV and HPA: General Report

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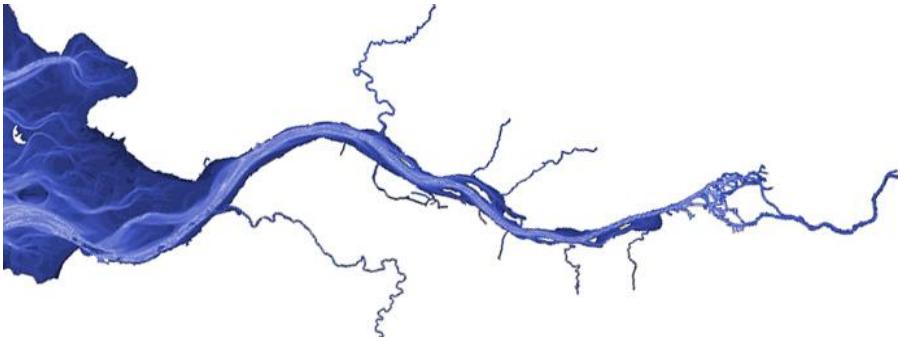

**8 July 2011**

# Evaluation of “River Engineering and Sediment Management Concept for the Tidal River Elbe” by WSV and HPA: General Report

Client: Wasser- und Schifffahrtsdirektion (WSD) Nord, Kiel

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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 primary source of motivation was the increase in energy input in the delta with disturbed material balance, the rise in the quantity of sediment to be dredged for the maintenance of the water depth, particularly in the Hamburg area and an altered legal framework.

The concept of 2008 specifies a number of causes for the rise in dredged volumes and on this basis not only develops a strategy for sediment management, but also for reduction of the dredged volumes, taking into account sediment composition and contamination. The latter encompasses measures of varying specific~~concrete~~ detail and feasibility and to this extent also different time spans. Individual aspects of the concept have already been implemented, others have yet to be commenced~~implemented~~.

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, for example. In view of this situation WSV and HPA have decided to arrange for an external evaluation of the concept in order to obtain suggestions for its further development. This work was carried out from a technical-scientific, not from a political perspective.

The evaluation was carried out by six~~6~~ independent international experts, who assessed the individual aspects of the concept based on their experience from other European estuaries, taking into account the European legal framework, and gave recommendations. The contribution of the experts took place from different perspectives in five~~5~~ work packages on the basis of information compiled for this purpose and was structured through targeted questions. The results are documented by a report for each work package. A project office (BioConsult Schuchardt & Scholle GbR), whose additional duties include structuring, organization, presentation and moderation of the work of the international experts as well as the overall evaluation, carried out this synthesis of the general report with recommendations for the further development of the RESMC.

This process was supported by an advisory body that consisted of representatives from WSD Nord, HPA, WSA Hamburg, BfG and BAW, who were also available for specific technical questions of the experts on the local situation and also included representatives of the clients. Joint meetings of the advisory body and project office took ~~and/or take place~~ during the project period.

**Conclusion**

As an overall approach, the RESMC is innovative and suitable for tackling the problems and it points out prospects for a "viable Elbe estuary". Given appropriate further development, it can make a major long-term contribution to securing the target depths of the shipping channel

specified in the approval procedure, regenerating ecological functions, improving adaptability to climate change and improving coastal protection.

It is urgently necessary to work out and further develop the (potential) synergies jointly with the other responsible parties, interest groups and parties concerned.

Implementation requires joint long-term efforts on the part of the federal and state governments in Germany for which the prerequisites are ~~presumably~~ favourable due to the existing situation regarding the problems (for example, as a result of the required long-term adaptation to climate change). In accordance with the order, however, the evaluation does not take into account current planning for further deepening of the shipping channel in the Lower and Outer Elbe. At this juncture it should be pointed out that acceptance and implementation of the RESMC will ~~presumably~~ not be facilitated by the overlapping of the two processes.

On the basis of the long-term prospects for full implementation, a two-pronged approach appears meaningful. On the one hand, WSD and HPA should specify the RESMC in greater detail as well as analyze synergies and impediments. The necessary measures should be further developed and the ecological impacts (risks and opportunities) as well as compatibility with the FFH Directive assessed.

On the other hand, communication with the other parties, possibly in the framework of the structures created through the IMP process, regarding the concept and its further development should be intensified and in parallel to that political support being sought. Implementation of the further developed RESMC and/or overall management of the tidal Elbe can only be realized together with the full commitment of all decision-makers, responsible players and parties concerned as an integrated approach.

Because of the challenges, particularly with regard to the river engineering measures, implementation~~bility~~ appears possible only if the (potential) synergies especially with nature conservation and coastal protection are developed jointly in such a way that implementation of the further developed RESMC and/or of an emerging overall management becomes the common interest of different parties.

**Technical recommendations**

- The feasibility, effectiveness, interaction and relative importance of the various approaches should be worked on and taken into account more specifically~~intensively~~
- Documentation of the effectiveness of the river engineering measures in particular as well as sediment traps regarding tidal pumping should be improved
- The contamination of the dredged material restricts the opportunities for efficient handling of dredged material; measures for reducing contamination are therefore pressing

- Different ways of relocating sediments with little to moderate contamination from the Hamburg area should be compared with a cross-sectional orientation

**Kommentar [PAW1]:** Not sure I understand what is being said here

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**Strategic recommendations**

- It is urgently necessary to analyze the possible synergy effects, especially of the river engineering measures, and further develop them jointly with other relevant fields (such as nature conservation, adaptation to climate and~~,~~ coastal protection)

- The form in which the cooperation and any joint responsibility regarding sediment management can be further developed by HPA and WSV should be examined

- Further development of the RESMC should take place jointly with the *Länder* within the scope of overall management of the tidal Elbe with clearly formulated and structured priority objectives

- The nature conservation perspective and the influence on ecological functions has to be taken into account appropriately in the further developed RESMC

- The overall approach of the RESMC and/or the individual measures should be examined in terms of their FFH compatibility; this must take place formally for the individual sites. As regards content, it appears more meaningful to gear the approach to cross-site (holistic) conservation objectives for the entire estuary, though this is legally not possible as things now stand ~~now~~. It should be examined here whether an initiative directed at the EU Commission may be meaningful.

**Kommentar [PAW2]:** ??

# 1. Background

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 increase in energy input in the delta with disturbed material balance, the rise in the quantity of sediment to be dredged for the maintenance of the water depth, particularly in the Hamburg area and an altered legal framework.

The concept of 2008, which further develops and specifies in greater detail the discussion contribution "Concept for sustainable development of the tidal River Elbe as a lifeline for the Hamburg metropolitan region", specifies a number of causes for the rise in dredged volumes and on this basis not only develops a strategy for sediment management, but also for reduction of the dredged volumes, taking into account sediment composition and contamination. The latter encompasses measures of varying specific~~concrete~~ detail and feasibility and to this extent also different time spans. The focus is on

- river engineering measures for reducing dredged quantities
- optimising sediment relocations and
- measures for reducing sediment contamination

Individual aspects of the concept have already been implemented, others have yet to be commenced~~implemented~~.

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, for example.

In view of this situation WSV and HPA have decided to arrange for an external evaluation of the concept in order to obtain suggestions for its further development.

# 2. Evaluation: Approach, procedure and process

**Purpose and objective**

The purpose of the project was to conduct an evaluation of the river engineering and sediment management concept (RESMC). An evaluation involves an analysis of the functions, systems, projects or organizational units and determines on this basis whether they meet the envisaged expectations or agreed objectives. The focus here is on two questions: "Are we doing the right

thing?" (validation) and "Are we doing it the right way?" (verification). Evaluations thus serve to review impacts and may represent a major tool for optimization.

The purpose of the project can be outlined as follows. On the basis of the available documents on the current practice of sediment management, the targeted practice described in the RESMC will be analyzed and assessed with regard to its strengths and weaknesses and its compatibility with the objective of sustainable development of the Tidal Elbe, and evaluation criteria derived on that basis, by external international experts. This work was carried out from a technical-scientific, not from a political perspective. The external evaluation of the RESMC primarily serves three goals in this context:

- Evaluating the approach
- Further developing the concept
- Increasing acceptance

The currently planned deepening of the shipping channel in the Lower and Outer Elbe for container vessels with a draft of 14.50 m and its implications are not the object of the evaluation.

**Approach and structure**

The following approach was developed and implemented to perform the specified tasks:

- Analysis by independent international experts
- Analysis and assessment from different perspectives
- Assessment also in view of experience in other European estuaries
- Evaluation of practice targeted in the RESMC on the basis of defined questions and criteria
- Compilation of the results for overall assessment and recommendations concerning further development

A project structure consisting of international experts, a project office and an advisory body was developed in line with this approach (see ~~Fig. 1~~Fig. 1~~Fig. 1~~). The evaluation was carried out by 6 **international experts**, who assessed the individual aspects of the concept based on their experience from other European estuaries, taking into account the European legal framework, within the scope of a contractual relationship and gave recommendations. The contribution of the experts took place in 5 work packages on the basis of information compiled and predominantly translated for this purpose (see below) and was structured through targeted questions. The results are documented by a report for each work package (regarding the work packages

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see section 5). The international experts were selected jointly by the advisory body and the project office (see below) according to such criteria as international scientific reputation, experience in managing large projects as well as European and international networking. The experts were chosen and their tasks defined in such a way that an overview of the concept is possible in a synthesis of the individual reports. A **project office** (BioConsult Schuchardt & Scholle GbR), whose additional duties include structuring, organization and moderation of the work of the international experts as well as the overall evaluation, carried out this synthesis.

This process was supported by an **advisory body** that consisted of representatives from WSD Nord, HPA, WSA Hamburg, BfG and BAW, who were also available for specific technical questions of the experts on the local situation and also included representatives of the clients. Joint meetings of the advisory body and project office took ~~and/or take~~ place during the project period.

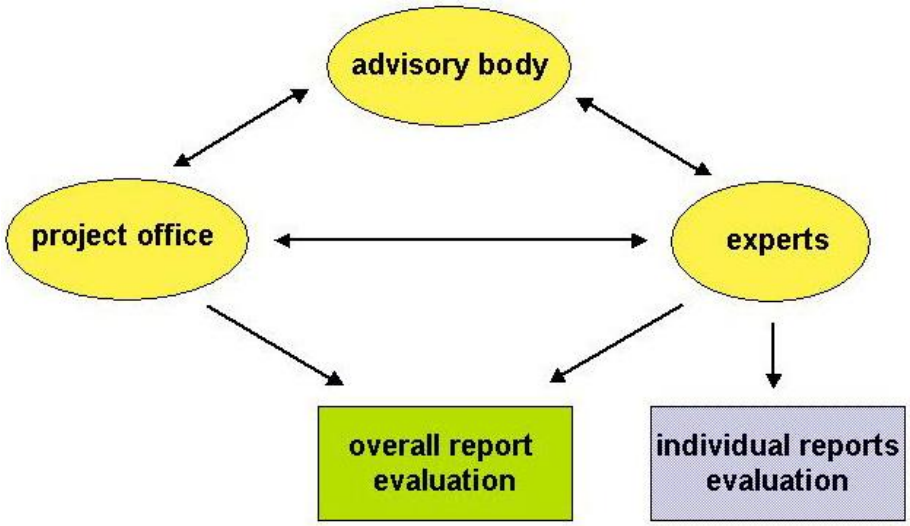


**Fig. 11:** Project structure of the evaluation of the RESMC.

The partial results of the experts and the overview were discussed with the advisory body and developed into an overall assessment. A consensus among the experts as well as with the advisory body was~~is~~ not imperative. The project office shall publicly present and discuss the results of the evaluation.

**Parties involved**

The parties involved in the project with different functions are shown in Table 1~~Table 1~~:

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**Table 1:** Parties involved and their function in the evaluation of the RESMC.

| Function | Name | Institution | Location |
|---|---|---|---|
| Expert | Gijs Breedveld | Norwegian Geotechnical Institute (NGI) | Norway |
| Expert | Patrick Meire | Universiteit Antwerpen | Belgium |
| Expert | Roger Morris | Bright Angel Coastal Consultants Limited | Great Britain |
| Expert | Lindsay Murray | Swift Impact Ltd | Great Britain |
| Expert | Dano Roelvink | UNESCO-IHE Institute for Water Education | The Nether-lands |
| Expert | Peter Whitehead | ABP Marine Environmental Research Li-mited (ABPmer) | Great Britain |
| Advisory body | Günther Eichwe-ber | Wasser- und Schifffahrtsdirektion Nord (WSD) | Kiel, GER |
| Advisory body | Ingo Entelmann | Wasser- und Schifffahrtsamt Hamburg (WSA) | Hamburg, GER |
| Advisory body | Peter Heininger | Bundesanstalt für Gewässerkunde (BfG) | Koblenz, GER |
| Advisory body | Nicole von Lie-berman | Hamburg Port Authority AöR (HPA) | Hamburg, GER |
| Advisory body | Axel Netzband | Hamburg Port Authority AöR (HPA) | Hamburg, GER |
| Advisory body | Klaus Rickert-Niebuhr | Wasser- und Schifffahrtsdirektion Nord (WSD) | Kiel, GER |
| Advisory body | Henrich Röper | Hamburg Port Authority AöR (HPA) | Hamburg, GER |
| Advisory body | Holger Weilbeer | Bundesanstalt für Wasserbau (BAW) | Hamburg, GER |
| Project office | Svenja Beilfuss | BIOCONSULT Schuchardt & Scholle GbR | Bremen, GER |
| Project office | Bastian Schu-chardt | BIOCONSULT Schuchardt & Scholle GbR | Bremen, GER |

**Information base**

The international experts performed their work on the basis of specially compiled and translated documents (see overview in annex), the lectures and discussions at the kickoff workshop (see below) and bilateral contacts between individual international experts and members of the advisory body and/or project office.

**Overview of project process**

The project was divided into 4 phases (see Table 2~~Table 2~~). In the preparation phase the project structure was developed jointly by the advisory body and project office, the international experts were chosen and the necessary information was prepared and translated. The work performed by the international experts started with an initial information package and in particular a kickoff workshop in January 2011 at which members of the advisory body introduced the subject matter in lectures, discussed the tasks and talked about further information required that was additionally provided. Initial results of the work carried out by the international experts and further information needs were discussed by the experts and the advisory body at another workshop in March 2011. A third workshop, at which the results were presented and discussed by the experts, took place in May 2011 on the basis of a draft of the respective reports of the international experts. The finished reports were submitted by the experts by approx. the end of May. These reports formed the basic foundation for the general report presented here.

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**Table 2:** Project phases of the evaluation of the RESMC.

| | | | |
|---|---|---|---|
| 1. | 09 to 12 / 2010 | Preparation | Structuring<br>Selection of experts<br>Preparation of information |
| 2. | 01 to 05 / 2011 | Expert reports | Workshops<br>Work reports<br>Exchange of information |
| 3. | 05 to 07 / 2011 | General report | Discussions |
| 4. | 2011 / 2012 | Presentation / communication | Federal and state administrations<br>Public<br>Tidal Elbe Symposium |

**Products**

The following products resulted from the evaluation:

- Compilation and preparation of background information (see list in annex)
- 5 individual reports of the international experts
- General report with recommendations
- Presentations

# 3. Characterization of region under study

The region under study encompasses the section of the Elbe estuary between the Geesthacht tidal weir (km 585.9) and the island of Scharhörn (km 750) (see ~~,~~Fig. 1~~,~~Fig. 2~~Fig. 2~~). The relatively narrow (200 m), so-called tidal Elbe stretches from the Geesthacht tidal weir to km 607.5. This then connects seawards to the area where the river forks, encompassing the city of Hamburg up to km 625.6. Only the Northern Elbe and Southern Elbe as well as the Köhlbrand flow through this area. The Lower Elbe extends from km 625.6 to km 727.7 and widens from approx. 500 to approx. 2,000 m between Hamburg and Brunsbüttel. It consists of several channels, one of which in each case has been expanded into a shipping channel, while the Elbe side arms are subject to increased silting in some cases. In the Elbe side arm area the width may be up to 600 m. Eulittoral sections exist with varying width. The following broad, funnel-shaped outer estuary between km 727.7 and 769.4 is designated as the Outer Elbe. The shipping channel here has very wide eulittoral sections.

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The hydrodynamics and morphodynamics of the Elbe estuary are significantly influenced by the tidal dynamics that~~in~~ interplay with the upstream water. The tidal range increases from 2.9 m at~~in~~ Cuxhaven to 3.6 m at~~in~~ Hamburg/St.Pauli. It is not until upstream from the Hamburg area where the river forks, and thus outside the section deepened for seagoing vessels, that the tidal range drops to 2.5 m at the Geesthacht tidal weir. The current tidal range in the inner estuary has been altered due to structural measures carried out in the past. Separation into a higher-energy current channel and sedimentary side areas has increased at the same time (SCHUCHARDT 1995).

Two characteristics of the estuary are the longitudinal gradient of salinity and its pronounced dynamics, which also have key significance for the biotic communities. The position of the brackish water zone is influenced, on the one hand, by the tides. On the other hand, particularly the upstream water influx plays an important role in controlling~~regarding~~ the location and formation of the brackish water zone. Overall, the tides and upstream water dynamics lead to a very substantial variability of the salinity in the region. Over the long term the brackish water zone in the Elbe has been mov~~shift~~ed upstream as a result of structural measures (e.g. RIEDEL-LORJE et al. 1992, BERGEMANN 1995; WGE 2004). The scope and in particular the in-

fluence of various factors or causes (dike construction, shipping channel deepening, port expansion, climate change, etc.) are currently still the subject of controversial debate. For simplification the salinity is classified according to biological aspects on the basis of the Venice system. A distinction is made here between the limnetic zone with a salinity of <0.5 PSU, the oligohaline zone (0.5–5 PSU), the mesohaline zone (5–18 PSU) and the polyhaline zone (18–30 PSU). The location and size of these zones in the estuary vary considerably. The location and size of the estuarine turbidity zone associated with the upper range of the salt gradient are closely related to the salinity gradient (RIEDEL-LORJE et al. 1992).

The composition of the sediments in the sublittoral zone of the Elbe estuary is primarily influenced by the flow speed. In the shipping channel, where higher speeds prevail, medium sands dominate while the side sections with little current mainly display fine sands. Both coarse sands and fine sediments, such as in situ bed load clay, are found only locally; the same applies to silt. However, silt may also dominate in tidal flats with reduced current like Mühlenberger Loch.

The oxygen concentration in the Lower Elbe has been very well documented since the 1950s (www.arge-elbe.de). The oxygen concentration in the upper section of the Lower Elbe can be substantially reduced in summer. In the 1980s concentrations of below 3 and even below 1 mg/l were measured over larger sections. Since the 1990s concentrations below 3mg/l were significantly reduced both spatially and temporally (ARGE ELBE 2004; KERNER 2007). In particular the reduced primary pollution due to expansion of the treatment plants in Hamburg and, after reunification, in the Upper and Middle Elbe provided for environmental relief, as well as the decline in industrial production in the new federal states in eastern Germany.

The reduced toxic inhibition of primary plankton production in the Middle Elbe and the resulting increase in secondary pollution in the Lower Elbe had a polluting effect (see ARGE ELBE 2004). The influence of partial backfilling of Mühlenberger Loch on oxygen concentration in summer is controversial. The contribution of shipping channel deepening in 1999/2000 to the oxygen concentration is also controversial (see ARGE ELBE 2004; NEUMANN 2004; BFG 2006; KERNER 2007; SCHÖL et al. 2009). At the moment it does not seem certain how the improvement in oxygen concentration documented for the 1990s as compared to the 1980s will continue to develop since there is a tendency towards increased seasonal oxygen deficiencies, primarily in the Hamburg region of the tidal Elbe and also below Hamburg, that has been documented since the beginning of the 21st century (ARGE ELBE/FGG ELBE 2007).

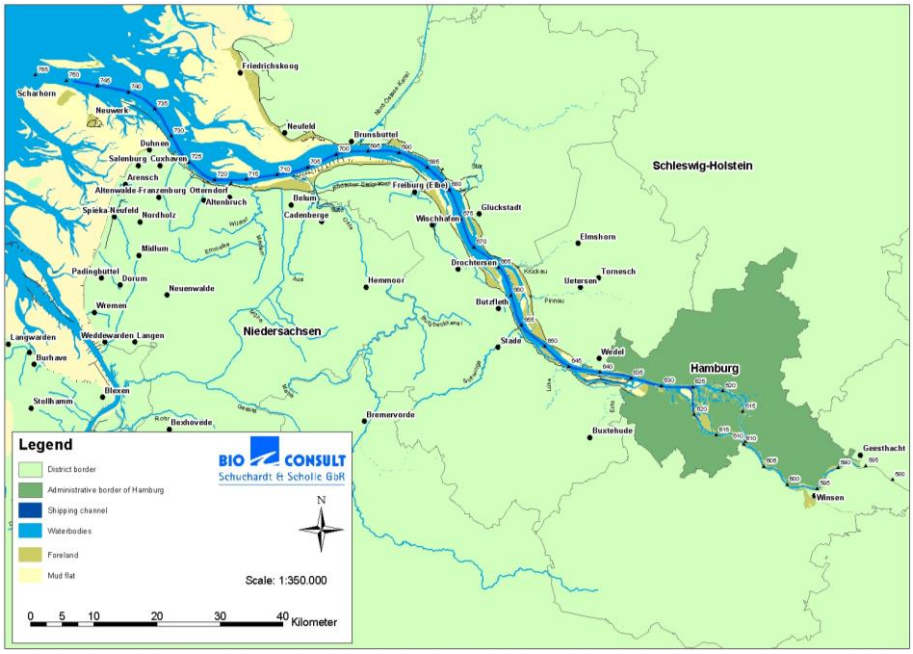


**Fig. 22:** Overview of the Lower and Outer Elbe with kilometrage.

# 4. Overview of River Engineering and Sediment Management Concept (RESMC)

The background and objective of the RESMC are outlined above in section 1. It combines different approaches and specifies them in detail on the basis of various measures that are mentioned in brief form in the following (the RESMC is available at http://www.hamburg-port-authority.de/presse-und-aktuelles/umfragen/192-strombau-und-sedimentmanagementkonzept-fuer-die-tideelbe.html and www.portal-tideelbe.de).

**Understanding of the system**

Continuous further development of the understanding of the system by means of relevant investigations and analyses as well as expansion of the monitoring of major parameters is a basis of the RESMC.

**River engineering measures in the Elbe mouth area to reduce the oncoming tidal energy**

The aim of the river engineering measures is to reduce upstream transport of sediments:

- Reducing oncoming tidal energy by river engineering measures

**River engineering measures to reduce the oncoming tidal energy on the way to Hamburg**

Aim of the following river engineering measures is to reduce upstream transport of sediments and create sedimentation areas:

- Aactivation of side arms of the Elbe
- Rreconnection of arms of the Elbe

**River engineering measures to create flooding areas on the way to Hamburg**

The aim of the following river engineering measures is to reduce upstream transport of sediments:

- Creation of flooding area in foreland
- Creation of flooding area in silted-up harbour basin (derelict land) and canals
- Creation of flooding area by relocating dikes
- Creation of flooding area by reconnecting side arms, etc.

**Optimized relocation of sediments**

The aim of the following measures for optimizing relocation of sediments is to reduce dredging quantities and improve the economic efficiency of shifting sediments:

- Relocation of dredged sand fractions to erosion areas
- Utilization of side arms of the Elbe and other side areas as sediment traps (fine sediment)
- Utilization of sediment traps in the shipping channel

- Reducing sedimentation focal points by means of local river-directing measures
- Optimizing use of water injection in the Lower Elbe in view of differentiated treatment of different sediment fractions
- Avoiding cyclical dredging by means of optimized relocation (local, timing-related) in the Lower Elbe (hopper dredging)
- Avoiding cyclical dredging through relocation from the tidal Elbe River system to the North Sea (provisional solution)

**Handling contaminated sediments**

The aim of the following measures is to reduce the impairment to~~s of~~ the environment that may result from release of contaminants during relocation of contaminated sediments:

- Supporting measures to reduce pollutant emissions in the catchment area (work of IKSE and FGG Elbe)
- Continuation of removal of contaminated dredged material from the system (storage/treatment on land)
- Avoidance of mixing contaminated and uncontaminated sediment due to sediment traps and reduction of tidal pumping (sediment transport further upstream with high tide)
- Reviewing evaluation criteria within the framework of a better understanding of the risk of sediment-bound contaminants

**Further development and implementation of the RESMC**

The RESMC envisaged short-term implementation of initial measures between 2008 and 2011, which has taken place to some extent. For the period up to ~~as of~~ 2011 the RESMC provides ~~for~~ a review of the effectiveness of the~~se~~ implemented allowing ~~measures, implementation of~~ further measures, further development of the concept ands possible implementation of further measures. It~~,~~ also allows ~~taking into account~~ regional and international findings to be taken into account along with~~,~~ coordination with Schleswig-Holstein and Lower Saxony as well as integration into general management of the Elbe. This evaluation is also linked to this management process~~ese measures~~.

# 5. Results of work packages 1 to 5

This section contains the unchanged summaries from the five~~5~~ reports of the six~~6~~ international experts that answer the questions posed to the experts in abridged form. The experts performed their work on the basis of the reports and information provided by the advisory body, three~~3~~ joint workshops and bilateral discussions. The reports of the international experts have not been translated and are available in English. They performed their work against the background of the specific experience at different estuaries and from different disciplinary points of view, structured on the basis of questions (see section 2 and below). The authors are responsible for the individual reports as well as for the following summaries.

## 5.1 The RESMC in view of sediment management strategies in other European estuaries from a morphological perspective (Peter Whitehead)

The report has concentrated on developing an understanding of the historical development of the tidal Elbe with respect to the morphology and how these have caused changes to the water levels and sediment characteristics which are important for maintaining navigability to the Port of Hamburg, maintenance dredging and flood risk along the Elbe. This understanding has then been used to evaluate the potential effectiveness of the various RESMC measures and indicate considerations and studies that will be required for any specific measure design. For the most part where the historical understanding or conceptual process analysis has identified implications for the objectives of the RESMC or the specific design of measures, these have been discussed at that point. This conclusion focuses on the specific questions raised for this work package.

**Assessment of the situation up to approx. 2005 ("initial situation"):**

**What is the assessment of the influence exerted by past expansion, river engineering and dredging strategy on the present-day morphological situation and/or morphodynamics?**

From the historical assessment it is clear that the combined effect of anthropogenic influences; reclamation, structures, flood defences, Port developments and various phases of channel deepening have changed the morphology and morphodynamics of the estuary as a whole. These have combined to cause 'coastal Squeeze', which along with the deepening up to a fixed location (the St. Pauli tunnel) has accentuated the tidal propagation and the reflection of the tidal wave, thus increasing the tidal range up estuary, particularly at Hamburg. At the mouth, however, it is important to note the tidal range and levels have only been affected by sea level rise (SLR). The most significant effects on the morphology/morphodynamics have occurred in the now narrow constricted section of the estuary above Brunsbüttel.

The assessment tends to indicate that the most significant factor in the enhancement of the tidal dynamics has been the large removal of accommodation space, particularly tidal prism along the estuary. This has caused channel constriction, particularly at the higher tidal states,

reducing the volume for the incoming tide. The progressive deepening has increased the speed of the flood tide propagation into a smaller volume. This process has increased flood flows, particularly the peak rates, increasing the flood flow dominance of the tide, both over a larger estuary extent and with increased magnitude in an up estuary direction.

This increased flood dominance has led to an enhancement in the phenomenon of tidal pumping where sediment entering on the flood has been moved ever further up estuary and if it has settled the reduced ebb flow speeds either cannot erode the sediment or cannot remove it, hence the need for maintenance dredging.

On the basis that tidal range at the entrance has not significantly changed, if the CSA and SSC have not altered then the amount of sediment entering the estuary will be the same. The change in flow speeds and relative dominance will have redistributed the material around the estuary. Over time the locations prone to sedimentation have not significantly altered, being controlled by the tidal harmonics and reflection of the tidal wave which have remained relatively constant (except in magnitude). The flow speeds at the individual locations have, as has the sediment distribution, moved both at the bed (the coarser sands) and in suspension (the fine sand and silts). The magnitudes of sedimentation at each location will have been changed due to the deepening, but not the overall volume available for transport, however more is concentrated in the up estuary sections.

The construction of in channel structures at specific locations has influenced local flows to prevent sedimentation, however the overall supply has not been changed and the material that once settled at these locations has moved up estuary as tidal pumping has increased. As there are more settlement areas, up estuary, e.g. the Harbour Basins, this has led to an increase in sedimentation needing maintenance dredging in these areas. This increase however, is only likely to be from a greater volume of the coarser material, moving nearer the bed than from the fines in suspension, unless the SSC of fine sediment has increased at the up and downstream boundaries, then there would have been little change in fine sediment supply to the basins, as little extra could be eroded from the sandy channel.

The analysis of dredge material disposal and dredging practices indicate that relocation to the Neßsand site set up a sediment re-circulation cell, which would have enhanced the amount of maintenance dredging required in the Port area once introduced. The last main dredge and in channel structures enhanced the tidal pumping and moved more sediment up estuary. To minimise transport distances the increased material from the Wedel area was deposited further up estuary than when it was dredged from the Rhinplatte area. This effectively enhanced the supply and setup another re-circulation cell, which interacted with that for Neßsand. This significantly increased sedimentation in the Port area until the supply was reduced by the change of the WSA Hamburg disposal practices in 2006 and alleviated further by the relocation of sediment out of the system to the North Sea, by depositing at Buoy E3.

This summary of the effects of past anthropogenic interventions on the estuary shows that there has been a significant influence on the estuary morphology and morphodynamics. This understanding therefore needs to be integral to any design of future RESMC measures.

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

**What sediment management strategies are practised and/or developed in other European estuaries? Are there similar problems there?**

A review of other estuaries around Europe has shown the general problems associated with the Elbe and their causes are not unique. However, the scale of the effects varies considerably depending on the location of the Port along the estuary, the tidal range and sediment dynamics. In the UK, whilst similar morphological and structural changes to the estuaries have occurred historically, few have developed where deep draught vessel access is possible throughout the tide at an up estuary location. Most up estuary Ports have developed on the basis of only allowing access on the higher range tides and LW levels are accommodated by either deep berthing pockets or within lock enclosed docks. Thus whilst significant reductions in accommodation space and coastal squeeze have occurred on a par with the Elbe, constriction and over deepening of channels has not taken place. Maintenance dredging and relocation of the arisings is still required and has to be managed. In the Humber Estuary, where a large proportion of UK maintenance and capital dredging takes place, sediment management programmes have been developed to account for the hydrodynamic and sediment regime of the estuary, and where possible these will minimise impacts on nature conservation features in general and for some specific functions, with the aim of providing some benefit. These measures follow similar principles to those being considered for the RESMC, but will be distinctly different due to the site specific environmental differences. In the Western Scheldt, which is probably the closest estuary of the Elbe type, sediment management techniques are being used which maintain the flood and ebb dominant channels, by extending sand banks to narrow (therefore lengthen) individual channels, thus maintaining higher flows in longer channels, both on the flood and ebb to reduce channel sedimentation. To some extent this has already been undertaken in the Elbe by the extension of banks to form Islands. The difference would appear to be that some of the secondary channels have been allowed silt up or deliberately filled, thus the Elbe is more of a single channel system than is presently the case in the Western Scheldt.

The report gives examples of measures of similar type to those proposed in the RESMC that have been undertaken or proposed, particularly with respect to modification of water levels. It is fair to say however, that in most cases this was a 'bi-product' of the measures, rather than the prime objective. They do however show that RESMC measures which increase flood storage, particularly tidal prism and accommodation space will benefit water levels in the Elbe. The examples, however, suggest that relatively large areas will be required to provide modest changes. Where MRs have been implemented in the UK, mainly for nature conservation compensation purposes, they have generally been accretional. This indicates that such measures on the Elbe are likely to reduce, SSC up estuary, which could benefit maintenance dredging as well as water levels, therefore could be designed to be multi-beneficial if implemented in the appropriate location.

To a degree all the proposed RESMC measures are not unique and have been effective and accepted both in the past and with respect to current environmental legislation, albeit with careful design, study and consultation.

**What is the assessment of the objective "reducing tidal pumping" as a sediment management strategy from a morphological perspective in view of the experience in other European estuaries? Are the envisaged river engineering measures (see section 1) for reducing tidal pumping expedient?**

For the most part, tidal pumping, to the same degree as is evident on the Elbe is not seen as a major problem, except where long over deepened (relative to the natural estuary morphology) channels have been dredged for navigation. In the UK there are few navigable estuaries of this type. The only one that is close (in type) is Southampton Water, however is much shorter in length. Whilst increased depths here have increased the maintenance dredge commitment has been focussed in the more up estuary locations. The volume by comparison to the Elbe is however small and contaminated sediments are not considered an issue; the significance of the effect is therefore low.

From the historic assessment for the Elbe, it would appear that the increase in tidal pumping effect is predominantly due to the deepened channel causing more asymmetrical tidal propagation within a constricted cross section. Whilst the incorporation of flood storage measures down estuary will have some effect, it is considered that reduction in the tidal pumping effect with respect to sedimentation in the future will be difficult to achieve, particularly in an economic and environmentally acceptable manner. It is likely to be more cost effective to remove/intercept sediment by 'trapping mechanisms' in areas where the sediment will be more efficient to dredge/ manage. In this way whilst the water that is pumped through the estuary remains, less sediment is transported with it in an up estuary direction.

As mean sea level rises, without the introduction of new flood storage areas (accommodation space) the coastal squeeze effect will increase leading to increased tidal pumping. The concept of increasing flood storage will therefore assist in overcoming the future effects of SLR.

**What is the assessment of the currently practised use of water injection in the main Elbe River (shipping channel) for attenuating sand riffles in comparison to the alternative of hopper dredging?**

WID has been assessed as being beneficial and cost expedient in the short term, for flattening sand ripples throughout the estuary. In the long term however, the sandy bed load will still be retained locally and slowly move up or down estuary (depending on location). It will eventually settle out in less dynamic areas where it will potentially need to be removed by TSHD. WID has little effect on the transport of fine sediments in suspension through the estuary. Benefits exist in the short term, particularly as it is not efficient to use a TSHD to 'hunt spots' or sand ripples. TSHD dredging will be needed at some point but the use of WID, possibly in conjunction with sediment traps, such as Wedel, should increase the efficiency of the dredge, when required, and it is likely to be carried out at the optimum time from environmental and relocation timing perspectives. In addition, the bedform roughness of the estuary is maintained for longer, thus aiding the dissipation of tidal energy.

WID is therefore a tool which will have benefit as part of an integrated dredged management plan for the estuary as whole, taking account of the combined effects of other proposed measures.

**Is breaking dredging cycles as a priority sediment management strategy appropriate and expedient from a morphological perspective in view of the experience in other European estuaries?**

It is clear from the historical and conceptual process analysis, that the interaction of the various developments along the estuary in combination with changes to dredge management practices caused a sediment re-circulation cell between Hamburg and the Neβsand relocation site. Initially this was manageable, however, following all the changes in the various activities and developments around the last channel deepening this re-circulation was significantly enhanced and self perpetuating, specifically due to the relocation of the sediments in the enhanced flood dominant flows. Any future RESMC measures (individually and in combination) will need to be thoroughly studied to ensure such cells are not set up or accentuated in the future. It is possible that these could occur throughout the estuary. In addition measures, where possible, should be used to reduce the magnitude or eliminate the possibility of such cells occurring.

In this assessment, however, consideration of the economics and environmental issues should be made, because as indicated in the Humber Estuary case example complete elimination of re-circulation, could potentially reduce the supply of sediments that the estuary needs to environmentally and ecologically function. Also, the estuary will always re-introduce sediment with the tidal flows; therefore there will always be sediment to manage. In such a case it is possible the best practical environmental and cost effective solution may be to allow/manage some re-circulation.

**What is the assessment of the removal of sediments from the Elbe estuary in view of the long-term "solids balance"?**

The tidal Elbe is for the most part strongly flood dominant and fine sediment is transported from the North Sea, through the mouth. This material is moved up the estuary where it settles out in the Harbour Basins, near the head of the estuary. This sediment will at some point have passed through any location where potential sedimentation could occur. If, therefore, sediment is dredged from the Harbour Basins and removed from the system, it will not affect the long term solids balance within the estuary as this material would have already had the potential to settle out down estuary. That being the case, the dredged material is only the sediment which the estuary did not require to morphologically evolve under the existing hydrodynamic conditions. Albeit, this assumes the existing sediment supply from outside the system is not changed. If the import of marine sediment reduces, the amount of material in the system would reduce and eventually no maintenance dredging would be required. Removal of fine sediment from the system as a whole, particularly from up estuary sedimentation areas is therefore not expected to affect the morphological functioning of the estuary in its own right.

**Is the practice of sediment trapping for fine material management appropriate and should the concept be extended?**

As discussed in earlier sections, the tidal pumping will always move fine sediment into the Port area, therefore, if recirculation cells are eliminated the only other way of reducing dredging in the Harbour is to trap the sediment from the water column before it reaches the basins. How-

ever, flow speeds are high, so large horizontal 'stilling basins' will be required, whereby flow speeds are reduced and sedimentation can occur along the estuary from the rising tide. Coarser material moving near the bed is more likely to be intercepted by a vertical trap in the estuary bed, such as at Wedel. It is considered that flood storage area measures should be designed in a way that they also act as sediment traps, both up and down estuary of Hamburg. Trapping of the sediment in this way will also reduce the volume of contaminated sediments that need to be managed, particularly until up river source control can further clean up the sediment entering from the river. Such multi-functional measures should provide the most cost effective way of managing the maintenance dredging, particularly in the Hamburg area.

**Overall assessment and recommendations:**

From this analysis and understanding of the tidal Elbe, the RESMC provides a means to manage sedimentation (hence maintenance dredging) and reduce the current levels of flood risk and ameliorate the future effects of SLR. It would appear the current level of tidal pumping is unlikely to be substantially reduced; however, the sediment concentrations it moves up estuary are likely to be able to be managed or intercepted. In order for the RESMC to be effective, a number of different measures of the type already envisaged will be required. It is clear from the historical analysis, however, that some measures could have local beneficial effects but could cause 'knock on' effects which could lead to greater problems elsewhere and/or in the longer term.

Careful design, supported by detailed modelling investigations of the effects of individual measures as well as the combined effects for the estuary as whole will therefore be required. The results of the modelling should also be assessed against the historical understanding from the past activities on the estuary.

## 5.2 Sediment relocation and river engineering measures of the RESMC from the perspective of effectiveness and economic efficiency (Dano Roelvink)

**Assessment of the situation up to approx. 2005 ("initial situation"):**

**What is the assessment of the influence exerted by past expansion, river engineering and dredging strategy on the present-day morphological situation and/or morphodynamics (maintenance effort and expense, lowering low tide)?**

The port expansion and associated successive regulations and deepenings have had a very clear effect on the tidal propagation in the Elbe estuary. Especially the deepening has led to a reduction in resistance and an increase in tidal wave length, bringing it closer to the quarter-wavelength resonance situation. This has led to an overall increase of maintenance dredging, though not excessive in quantity. The apparent shift of the fine sediment turbidity maximum and sediment transport pattern may in part have led to the increased dredging costs in the HPA area up to 2005.

The lowering of the low tide is in part related to the general increase of tidal amplitude, but is likely enhanced by the increased opening of the mouth area, especially related to the Medemsand region.

It is likely that in some areas before 2005 dredging strategies applied led to considerable recirculation, which could in part explain the increased quantities in some areas, notably Neßsand.

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

**What is the assessment of the current practice of sediment management on the tidal River Elbe (particularly sediment traps, relocation of dredged material to buoy E3, water injection procedures, disposal at Neßsand as well as relocation of the dredged material quantities of the Kiel Canal)?**

In general it can be stated that the practice of sediment management on the tidal Elbe seems to be effective in reducing sediment recirculation, given especially the reduction in dredging effort in the HPA area in recent years; especially the reduction in dumping at Neßsand seems to have a positive influence.

Relocation of dredged material to buoy E3 appears to be feasible but very expensive and finding relocation areas within the estuary could be preferable, both from a cost point of view and given the desirability to keep sediment in the system.

From the data provided it is difficult to assess whether using WI dredging to shave off sand dunes is more effective than taking the sediment elsewhere; this depends on how often the procedure has to be repeated. Based on conversations with WSV the procedure appears to be much more cost-effective than hopper dredging, and furthermore reduces the risk of a 'fining' of bed sediments in these areas.

Relocation of the dredged material quantities from the Kiel Canal appears to be based on reasonable assessment of transport paths.

**Is the objective "reducing tidal pumping" expedient as a sediment management strategy?**

Under this term both the measures in the river mouth and those in the upstream area are mentioned. It is useful to separate both types, since in the first case the tidal motion (horizontal and vertical) in the tidal Elbe is reduced, with likely beneficial consequences both in terms of water levels and dredging quantities, whereas the second type has noticeable effects on the water levels but the effects on sediment transport and dredging quantities are less clear.

**Are the river engineering measures planned for reducing tidal pumping expedient?**

As stated above, measures in the mouth of the Elbe may be quite effective, but need very careful design, especially when hard structures are involved. It seems likely that increasing the sand volume by large but feasible amounts can reverse part of the trend in increasing tidal

range and reducing low waters. Possibly such measures must be accompanied by hard structures such as large cross dams, which could additionally be used for locating wind energy farms in some cases.

**What is the assessment of the current practice of using water injection in the Lower Elbe with regard to management of the various sediment fractions? Is the practice of sediment trapping for fine material management appropriate and should the concept be extended? Is there related experience elsewhere?**

Using WI dredging to clear the ports and tributary mouths of fine sediment appears to be quite efficient since the sediment flows into the main channel to be dispersed quickly. For shaving off sand dunes it may be effective, depending on how often the procedure has to be repeated.

Sediment trapping is widely used to create a buffer space in order to more conveniently plan the dredging operations and to allow fine sediment to settle. In this respect the trap at Wedel already seems to be having a positive effect. If the traps are meant to capture larger percentages of fine sediment, for instance to avoid mixing with more polluted sediments, then much deeper and/or wider traps must be considered, ideally both upstream and downstream from the Hamburg port area. Some of the projected new tidal areas upstream of Hamburg may be suitable for this, provided they are regularly dredged out. Alternatively, old harbour basins now silted up could be used as efficient sediment traps when dredged out regularly.

**How is the effectiveness of the opening of the side arms of the Elbe seen?**

Their effect on the tidal pumping will probably be limited, but allowing more frequent flooding of tidal marshes would introduce a (modest) sink of fine sediment and additionally allow the marshes to follow the sea level rise trend.

**Is breaking dredging cycles as a strategy for reducing quantities of dredged material appropriate and expedient?**

This is definitively a sound strategy and it has been used successfully in many places, e.g. in the case of the relocation of Rotterdam harbour sediments from Loswal Noord (just north of Hook of Holland) to Loswal Noordwest, closer to Scheveningen. Reducing and better timing of the dumping at Neßsand has led to considerably smaller dredging quantities in the HPA area.

**According to what criteria should relocation sites/disposal sites be selected?**

Some criteria relevant to dredging efficiency and morphological impact are:

- Minimum recirculation of sediment to originating dredging sites or nearby dredging locations
- Preferably in sedimentation areas
- Easy access and minimum sailing distance

- For coarse material, use in scour locations can be appropriate
- Preferably keep sediment within the system
- Where possible 'make work with work'

**What is the assessment of the removal of sediments from the Elbe estuary in view of the long-term "solids balance" of the estuary?**

In principle, given the discussion of the sediment loss from the Elbe mouth, it is advisable to leave the sediments in the system. It is possible that part of the sediment loss in the mouth is related to dredging practices, and if so this should be stopped. The dumping of relatively small quantities of sediment at E3 will not have a very large impact on the system.

**What is the assessment of the further measures for optimizing sediment relocation (see above)?**

These measures, such as relocation of sediment to more downstream locations in the WSA Hamburg area seem quite sensible. However, more can be done to substantiate the processes of sediment dispersal, both in terms of modelling the fate of the dumped sediments and the morphodynamic impacts, supported by local measurements e.g. tracer studies.

**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?**

These objectives were formulated as follows:

1. reducing dredged quantities for example by river engineering measures for reducing tidal pumping also in the delta; sediment traps; creation of flooding areas

   The way this objective is formulated it is a bit of a mix of objective and three methods; the objective of reducing dredging quantities is obviously valid; the effectiveness of the measures for actually reducing the dredged quantities needs to be further substantiated but positive effects are quite likely.

2. measures for management of the sediment budget by optimising relocations

   This seems to be working already given reduced dredging amounts in recent years; further development of operational modelling capability in combination with monitoring can further refine this strategy.

3. measures for improving sediment contamination (in particular remediation measures in the entire catchment area)

Obviously this is a sound strategy, though it will only work on a very long timescale

In my opinion, the HPA and WSV are facing problems that are quite similar to those encountered by the other major ports in Europe and are dealing with them in an adequate way, given the sometimes difficult administrative circumstances. On the longer term, further integration of their objectives with those of other organizations and stakeholders in the estuary seems inevitable.

**Do the measures outlined in the RESMC represent overall the right way to achieve the objectives?**

As stated before, the measures appear generally logical, but in many cases need further substantiation.

**Recommendations for the further development of the RESMC**

Our main recommendations for the further development of the RESMC based on the discussion above are:

- Develop long-term integrated plan for Elbe mouth nourishment strategy plus hard structure plus deposition site of fine sediment plus possibly other uses (e.g. wind energy)
- Develop upstream locations as sediment traps both upstream and downstream of Hamburg
- Develop operational sediment transport and morphodynamic modelling system for short- and long-term simulations; pay more attention to sand behaviour.

## 5.3 Measures of the RESMC for handling contaminated sediments from the perspective of ecology and economic efficiency (Lindsay A. Murray/Gijs D. Breedveld)

**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?**

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 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 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, 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.

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?**

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. 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 (see MURRAY & BREEDVELD 2011) 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 (see MURRAY & BREEDVELD 2011). Additionally, it may be necessary to consider additional interventions to reduce the contaminant load reaching the tidal Elbe. 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. 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.

The Marine Strategy Framework Directive (MSFD) is linked to the regional conventions. National measures to implement this Directive are still at an early stage. 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.

**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?**

The objectives of the RESMC are according to our evaluation highly relevant and sensible for the short to middle long-term. 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.

**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.

## 5.4 Sediment relocation and river engineering measures of the RESMC from an estuary ecology perspective (Patrick Meire)

This assessment is made from the point of view of the ecological functioning of the estuarine system and does NOT take into account any aspect of legislation. It is not unlikely that some measures, although beneficial for the ecological functioning of the river, might be difficult to implement due to environmental legislation.

This assessment is based on the documents made available by HPA and WSV (see references) and other reports and publications found in the scientific literature and the internet. Although a lot of information is available on some aspects of the system (mainly dredging related) it is remarkable that very little information on the ecological aspects of the Elbe are present. Water quality data are available from the FGG Elbe site but other ecological information is very difficult to find and seems not to exists in a comprehensive way. This is a serious drawback for this evaluation. Another drawback is the very limited information on most of the proposed measures. The success of a measure will largely depend on the design of the project. As long as this information is not available, it is not possible to give a correct assessment of the measure. Therefore the overall approach is evaluated.

The ecological functioning can be subdivided into 3 main series of processes:

1. Maintenance of geomorphological processes

2. Maintenance of biogeochemical processes

3. Maintenance of ecological processes

These will be the major criteria used for evaluating the present situation and the proposed measured: how much do they contribute to the maintenance of these processes.

To make an evaluation, we must have a reference against which we have to refer to. As both historical and geographical references are not very useful it is argued that an approach based on ecosystem services (see TEEB, www.teebweb.org ) might be very helpful. Although there is no quantitative reference against which we can assess the present situation, the delivery of services and the human benefits related to this can be used as a reference. So measures or impacts that have negative influence on the production of fish populations, on the dissipation of tidal energy, on the possible volume of flood water that can be stored etc. will be assessed as negative.

**Assessment of the situation up to approx. 2005 ("initial situation"):**

**What is the assessment of the influence exerted by past expansion, river engineering and dredging strategy on the present-day situation regarding estuary ecology?**

It is clear that the changing hydrodynamics (increasing tidal amplitude, increasing tidal asymmetry) in combination with the historical loss of habitat (due to different reasons) and possibly changes in sediment loads had a very important impact on the geomorphological development of the estuary and it is unlikely that tidal habitats, especially tidal marshes and flats, can be sustained without human interventions (like revetments), at least in a significant part of the estuary. This indicates that the **maintenance of geomorphological processes** is seriously hampered and human intervention is needed to maintain the structure of the habitats. Thesees changes in hydrodynamics and geomorphological processes can also have an impact on the ecological quality of the marshes as evaluated by the vegetation communities. Information on other biota is lacking.

Also for the **maintenance of the biogeochemical processes** there seems to be still major problems. Oxygen patterns, certainly in the neighbourhood of Hamburg harbour are a problem. Although the reasons for this oxygen sagck in summer are still not really understood we believe, based on a detailed analysis of the data, that it is very likely that the problems are due to local phenomena within the estuary, rather than to the import from upstream. There are indications that local resuspension might be very important. This should be studied in more detail. The primary production in the Elbe is also rather low what could be attributed to an unfavourable Zm/Zp ratio (average mixing depth/photic depth) due to higher turbidity values and a high average depth. In overall conclusion, we can say that the ecological functioning of the system is certainly hampered and it is more than likely this is to a large extentd due to the different measures taken in the past. As average depth, resuspension, current patterns and concentrations of suspended solids are all influenced by measures in the RESMC, the impact of the measures on ecological functioning should be studied and evaluated in detail.

**The maintenance of biodiversity and other important ecological processes** such as the food web, transfer of matter to higher trophic levels etc. is difficult to assess as information is too scattered, absent or not available at this stage.

It is clear that past measures have had a strong impact on ecological functioning. The geomorphology and hydrodynamics are not in equilibrium and further developments of the tidal amplitude towards even more tidal asymmetry and/or increase of tidal amplitude would be very negative for the system. The ecological functioning is also impacted but overall it is clear that still a lot of open questions exist. Especially understanding of how the system will further develop and whether or not some thresholds are reached leading the system to another state of the system is crucial.

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

**What is the assessment of the objective "reducing tidal pumping" as a sediment management strategy from an estuary ecology perspective?**

Although tidal pumping is a natural phenomena, past river engineering measures have strongly increased tidal asymmetry and hence tidal pumping. As this results in a major increase in dredging activities the objective of reducing tidal pumping and hence less maintenance dredging, is seen as a positive and good objective. As will be mentioned later, this should be made more precise, to what degree tidal pumping should be reduced.

**What is the assessment of the river engineering measures envisaged for "reducing tidal pumping" from an estuary ecology perspective?**

A detailed assessment of the individual measures is not possible as this must be based on the detailed engineering design of each project as the individual design is crucial to the success. One measure can turn out to be extremely good or bad depending on the design AND the local conditions. Therefore only a general evaluation of the approach and types of measures can be given.

Reducing, or dissipating tidal energy is seen of utmost importance and it is clear that this cannot be achieved by one measure but that it will require a series of measures at very well selected sites along the estuary. All these measures will lead to a change in morphology. Successful measures should fulfil several criteria like, require as leastss as possible maintenance, trigger further "wanted" morphological developments, such as sedimentation or build up of intertidal areas. "Soft" measures are preferable over hard engineering and measures should be reversible. Indeed, the morphological development of estuaries is still poorly understood and even well designed measures may have unexpected negative consequences. Therefore it should be possible to adapt the measure according to the results and it is clear that adapting hard measures is more difficult. Reducing the cross section of the mouth is a potential measure that could reduce tidal energy. This seems to be a very sensible measure, but if this is realized by a hard structure it is likely to cause important unknown and possibly unwanted consequences. Therefore using a combination of dredged material with as little hard constructions as possible might be preferable. Experience with "morphological dredging" from the Western Scheldt might be particularly useful. Dredged material is now used to maintain and/or build morphological structures in a soft way. Also the sand motor, being applied in the Netherlands is a useful concept that should be studied as this might be used in the mouth of the Elbe.

The basic idea of the different measures is sound and a correct implementation might improve the ecological functioning. Reconnecting Elbe branches is likely to be very successful, but as mentioned this will depend on the design. Especially the amount of sedimentation and hence the maintenance will determine the success. The creation of flooding areas is assessed as very positive however there might be a very important conflict between the efficiency for ecological functioning and the efficiency for hydrodynamics. The efficiency of the restoration site from a hydrodynamical point of view, is the bigger, the lesser the area dries out at low tide, however from an ecological point of view the gradient from rarely exposed to rarely flooded areas is important. Also the removal of sediments from tidal areas to increase the flooding frequency is

likely to cause ecological problems. Therefore preference should be given to these measures where new intertidal areas are created by replacing dikes more landwards or removing sediments from sides that are not flooded any more. Creating flooding areas by removing sediments in harbour docks is seen as positive as their ecological role is limited. When creating new habitats special attention should be given to their morphological stability.

**What is the assessment of the current practice of using water injection in the Lower Elbe from an estuary ecology perspective? Are there comparative studies elsewhere?**

Very little information is available on the environmental impact of water injection dredging. Especially in very fine sediments it could cause some problems as organic matter, nutrients and pollutants could be released from the sediments into the water column. Although this might be~~y~~ less than during normal dredging operations it is advised to carry out some measurement~~s~~ campaigns to be sure the impact is minimal.

**What is the assessment of breaking dredging cycles as a priority sediment management strategy from an estuary ecology perspective?**

In general we can conclude that breaking up the sediment cycle is a very positive strategy but care must be taken that it is not just moving the problem from one place to another. In breaking the sediment cycle priority should be given to use natural areas for deposition, such as side branches, and make maximal use of high discharges to move the sediments downstream. When dredging, the disposal strategy should be optimized in a way the dredged material has as much as possible a beneficial use in the sense that the material is used to improve the morphology of the estuary, rather than just getting rid of the sediment. A sediment trap should be only a temporary measure until the whole project is realized.

**According to what criteria should relocation sites/disposal sites be selected?**

As already mentioned above, the disposal sites should be selected in such a way that the sediments play a role in the morphological development of the estuary. In doing so, it is important that resuspension of fine sediments is kept to a minimum as there is quite some evidence that resuspension might cause water quality problems. Local negative impacts should be weighed against larger benefits for the whole system. Of course, necessary attention should be paid to the quality of the sediments, but this is outside the scope of this review.

**What is the assessment of the removal of sediments from the Elbe estuary (disposal on land and in the North Sea) in view of the long-term "solids balance" as well as consideration of the concerns of estuary protection, on the one hand, and those of marine protection, on the other hand?**

Removing the contaminated sediments from the system is a sensible management strategy. Although extremely expensive the processing of sediments in the Metha plant and the land disposal is evaluated as positive. The sea disposal might be a temporary solution but given the large costs it is clearly unsustainable. The aim should be to keep the dredged sediments within

the system. If too much sediment is imported from the catchments, measures should be taken there to reduce the amount of sediments transported to the estuary.

**What is the assessment of the practice of sediment trapping for fine material management?**

The present sediment trap near Wedel has seemingly no impact on environmental parameters and hence on ecological functioning. The efficiency as a sediment trap is outside the scope of this review. As it allows to concentration ofe the dredging activities to certain periods (and of course in space) this can be preferable to other dredging activities seen from an ecological point of view. However, I would strongly advisee to study the options of installing sediment traps more upstream, both in the river, upstream Geesthacht and in the port area. Several possibilities exist to increase sedimentation in shallow areas. Using old docks in the harbour might be very efficient to capture polluted sediments before they are mixed with the cleaner marine sediments.

**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?**

Yes, the objectives are very sensible and in agreement with the situation in other estuaries although they need to be formulated much more precisely. Although no really new concepts are described, the overall approach is certainly ahead of many other estuaries.

**Do the measures outlined in the RESMC represent overall the right way to achieve the objectives? Are the aspects of nature conservation, water protection and marine protection given appropriate and equally weighted consideration?**

Yes the measures represent the right way to achieve the objectives although they it are at the moment by now mainly building blocks. However the objectives are defined very narrow in relation to the dredging/sediment problems. In this respect the aspects of nature conservation, water protection and marine protection are not at all equally weighted. The aspects of nature conservation are just mentioned, there is no link at all to the conservation objectives related to EU-HD and ecological functioning is not really mentioned.

**Recommendations for the further development of the RESMC**

A crucial step is to integrate these RESMC into a broader overall management plan for the estuary. Indeed the measures proposed can have multiple benefits going far beyond the benefits for sediment management. Making these benefits clear might also be very helpful in creating a public acceptance for the plan. The concept of ecosystem services might be very helpful in this regard.

A crucial step is also the formulation of clear and measurable objectives. Now, the objectives are formulated in very broad and general terms like "reduce tidal pumping", but this is very

vague. Integrated objectives, taking into account different objectives is crucial. This would allow ~~an~~to ~~-~~ evaluation~~e~~ of the multiple benefits arising from the measures.

The success of the plan will also depend largely on the detailed planning and design of the projects and the right mix of the different projects at the different places within the estuary.

A very detailed ~~-an~~ integrated monitoring plan should be set up. ~~- Now already l~~Large amounts of data are already collected but there seems to be a lack~~ing some~~ of coordination in the monitoring and there is certainly a need for more integrated reporting of data. The problem of collecting data on birds and benthos is a clear example of this. There is also a clear need for more ecological data from the estuary.

When working out the concept in more detail, ~~- enough~~ attention should be paid to the consequences of climate change, not only the sea level rise, but also the expected changes in discharges and loads from the catchment.

If there is a conflict between objectives with N2000 sites, this should take account of~~be situated~~ in an overall (holistic) approach and not on a site by site basis.

## 5.5 The RESMC in view of sediment management strategies in other European estuaries and European directives from an ecological perspective (Roger Morris)

**Conclusions**

Environmental and economic problems concerning dredging in the Elbe Estuary arise from a complicated suite of anthropogenic influences. There are no obvious parallels in northern Europe. Other major estuaries exhibit a range of similar problems but differ in the physical size of the estuary or the scale of the problems. This means that whilst there are external models that can be drawn upon to find solutions, there are no directly applicable models. Hamburg Port Authority and WSV are therefore developing an approach that will be watched with interest by other ports that lie a long way up major estuaries.

This assessment largely focuses on the relationship between the RESMC and various European environmental Directives, most notably the Birds and Habitats Directives, the Water Framework Directive and the Marine Strategy Framework Directive. The analysis therefore considers the interpretations that are relevant in a **legal** rather than a biological context. Biological, toxicological and geomorphological considerations are made by the five other specialists in the Expert Group.

This analysis has been greatly hindered by the fragmented nature of information supplied on the biological attributes of the Elbe Estuary and the apparent weaknesses in the mechanisms of governance of the designated sites. The high-level message of this analysis is therefore that a coherent approach to estuary management has not been very obvious. Supplementary information has been supplied that provides some reassurance that the issue of fragmentation is

being addressed. However I have been left with the impression the Port of Hamburg and WSV have been trying to find solutions without access to coherent and integrated Conservation Objectives for the estuary as a whole. High level objectives need to be qualified by descriptors of what constitutes favourable condition within various attributes within the estuary.

Complaints about the lack of consistency by UK ports ultimately led to additional Commission guidance on what should be included within Natura "Estuaries" sites. Several Member States, including Germany and France were required to re-define estuary boundaries to include navigation channels (fairways). This means that by default the UK has longer experience of development of integrated plans and the issues relating to reconciling dredging with management of Natura 2000. Several models for strategic management initiatives are offered and emphasis is placed on the benefits of developing coherent and integrated Conservation Objectives combined with Favourable Condition tables.

The overall package of measures developed by evolution of the RESMC has the potential to address a variety of additional problems. Many relate to the need for climate change adaptation strategies and in particular measures to reduce the dangers associated with sea level rise. Increasing accommodation space will greatly assist in many ways, both as a measure that changes tidal propagation, but also as a means of absorbing additional sediment, nutrients and carbon. The RESMC therefore needs to be developed with reference to climate change mitigation and adaptation.

**Assessment of the situation up to approx. 2005 ("initial situation"):**

**What is the assessment of the influence exerted by past expansion, river engineering and dredging strategy on the present-day ecological situation?**

1. The modern geometry of the Elbe Estuary is heavily modified by a variety of interventions that include channel deepening, loss of accommodation space to sea walls (dykes), cutting off tributaries, groyne fields and removal and relocation of sediment.

2. The loss of natural meanders and braided channels means that the Elbe estuary in its modern form lacks many of the structural and functional features that might be expected in one the biggest estuaries in northern Europe. Consequently it is difficult to argue that the estuary as a whole meets the desired state of 'good ecological potential' in relation to the Water Framework Directive.

3. The current distribution of habitats within and adjacent to the tidal Elbe differs greatly from those existing in the original floodplain. These habitats would have supported a different, and doubtless richer assemblage. Some of the changes in fish breeding success may be attributable to these changes, but other more significant influences such as pollution levels, depressed oxygen availability and loss of spawning grounds are arguably as significant. In the case of Twaite Shad *Alosa fallax*, these influences combined with overfishing are reported to be highly significant (THIEL et al. 2008).

4. It must be recognised, however, that the modern distribution of habitats and species has been reflected in the suite of designations under the Birds and Habitats Directives. This

means that the wildlife value is recognised **despite** the impact of changes. This is the baseline against which legal determination of the impacts of measures to address the need to reduce levels of dredging will be assessed.

5. It is important to bear in mind that the changes to channel geometry and to the extent of accommodation space has a significant bearing on the ability of the estuary to respond to relative sea level rise. Current sediment loads appear to be sufficient to allow inter-tidal habitats to keep pace with rising sea levels and this is an important issue when considering the need to integrate climate change adaptation measures.

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

**How do sediment management concepts of other European estuaries take into account the requirements of the WFD, MSFD and the Habitats Directive?**

1. There are several initiatives to manage sediment in northern Europe. The reasons behind their development differ according to the port, its host country and the estuary concerned. There would appear to be no complete package of measures that in any way resembles that of the RESMC proposed by the Hamburg Port Authority and WSV. It is also worth emphasising that the problems faced by HPA and WSV appear to exceed those faced in virtually any other northern European estuary.

2. There is very little to suggest that a comprehensive package of measures has been completely evaluated according to the provisions of the Birds, Habitats and Water Framework Directives at any other location. This is complicated by the inter-relationship between channel deepening, loss of accommodation space through land reclamation (poldering and industrial) and limiting the influence of tributaries and meanders.

3. There are models in the UK that predict the possible loss of inter-tidal habitats and their implications for Natura 2000 (referred to as Coastal Habitat Management Plans [CHAMPS]), but that this has only been applied in relation to flood defences. Such approaches cannot be directly translated into a mechanism to assist in management of the Elbe Estuary but they do offer an additional way of responding to some of the problems that are being experienced on the Elbe.

**What is the assessment of the objective "reducing tidal pumping" as a sediment management strategy in view of the requirements of the WFD, MSFD and Habitats Directive?**

1. The principle of 'reducing tidal pumping' is a reasonable objective and **if** it can be achieved without the loss of key Natura 2000 Habitats and species then it is laudable and should be pursued.

2. The big problem is that the measures to reduce tidal pumping involve major changes to the geometry of the estuary and in particular appear to be largely confined to areas within the boundary of the site(s). Measures that lead to the loss of existing Natura 2000 habitat

(and species) may not be **legally** appropriate. Particular concern is raised about those measures that involve changing inter-tidal habitat into sub-tidal habitat.

3. Although the EC has emphasised that no hierarchy exists between the various environmental Directives it is important to bear in mind that the most demanding objectives take priority. In this respect, achieving favourable conservation status for Birds and Habitats Directive attributes is likely to be the highest priority. In the UK, where I am most familiar with the relationship, this means that measures to meet WFD objectives cannot be pursued to the detriment of the Birds and Habitats Directive objectives. An alternative interpretation may be followed in Germany.

4. Using high level objectives relating to the extent of habitat within the Natura 2000 site, it becomes clear that proposed measures within the RESMC are unlikely to be **legally** appropriate. However, it is also recognised that interpretations of the Directives may differ between Member States and that the German view may be at variance with UK experience. However, the Waddensee Cockling judgement is apposite and must be taken into account when making any assessment. It is important to remember that this Directive is highly precautionary – it must be proven that there will **not** be an adverse affect on the Conservation Objectives for the site(s).

**What is the assessment of the objective "reducing cyclical dredging" as a sediment management strategy in view of the requirements of the WFD, MSFD and Habitats Directive?**

1. In principle, the objective of reducing cyclical dredging is a sound one and is not incompatible with the objectives of the various environmental objectives.

2. Measures to achieve this may, however, involve changes to the geometry of the Elbe Estuary. These may have a bearing on the distribution and extent of Natura 2000 habitats and species, and consequently the overall package of measures is unlikely to meet the test 'can it be ascertained that there will not be an adverse affect on the Conservation Objectives'.

**Does the paper "Waterways and Ports" in the Lower Elbe Integrated Management Plan, along with the measures presented there concerning optimization of maintenance dredging, represent an appropriate basis for implementing the Habitats Directive from a European perspective?**

1. This paper has not been prepared as far as I am aware, and consequently it is not possible to comment on the paper itself. Analysis of the issues based on a paper drafted by Günther Eichweber highlight the main problem; that the RESMC has progressed at a pace that far outstrips the progress by the three Länder who are responsible for preparation of the nature conservation components of the plan.

2. The most significant impediment to the development of a dredging strategy is the degree to which Natura 2000 designations are fragmented. Figures provided by Bioconsult indicate that there are 14 SAC and 5 SPA. At the moment, each will have Conservation Objectives but they may bear little resemblance to one another and the absence of any over-arching

geomorphology- based principles means that further confusion is inevitable. Supplementary information supplied in July 2011 indicates that estuary-wide objectives have been agreed. These will help to resolve conflicting objectives for individual sites.

3. It is important to bear in mind that the 'Integrated Plan' is a non-statutory document and as such does not form a legal basis for managing the estuary. This approach seems to be analogous to 'Estuary Management Plans' prepared in the UK in the 1990s, although the application of specific statutory powers may mean that there are parallels with Regulation 34 'Management Schemes' that have been prepared for European Marine Sites in the UK. Experience with both has given mixed results.

4. Creation of new inter-tidal habitats may also be a small but useful positive contribution towards carbon sequestration, as saline mudflats and green foreshore has been shown to act as a carbon sink (e.g. ANDREWS et. al. 2008). Wider environmental benefits can therefore be gained from the total package developed around the objective of reducing cyclical dredging. However, these alone cannot be used to justify loss of Natura 2000; any losses would have to be offset by new habitat creation.

5. Dredgers and associated equipment emit considerable levels of greenhouse gasses and consequently there is a great deal of sense in seeking a long-term reduction in dredging demands as part of a long-term climate change mitigation strategy.

**What is the overall assessment of the RESMC and the measures specified there with respect to the objectives of the WFD, MSFD and Habitats Directive?**

1. The RESMC focuses on the need to reduce dredging costs and the cost of remediation of contaminated sediments. Consequently, most confluence lies between the RESMC and the Water Framework Directive. However, it must be remembered that WFD objectives cannot be pursued without reference to the issues relating to both the Birds and Habitats Directives and the Marine Strategy Framework Directive.

2. The RESMC appears to have been developed without access to the information needed to make sure that proposed measures conform to the requirements of the Habitats Directive. Consequently, this analysis concludes that it does not conform to the requirements of Natura 2000. Analyses at various stages relating to this and other questions highlights the major problem: that many measures will lead to significant loss of existing Natura habitat and creation of habitat that may or may not be of comparable value. At least in the short to medium-term the impacts will be highly detrimental.

3. An impression is gained that the highest level of attention has been paid to problems with the breeding success of the protected fish *Allosa fallax* – the Twaite Shad or 'Red Herring'. This may have deflected attention away from the broader issue that shallow inter-tidal is linked to the extent of inter-tidal mudflats and green foreshore; which in turn is related to the extent of accommodation space.

4. Measures that lead to an increase in accommodation space are highlighted as the most likely to be consistent with the requirements of the Habitats and Birds Directives; provided

they do not lead to the loss of extent of another habitat. Consequently, the most promising proposal from this perspective is the Borsteler Binnenelbe, and the least appropriate is Haseldorfer Marsch.

**Are conflicts regarding objectives between protection of the estuary and marine protection reduced by virtue of the RESMC?**

1. The RESMC changes the nature of the conflicts. It may reduce levels of contaminated sediment entering the marine environment but in doing so it will exacerbate conflicts between nature protection and navigation.

2. The most helpful way of determining whether the RESMC is consistent with the objectives of the Water Framework and Marine Strategy Framework Directives is to make sure that it meets the requirements of the Habitats Directive. This is because a significant component of EU environmental sustainability centres on the need to deliver favourable status [Favourable Conservation Status (FCS) – Habitats and Species; Good Environmental Condition (GEC) or Good Environmental Potential (GEP) – WFD]. A package of measures that takes a site or habitats away from Favourable Conservation Status will not meet GES or GEP because the habitats and species have been pushed further away from FCS.

**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?**

1. All of the objectives set by the RESMC in relation to volumes of dredging and levels of contamination make sense and can be reconciled with many strategic priorities within the Elbe estuary. They are consistent with other European estuaries in relation to sediment contamination remediation. It must therefore be concluded that the **strategic direction** of the RESMC is correct and that the objectives set provide a sound foundation for the development of specific measures.

2. There is, however, considerable potential for conflict between strategic dredging objectives and objectives relating to nature conservation and other uses/activities within the Elbe estuary. In this respect, the RESMC differs from the most other established packages of measures used to manage estuaries as an entity.

3. The most comprehensive packages in this respect emanate from the UK where assessment of dredging is made in combination with measures to remediate nature conservation problems and flood risk management. The strategic framework developed in the UK offers a model that is worthy of further examination.

**Do the measures outlined in the RESMC represent overall the right way to achieve the objectives? Are the aspects of nature conservation, water protection and marine protection given appropriate and equally weighted consideration?**

1. There are a variety of possible benefits and drawbacks that may arise from the overall package of measures. If the total package were to be implemented it is difficult to see how the relevant environmental legislation will be satisfied.

2. It would be inappropriate, however, to judge the RESMC without recognising the very peculiar circumstances that HPA and WSV face. The estuary is huge; it is much larger than the majority of other northern European estuaries whose management may be used to inform the analysis. Furthermore, the development of the RESMC has not been helped by what appears to me to be a fragmentary approach to development of the 'Integrated Plan' for the Elbe estuary.

3. The conceptual thinking behind the RESMC has many merits, and the suite of possible options is sufficiently comprehensive to generate debate. In this respect it is therefore an important advance and offers the basis for future dialogue and options development.

4. **However**, some of the options will lead to loss of Natura 2000 habitat that cannot be regarded as viable from a strictly legal perspective.

5. At this stage, it must therefore be concluded that the RESMC has identified a series of measures that maybe appropriate to delivering the sediment management objectives sought by HPA and WSV, but are inappropriate to delivery of Habitats and Birds Directive objectives, and by inference the objectives of the Water Framework and Marine Strategy Framework Directives.

**Recommendations for the further development of the RESMC**

1. A three stage approach to further development is suggested.

   - In the short-term the issues relate to relationships with the Länder and development of a common vision.

   - In the medium-term the focus should be on sensitivity testing and development of a clear understanding of the impacts of proposed remedial measures in the RESMC.

   - Finally, live projects should focus on creation of new freshwater wetlands that will act as sinks for suspended sediment and will yield broader flood management and nature protection benefits.

2. It is suggested that the model developed by the UK Marine SACs LIFE projects (see http://www.severnestuary.net/secg/docs/executive_summary.pdf) might form the basis for discussion with the Länder. However, it would not be appropriate to simply copy the UK approach. A German solution is needed.

3. The critical issue for development of an integrated plan is the provision of a clear relationship between the different components. A plan developed as a series of independent units will never be 'integrated' because each party will simply follow its bit of the plan and over time will diverge further and further from any consideration of related issues. A model for the relationships is provided.

4. It is recommended that the high-level framework for managing the Elbe Estuary should be geomorphologically driven. Simple 'Regime' analysis combined with existing knowledge of the way the system functions should help to explain the relative sensitivities of the estuary to interventions. The model of best practice is arguably the Humber Estuary Flood Risk Management Strategy (Planning for the Rising Tides). This approach should help to climate-proof the 'integrated plan'.

5. Where physical changes are made to the location and structure of flood defences experience has shown that the case for change should focus on social and economic benefits rather than the nature protection issues.

# 6. Overall assessment and references to further development

The assessments and recommendations in the various expert papers have been prepared from different perspectives according to the evaluation approach. The experts were not always aware of special local features in detail. For this reason the various perspectives are compiled in this section taking into account the objectives formulated below.

## 6.1 Evaluation criteria

An evaluation focuses in particular on two questions: "Are we doing the right thing?" (validation) and "Are we doing it the right way?" (verification). The result of an evaluation thus essentially depends on the formulation of the objectives of the process to be evaluated. However, the RESMC makes few statements in this connection. The **long-term and equally weighted objectives of the RESMC** as a contribution to sustainable development of the tidal River Elbe have been formulated on the basis of the overall approach of the RESMC in coordination with the advisory body 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 dredging
- 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

These objectives, which are only partially described the background of the assessments in the individual reports of the experts according to the respective perspective, form the reference framework for the following overall analysis.

## 6.2 How is the overall approach of the RESMC assessed?

**Overall approach**

The RESMC combines different approaches with the aim of reducing and/or optimizing maintenance dredging with minimal ecological impairment. The approach is innovative and far-reaching and in all likelihood can be implemented in its entirety only in the long term.

The overall approach seeks to deliver ~~can point out prospects for~~ a "viable Elbe estuary" through a combination of different complementary approaches as it basically provides~~oints out~~ a paradigm shift to holistic estuary management enabling a number of synergies for tackling current and in particular future challenges. This becomes evident in the following passage: *"The aim is not to establish the original condition again, but rather to achieve a dynamic state of equilibrium which can be maintained with the minimum outlay and minimum negative impact on the ecology. Instead of a very concentrated tidal current, the main aim is the reduction of the tidal hub; instead of the highest possible level of control of the current by hydro-engineering, the objectives become the natural development of the marginal areas and, where possible, of the free morphodynamics in the estuary"* (HPA & WSV 2008, p. 12).

**Synergies**

The overall approach was developed with the aim of reducing and/or optimizing maintenance dredging, but at the same time it represents an approach for tackling different current and expected future challenges:

**Regeneration of ecological functions:** Many ecological functions are significantly restricted in the Elbe estuary due to anthropogenic measures. This has been documented in numerous cases that encompass habitat loss and impairment of biodiversity as well as pollution, such as by virtue of oxygen deficiency and harmful substances (some are outlined in section 5). Some of the river engineering measures are fundamentally suitable (although they may not necessarily be compatible with the FFH Directive, see below) for compensating for habitat losses that have occurred historically, reducing the anthropogenically increased tidal range in the inner estuary and improving ecological functions.

**Adaptation to climate change / coastal protection:** Climate change will affect the North Sea coast, especially the estuaries, primarily via the accelerated rise in sea level and, to an increasing extent, ~~presumably~~ bring about more anmd greater magnitude extreme events in a

variety of ways. Currently this phenomenon is undergoing analysis in connection with the Elbe estuary, such as in the projects KLIWAS (www.kliwas.de) and KLIMZUG-Nord (www.klimzug-nord.de). Adaptation of coastal protection has already begun (a "supplementary climate change factor" is taken into account in the current general plans) and the German *Länder* as well as the federal government (German Strategy for Adaptation to Climate Change, DAS) are preparing long-term adaptation strategies.

It can be assumed that the coastal protection requirements will continue to mount and other coastal protection strategies may become necessary and/or meaningful in the estuaries in the long term. Investigations on the Weser estuary, for instance, show that storm surge peaks can be reduced significantly through the use of storm surge polders. Considerable synergies with the RESMC appear possible here. Some of the river engineering measures will lead to a reduction in the mean tidal high water and thus in storm surge peaks. This could be intensified by means of targeted management of the polders. At the same time it is possible that areas subject to managed realignment will also grow because of sediment deposits. Overall, implementation of the RESMC is likely to ~~may~~ increase the resilience of the estuarine system.

These synergies are hardly examined in the RESMC and should be worked out appropriately in the course of further development since they enable broader political support and may thus facilitate implementability.

**FFH compatibility**

Nearly all RESMC measures also touch on aspects of nature conservation (simplified here with focus on the FFH Directive), both from a formal and substance-related point of view. Apart from possible synergies (see above), considerable conflicts are also foreseeable. It can be assumed that some of the measures will not automatically be compatible with the protection and conservation objectives of the respective Natura 2000 sites affected.

The RESMC extensively omits the topic in terms of legal and substance-related aspects. This will make an assessment of feasibility as well as acceptance difficult. There is a significant need for action in connection with further development here.

On the one hand, the impacts of the individual measures on the protection and conservation objectives should at the same time be analyzed. On the other hand, there should be an analysis of the individual measures and also of the overall framework of measures in terms of their consequences for the ecological functions of the Elbe estuary in general as well as of coherence with Natura 2000. The protection and conservation objectives of the individual sites are ~~presumably~~ a meaningful reference framework for evaluation of the impacts on the entire estuary (which is legally necessary at present~~, however~~) but only to a restricted extent. Such an overall analysis represents a great challenge both formally and as regards the subject matter.

However, the draft of the IMP (www.natura2000-unterelbe.de) already points in this direction as general conservation objectives for the Elbe estuary are ~~also~~ formulated there. These objectives could form a suitable reference framework for evaluation of the RESMC measures. Whether and how a formal basis can be created for such an overall analysis are questions that

need to be looked into as a separate task. As a result, an FFH compatibility study at the level of the individual sites cannot be replaced at the moment.

In general, it can be presumed that implementation of the RESMC will additionally require coherence measures particularly due to use of areas that are valuable for avifauna (birds).

**WFD and MSFD**

Both the WFD and the more extensive MSFD target achievement of a good ecological state or potential through formulation of environmental objectives and specific action plans. The RESMC will presumably make a contribution to achievement of these objectives via the targeted reduction of environmental impairment and particularly of pollution of the aquatic environment. In the case of further development of the RESMC, however, this requires a special analysis, also in view of possible shifts in pollution between the estuarine and marine environment due to individual measures. To assess the consequences of maintenance dredging for the WFD objectives, a Web-based proposed procedure is available in GB that covers the four stages, i.e. screening, scoping, assessment and identification of measures (http://www.environment-agency.gov.uk/business/sectors/116352.aspx).

**Fragmentation**

The RESMC attempts to view the Elbe estuary as a complete system and to gear the measures to this approach. However, the boundaries between the areas of responsibility of HPA and WSD are still clearly perceptible, e.g. in relocation practice. The joint development of the RESMC shows in this context a perspective for gearing action to the complete system that should be expanded further.

Such a perspective of the complete system also reveals relatively pronounced fragmentation of the network of Natura 2000 sites (large number of sites), at least for the side arm areas. It will have a strong influence on implementation of the RESMC because many of the measures for creation of additional tidal volumes would take place in areas in which such a measure is not necessarily compatible with the protection and conservation objectives applying there.

This fragmentation of the Natura 2000 sites is partially overcome in terms of substance in the currently ongoing IMP process, e.g. by virtue of the formulation of overriding protection and conservation objectives. However, the need for formal reviews of FFH compatibility at the level of the individual sites will not be affected by that. Future implementation of a perspective that looks at the complete system thus remains a special challenge: *"High level objective-setting must include development of a common policy towards the way in which the Estuary SAC(s) and its SPA hinterlands will be managed. For example, one policy line might be to seek to maintain the existing distribution and extent of particular habitats. An alternative approach might be to recognise that change is inevitable and that the processes that drive change can be harnessed to yield a more ecologically sustainable environment. This is a key issue because it will help to determine whether some of the proposed interventions are consistent with the policy and management measures that statutory and voluntary conservation bodies aspire to achieve"* (report by MORRIS 2011 p. 47).

Further fragmentation, which should be weakened further in the framework of overall management, results, for example, from administration boundaries and the incompletely coordinated implementation of WFD and Natura 2000. However, significant progress has been made here in the past years, also due to legal requirements, as can be seen, for instance, in the examination of the entire catchment area of the Elbe within the scope of implementation of the WFD.

**Flexibilization**

Estuaries are very dynamic systems – this applies to geomorphological, biogeochemical and also ecological processes on different time scales. An RESMC has to give appropriate consideration to these dynamics and have 'built-in' flexibility to allow change in the future as required ("adaptive management"). Thus, it may be meaningful to adjust ~~make use of~~ relocation sites for dredged material based on the hydrodynamic understanding and/or monitoring ~~depending on the current upstream water so as~~ to ensure geomorphologically favourable behaviour of the relocated material. Such flexibility requires a good understanding of the system, monitoring, defined decision-making criteria, a correspondingly flexible version of the necessary approvals[1], etc. and the capability of performing the tasks on an appropriately flexible basis.

**Definition of objectives**

The objectives of the RESMC focus on a reduction in the volumes to be moved with minimal ecological impairment and a reduction in sediment pollution so as to generally optimize maintenance dredging. However, they are not formulated very precisely. For this reason assessment criteria that are also regarded as objectives of the RESMC were coordinated for the evaluation (see section 6.1) during preparation of the evaluation process. The formulated objectives are reasonable also in view of the situation at other European estuaries, though they need to be specified further.

Although it essentially contains the basis for a broad approach, the RESMC is a sector-geared concept that has been developed without being incorporated into an integrated approach of estuary management. Further development of the RESMC should absolutely involve such incorporation. The current IMP process helps in this respect ~~points out a possible perspective here~~.

Detailing and defining a hierarchy for ~~hierarchization of~~ the definition of objectives should take place in close communication with other parties involved at the Lower and Outer Elbe so as to ensure a coordinated system of priority objectives for shipping, nature conservation, coastal protection, agriculture, recreation, etc. The question regarding the level at which such a process should proceed and whether it can immediately follow the ongoing IMP process requires discussion.

[1] Since the basic principle of certainty in approvals has to be ensured (sufficiently clear formulation and specification of the legal consequences), this is not trivial.

**Detailed specification**

As already provided for in the RESMC, detailed specification of the measures envisaged in the RESMC is necessary. This means detailed analyses, data collection, numerical modelling and further development of the understanding of the system are required. Only in this way can short-term effects and long-term consequences of both the individual measures and the interaction of the various measures be assessed. Prior to this detailed specification priority objectives should be defined jointly with the other parties (see above) to be able to fully develop possible synergies.

In particular the river engineering measures should be designed in such a way that they can be modifiedadapted in the future (adaptive management) in response to thebecause of the pronounced morphodynamic and ecological effects.s In this way the uncertainty in predicting the impacts and limited comprehensive predictability of the impacts (in terms of both river engineering and nature conservation) can be taken into account leading to continual improvement over time.

**Implementation**

Implementation of the RESMC has already started. Besides the continuous analyses concerning further improvement of the understanding of the system, primarily measures for optimizing sediment management have been implemented. River engineering measures for increasing the tidal volume are in the planning phase. The great challenges regarding costs, practicalityim-plementability and acceptance are emerging in this context. This has to be taken into account in the necessary further development and detailed specification of the RESMC.

**Kommentar [PAW3]:** Started?

**Formatiert:** Hervorheben

**Acceptance**

The RESMC formulates a clearly altered river engineering strategy that is of considerable importance also for other users and parties concerned on the Lower and Outer Elbe. Brief note will be made of this here on a simplistic n exemplary basis, without conducting an analysis of the degree to which all users and parties arewere affected (either both positively orand negatively) within the framework of the evaluation.

**Kommentar [PAW4]:** ??

**Formatiert:** Hervorheben

Acceptance of the RESMC by the conservation authorities and organizations essentially depends on further detailed specification and consultation the further procedure. Based on the altered river engineering strategy, the RESMC opens up new ways for nature conservation and the ecology to be generate an ecologically positively developedment of within the Elbe estuary. If the possible synergies can be jointly developed successfully through intensive communication, as has already been started during the IMP process, not only will acceptance be achievable, but also support, at least via regional nature conservation organisations.

The managed realignment measures will presumably lead to massive conflicts with agriculture since the optimum locations will be within current agricultural areas substantial use is currently made of agricultural areas. Even though ensuring dike security has top priority , of course, this will assumedly overlap with resistance to managed realignment "as such" because the latter is not compatible with the traditional and firmly established view of the local coastal protection

parties. Therefore, further development of the RESMC has to be supported by an active communication strategy and managed realignment must be developed and communicated jointly with the coastal protection and nature conservation players, also as part of the adaptation to the accelerated rise in sea level.

**Conclusion**

- Combination of different approaches is innovative, purposeful and problem-oriented
- Overall approach can deliver~~point out~~ a perspective for a "viable Elbe estuary", but compromise will be required from all interest groups
- Compatibility with nature conservation objectives (especially Natura 2000), among others, is not easily ensured, particularly on individual sites, but may be if a holistic approach can be taken
- Presumably supports achievement of WFD and MSFD objectives
- Implementation holds substantial potential for conflict
- Effectiveness and/or cost-benefit ratio of individual approaches has not yet been sufficiently verified
- Further development and detailed specification is necessary

**References to further development**

- Take a closer look at synergies (ecology, nature conservation, coastal protection, climate change and navigation channel maintenance)
- Take into account other perspectives (including nature conservation and ecological functions)
- Take into account climate change
- Examine FFH compatibility
- Overcome fragmentation

- Make approach more flexible in responding to observed impacts ("adaptive management")
- Define objectives more clearly and comprehensively
- Specify RESMC and the individual components thereof in more detail and evaluate each with respect to the combined morphodynamic, ecological and nature conservation effects
- Make RESMC part of overall management of tidal Elbe (possibly in the framework of IMP process)

## 6.3 How is the basic understanding of the system assessed?

**Investigations and analyses to improve understanding of the system**

The RESMC involves targeted further development of the understanding of the system for the Elbe tidal estuary. The morphodynamic and hydrodynamic understanding of the system has been constantly ~~further~~ developed in the past years and the causes of the problems are predominantly specified correctly.

The existing calibrated numerical model of the BAW can be used for retrospective reviews (hindcasts), for analyses of the impacts of bathymetric changes, etc. and (to a limited extent) for sediment management. However, the capacity for modelling morphological changes over a longer period (e.g. changing channels) has been limited to date. Although large sections of the estuary and dredged material are sandy, work thus far has focused mainly~~strongly on~~ modelling suspended matter and fine-grain material. This should be extended to include work on morphodynamic processes bringing about changes in the river bed.

Understanding of long-term changes and long-term impacts of measures may therefore also be improved by making certain "simplifications" (shortcuts) in addition to the models used. That includes use of grid resolution, 2DH or quasi-3D representation, acceleration of the "morphological time" (use of a "morphological factor") as well as reduction of the spring and neap tide cycle to a simple representative tide. The aspect of resonance of the tidal wave and its change due to river engineering measures should also be the subject of in-depth analysis in connection with the RESMC. Whilst such modelling will aid the understanding this has to be considered taking account of the knowledge gained from the historical changes and on-going observations in a weight of evidence approach.

However, the above assessment for improving understanding of the system in the past years scarcely applies to the ecological functions and here in particular the biogeochemical processes, also in connection with the change in morphodynamics and hydrodynamics are not well understood. The data available is inadequate here and in some cases there is a lack of in-depth analyses of existing data. For instance, the causes of the summer oxygen deficiency in the Lower Elbe are ~~have~~ not ~~been~~ understood sufficiently to really be in a position to assess

the significance of the RESMC measures for the future scope of this deficiency. Among other things, the role that resuspension may play should be examined.

**Monitoring major parameters**

Improving understanding of the system and determining~~monitoring~~ the effect of measures taken are only possible on the basis of specifically targeted monitoring data. Concerning the Lower and Outer Elbe, a large volume of data is collected on different spatial and time scales, both in connection with relocation of dredged material and in other contexts for the~~like~~ WFD and FFH, and availability and accessibility have been substantially improved in the past years but further integration of the assessments is required. Monitoring in connection with implementation of the RESMC and/or individual measures is relatively extensive. Especially the impacts of dumping dredged material at ~~dumping~~ site E3, which are examined in depth.

However, the available data as a whole cannot be considered e~~designated~~ as adequate. Significant gaps exist particularly in the area of biogeochemical processes and ecological functions and how these vary with respect to the hydro- and morphodynamics. The requirements resulting from implementation of the WFD and FFH Directive and monitoring in connection with the last deepening of the shipping channel have improved the available data. ~~situation here, however.~~ The following, however, are still desirable: a more systematic structure and more intensive compilation and integration of different programmes, identification and closing of gaps, linking long-term monitoring to modelling and individual in-depth investigation campaigns to clarify special causal interrelationships. Currently initial consideration is being given to further integration of the various monitoring programmes.

**Conclusion**

- Causes of the problems are predominantly specified accurately
- Understanding of system of biogeochemical and ecological processes and links to hydr- and morphodynamics is inadequate

**References to further development**

- Improve verification of effectiveness of measures from all interest perspectives
- Further improve understanding of the system (including dynamics of sand fraction, resonance of the tidal wave and in particular biogeochemical and ecological processes; among other things, question of relevance of resuspension for oxygen balance)
- Further investigate the~~intensify analysis of~~ causes of sediment loss in the mouth of the Elbe

- Apply additional model approaches integrated with the existing estuary understanding

Formatiert: Englisch (Großbritannien)

## 6.4 How are the river engineering measures in the area around the Elbe mouth area for reducing the oncoming tidal energy assessed?

**Reducing oncoming tidal energy through river engineering measures**

Extensive erosion and thus an enlargement of the cross-section has~~ve~~ taken place in the mouth of the Elbe in the past decades. The reasons for this are not~~have not been~~ completely understood to date. However, the enlargement of the cross-section represents a major factor for increasing tidal pumping. The RESMC therefore provides for river engineering measures to reduce the cross-section in the Elbe mouth area with the aim of achieving a reduction in upstream transport of sediment in this way. The RESMC does not specify the type and scope of the measures, therefore additional analysis of potential design of such measures is required.~~.~~

Reduction of the oncoming tidal energy by diminishing the cross-section in the Elbe mouth area basically represents a promising approach. ~~Both t~~The effectiveness with respect to the ~~and the~~ ecological and nature conservation consequences are determined to a great extent by the type and scope of the measures~~, however.~~

In view of the fact that between approx. 1970 and 2000 a total sediment volume of circa 150 million $m^3$ has been lost in the Elbe mouth, it is obvious that very extensive measures are necessary there to significantly reduce tidal pumping in this way. Since the causes and whereabouts of the loss have not yet been completely understood, understanding should be improved by means of further bathymetric analyses and long-term morphological modelling. It appears conceivable that part of the increased transport in the mouth area results more from a decadal cyclical process. That would have to be taken into consideration accordingly in the specific definition of the measures.

From a morphological perspective different types of measures to reduce the cross-section in this area are conceivable:

**Bolstering sandbanks:** Positive experience with the bolstering of sandbanks (i.e. artificial addition of sand) is available from the Netherlands (e.g. Galgenplaat, Osterschelde), among other places. This can be done via "rainbowing" from the edge of the shallow areas or, if larger sections are to be bolstered, via pipelines (though much more expensive). Alternatively to single relocation of very large volumes, it would also be conceivable to dump a large portion of the sediment dredged as part of maintenance dredging in the Elbe estuary in the Medem channel or at the edges of Medemsand on an annual basis. Amounts of 5–10 million $m^3$/year could lead to changes in volume of the desired magnitude over a period of 15–30 years. An advantage of this would be that both local and large-scale effects can be monitored and adapted at the same time and expensive fixed structures avoided. The impacts of removal at other places would have to be assessed parallel to that and it would make sense to control the entire measure via modelling and monitoring.

**Securing the sandbanks:** Securing the existing sandbanks by means of a hard support is not the best option at first glance because of the great variability in the mouth area. It may, for example, lead to high maintenance costs. Relatively stable, slowly eroding sandbanks can fundamentally be stabilized by means of groynes, especially in combination with additional bolstering/maintenance. In contrast to the previous option, this variant would mean higher initial costs and would have to be very carefully designed with full understanding for the short- and long-term consequences since such measures are not very flexible and there is a risk of failure.

**Filling Medem channel:** A large barrier that cuts through the Medem channel is also conceivable. Such a barrier could lead to pronounced sedimentation in the remaining channel and effectively reduce the cross-section. Connection with placement of contaminated sediments that are covered with uncontaminated sediment through sedimentation is conceivable. The analysis of the expected effects should not only focus on the direct hydraulic effect, but also on possible secondary morphological changes that may partially cancel these effects. In this option the capacity for dismantling and the dynamic control are extremely restricted.
~~Quite g~~Good experience has been gained in the Western Scheldt with approaches such as bolstering sandbanks, often referred as "building with nature", a designation of limited applicability, however: *"In this concept dredged material is used in a beneficial way. The experiment "Walsoorden" in the Western Scheldt is a very good example. Dredged material is deposited subtidal with a diffuser at the tip of a sandbank that was heavily eroding due to the currents. The deposited sands are now transported by the currents up the sandbank/tidal flat and in this way the morphological development is steered in the desired way. The experiment is seen as very successful and this method is now applied in several sites in the Western Scheldt and an essential part of the dredging and disposal strategy"* (report by MEIRE 2011 p. 38–39). An assessment of this approach based on FFH aspects is not available~~, however~~.

Reduction of the cross-section in the mouth area presumably also leads to a reduction in the tidal range as well as in tidal pumping and thus in dredged volumes. Extensive measures are necessary, however. ~~- d~~Due to the fact that this is an exceptionally dynamic area, for which the causes of the pronounced erosion have not yet been fully understood (both at the local and large-scale level), the impacts and possible "side effects" cannot be assessed reliably.

**Formatiert:** Hervorheben

**Kommentar [PAW5]:** Not necessarily

*"Whatever the option considered it is very important to not just evaluate the immediate hydraulic effect but also to consider how subsequent morphological changes may undo these immediate effects to an unknown extent. As a simple example, restricting the width of a channel may enhance the resistance initially, but is likely to be followed by scouring that counteracts this effect, unless measures to prevent that are taken"* (report by ROELVINK 2011 p. 34).

Approaches such as the so-called "bolstering of sandbanks" are reversible and can be implemented successively over a long period of time. For this reason the impacts can be observed as a parallel operation and implementation of the measure can be adapted as required. Such approaches should be analyzed in greater depth.

Whether, however, such approaches may be more effective in achieving FFH compatibility than measures with fixed structures is a question that should be examined in an in-depth analysis. With measures of this type the targeted and/or achieved shift in relation from sublittoral to

eulittoral habitats has to be looked at from the point of view of FFH aspects and assessed against the background of the protection and conservation objectives.

**Conclusion**

- Approach basically correct (detailed specification not yet included in the RESMC or studied)
- Very extensive measures necessary
- FFH compatibility does not automatically exist
- Synergies with nature conservation, coastal protection, adaptation to climate possible

**References to further development**

- Continue analysis of causes of sediment loss
- Analyze connection between dimensioning and effectiveness more intensively
- Compare different designs
- Consider possible "side effects"
- Target reversibility and dynamic controllability

## 6.5 How are the river engineering measures for reducing the oncoming tidal energy on the way to Hamburg assessed?

**Activation of side arms of the Elbe**

Activation of side arms of the Elbe is aimed at reducing tidal energy by improving the flow through sedimented side arms of the Elbe. This can take place by means of appropriate maintenance dredging and/or improvement of the flow through current-controlling measures.

The approach is basically correct. The contribution to reduction of tidal pumping is limited, but the measures may be meaningful within the framework of an overall concept. Restoration may lead to conflicts with nature conservation due to the necessary excavation of eulittoral areas. ItPresumably one cannot be assumed that the measures are compatible with the FFH conservation objectives.

On the other hand, activation of side arms of the Elbe may also result in new shallow-water zones, which were extensively lost in the past and perform a variety of ecological functions that are not fully depicted by the protection objectives of the FFH Directive. In this context of conflicting priorities a careful analysis of the advantages and disadvantages from an overall view of the estuary is ~~extremely~~ necessary ~~here~~.

**Reconnection of side arms of the Elbe**

Reconnection of old arms of the Elbe, such as Borsteler Binnenelbe, is aimed at reducing tidal energy by restoring the flow through side arms of the Elbe that were cut off in the past. This means appropriate structural measures and possibly maintenance dredging are required.

The approach is basically correct. The contribution of individual measures to reducing tidal pumping is limited, but they may be meaningful within the framework of an overall concept. Depending on local conditions, restoration may conflict with objectives of nature conservation or, when a Natura 2000 site is involved, may not necessarily be compatible with the protection and conservation objectives.

On the other hand, substantial synergies with the objectives of nature conservation are possible as the restoration of shallow-water zones in secondary channel systems through which water flows is an important development objective on the Lower Elbe, also in terms of FFH aspects.

An example is Borsteler Binnenelbe, which was separated from the tidal Elbe due to diking in the past. Reconnection is proposed as a measure in the RESMC and, given appropriate planning, it may contribute to the objectives of the RESMC (increase energy~~in~~ dissipation; enlargement of accommodation space) as well as support ecological functions (such as creation of additional FFH Directive estuary). Reconnection may basically take place as part of rediking or via controlled sluices. Currently it also being examined within the scope of compensation measures in connection with nature conservation and thus illustrates the possible synergies between nature conservation measures and RESMC measures.

**Conclusion**

- Approach basically correct
- Contribution ~~presumably~~ rather small
- Synergies with nature conservation, coastal protection, adaptation to climate possible
- FFH compatibility is~~presumably~~ not automatic~~ally provided for~~

**References to further development**

- Detail structural requirements and possibilities

## 6.6 How are the river engineering measures for creating accommodation space on the way to Hamburg assessed?

**Creation of accommodation space in general**

Creation of additional accommodation space, especially in the inner estuary, leads to a decrease in the tidal range, primarily due to a rise in the tidal low water. This in turn reduces the currently significant distortion of the tidal curve (steep tidal rise, flat tidal drop) and the corresponding flow speeds that are responsible for the increased upstream transport of fine-grain sediment. Fundamentally, however, upstream transport of the specific fraction of particulate material is a natural process in an estuary. It only becomes a problem when it increases drastically and makes use difficult, as in the Elbe estuary.

In principle, the approach is expedient. Creation of additional accommodation space may (partially) undo the distortion of the tidal curve, given appropriate arrangement and dimensioning. To what extent the upstream transport of sediment can be reduced, however, is a question that should be subject to in-depth analysis and examined from the point of view of cost-benefit aspects. *"A review of Managed Realignement (MR) projects in Europe and the USA has shown that there is little or no experience of such large scale projects (over 500 ha). The success of any such scheme would be completely dependant upon the nature, size and position of the MR sites within the estuary and there would be considerable uncertainty without significant detailed investigations of the existing local hydrodynamics and taking account of climate change"* (report by WHITEHEAD 2011 p. 42).

The accommodation space of the Elbe estuary has been ~~very~~ substantially reduced due to dike construction (particularly diking in the 1970s), separation of side arms, accretion in foreland areas and use of land for settlement and industrial purposes. Available studies on the hydraulic effectiveness of additional accommodation space show that the tidal range can be effectively reduced in this way and that very extensive measures are required. There seems to be less reliable documentation of the extent to which these measures can reduce the upstream transport of ~~which~~ sediment fractions. There is further need for investigation here.

The RESMC contains a list of measures where restoration of accommodation space appears spatially possible (the RESMC provides a~~n~~ basic assessment of the hydraulic effect, degree of ecological impact and potential for conflict for each possible measure).

These former meadow areas (located in front of or behind the main dike) are subject to various uses today or are part of the Natura 2000 sites. The (restoration) creation of accommodation space intended in the RESMC will compete with these existing uses and protection objectives in many places.

Although an evaluation of the possible conflicts with the Natura 2000 protection and conservation objectives requires detailed information, planning and analyses, one can assume that, to the extent they take place at Natura 2000 sites, the measures for creating accommodation space mentioned in the RESMC are, in their current form, not compatible with the protection and conservation objectives of the protected sites affected in each case. The RESMC does not go into that, in accordance with its concept nature.

However, the measures for creating accommodation space may at the same time serve nature conservation objectives (improvement of ecological functions), given appropriate design and implementation, and may also serve FFH Directive and Birds Directive objectives in a general examination going beyond the individual protected site. These possible synergies are of special relevance for further development of the RESMC and it is therefore meaningful and/or necessary to develop the measures in such a way that synergies with, for instance, nature conservation objectives result.

The RESMC measures have already been discussed in the course of the IMP process. Various measures, such as rediking of Haseldorfer Marsch, have been included in the IMP as possible activities. This clearly indicates that possible synergies exist here and have also been identified as such by various parties.

An assessment of the FFH compatibility certainly has to be part of ~~a~~ further development of the~~d~~ RESMC. At the same time a solution must be found for the formal and substance-related challenge of conducting the evaluation at the level of the individual protected sites affected as well as giving appropriate consideration to the entire estuary system as an ecological unit. This is made difficult by the fragmentation of the network of sites. As regards content, the process for preparation of the Integrated Management Plan (IMP) is a step in this direction. Whether and how such an integrated analysis may also be formally possible is a question that should be subject to in-depth analysis in future (see also section 6.2).

However, even in such a procedure it cannot be ruled out that additional measures, particularly regarding avifauna, will have to be taken for implementation of individual measures for creation of accommodation space.

In view of their significance for coastal protection in the Elbe estuary the possible managed realignment measures indicated in the RESMC require intensive analysis in connection with further development of the RESMC. The measures, which would reverse part of the diking carried out after the storm surge of 1962, would also mean a paradigm shift for estuarine coastal protection. Depending on the specific design, however, the managed realignment measures could lead to a reduction in storm surge peaks and an extension of the advance warning times (extended residence time). In view of the increasing requirements of coastal protection due to climate change, this may be relevant and meaningful.

As already mentioned above, a reduction in tidal pumping through creation of accommodation space requires very extensive measures that involve large areas. Many of the possible measures indicated in the RESMC will conflict with the demands of agriculture because the areas are currently used for agricultural purposes. Creation of accommodation space to reduce tidal pumping requires volumes within the local tidal range, i.e. between local mean tidal high water

and mean tidal low water. This means that these areas are no longer suitable for classic agricultural use. Thus, high costs for purchasing the areas as well as greater potential for conflict are foreseeable here so that implementation of these measures has to be incorporated into an appropriate process and longer periods for implementation have to be provided for.

At the same time, however, it is precisely the measures for creating accommodation space that not only enable synergies with nature conservation, but also with the aspect of adaptation to climate change / coastal protection (SCHUCHARDT et al. 2010). These measures may possibly only be used as a sediment trap, especially for fine sediments, so that upstream transport and mixing with more contaminated sediments in the port of Hamburg are reduced. These areas may simultaneously serve as nutrient and carbon sinks.

In many cases creation of accommodation space (and thus additional sedimentation space) also means maintenance of accommodation space so that more dredged material accumulates. This has to be taken into account appropriately in the consideration of action planning. In future, however, it will also be important to develop concepts for utilizing these sediments for parallel growth of the (former) meadows that was prevented by dike construction (e.g. by means of controlled tidal influence).

In general, it becomes obvious that reduction in tidal pumping through creation of accommodation space requires very extensive measures and long-term implementation periods. In terms of economic aspects the measures as part of the RESMC may therefore be meaningful only to a limited degree. However, if it is possible to further develop this type of measure as part of integrated overall planning with synergies in the areas of nature conservation and climate change / coastal protection, it may constitute a major contribution.

**Creation of accommodation space in the foreland**

Hydraulically effective accommodation space in the foreland can be created by excavating eulittoral or supralittoral areas open to the tides and opening summer dikes (not indicated in the RESMC). The RESMC specifies a number of potential measures in connection with eulittoral and supralittoral areas. The effectiveness essentially depends on the location and volumes and can therefore only be viewed in the overall framework of all measures. The RESMC mentions Schwarztonnensand, Bishorster Sand, Fährmannsander Watt and Hanskalbssand as possible eulittoral excavation areas. However, these measures areare ~~presumably~~, in their current form, not compatible with protection and conservation objectives since preservation and development of eulittoral areas are indicated as protection and conservation objectives. At the same time, however, the development of shallow-water zones is mentioned as a protection and conservation objective. This makes it obvious that a viable evaluation of the consequences of individual measures for the dynamic ecological system of the Elbe estuary is not possible only on the basis of an overall view.

**Creation of accommodation space in harbour basins**

Creation or restoration of accommodation space in existing harbour basins, especially in Hamburg, is feasible in the short term. However, its effectiveness can also only be evaluated in the overall framework of all measures. Due to the location far upstream, its contribution in relation

to the volume is relatively substantial and hardly any formal conflicts with FFH concerns arise. However, contaminated sediments requiring special handling may occur here (see below).

**Creation of accommodation space through dike relocation / managed realignment**

Reduction of tidal pumping by creating accommodation space requires very extensive measures. The large areas necessary can only be created if measures for partial restoration of the original accommodation space through managed realignment are also taken into account, as fundamentally provided for by the RESMC. There has already been quite extensive positive experience, particularly in the UK. However, it was more the aspects of coastal protection and nature conservation that formed the background ~~of~~for the managed realignment. In northern Germany there has been experience with moving back the main dike and also summer dikes only on an isolated basis and on a small scale. Discussions regarding such measures (e.g. currently the opening of Langwarder Groden in Butjadingen) already demonstrate the very pronounced local potential for conflict and high costs~~, however~~.

On the other hand, moving back dikes, especially in the estuary, also opens up opportunities for coastal protection, improvement of adaptability to climate change and nature conservation. In view of the potential for conflict and costs,~~ therefore,~~ it is urgent~~ly necessary for implementation of such measures~~ to develop and actively pursue the~~se~~ potential synergies jointly with the parties responsible and affected.

This draft for the Integrated Management Plan, Hamburg/Schleswig-Holstein part (www.natura2000-unterelbe.de), represents a step in this direction, as can be illustrated by the example of Haseldorfer Marsch.

**Digression Haseldorfer Marsch**

Until diking in the 1970s as part of coastal protection measures after the storm surge in 1962, Haseldorfer Marsch (approx. 500 ha) was a typical estuarine habitat complex interspersed with channels in the North Sea shallows and old water bodies. Due to diking, substantial ecological changes have taken place as the area is largely no longer subject to tidal influence. Apart from that, however, it has been able to develop in such a way that areas valuable for nature conservation and having other characteristics have come into being (to an increased degree in the last 10 years also due to the fact that intensive grassland has been transformed for forms of use compatible with nature within the framework of compensatory measures). As a result, Haseldorfer Marsch is now part of the Natura 2000 network of sites. The ecological functions for the estuary, however have extensively been lost~~, however~~.

The RESMC proposes rediking of Haseldorfer Marsch primarily to create accommodation space, but also to create tidally influenced areas and potentially as storm surge relief polders. This means sedimentation space is additionally created, diverse estuarine ecological functions are enabled again, estuarine FFH habitat types are enlarged and habitats for FFH species are created. However, rediking leads at the same time to losses of habitats and species that are targeted by current protection and conservation objectiveion~~s~~. The measure would presumably have to be classified as incompatible in an assessment of compatibility with the protection and conservation objectives of the site. This illustrates the (potential) contradiction between an

analysis of the whole ecological system and the site-related protection and conservation objectives.

This contradiction and interrelationship has also been the subject of extensive discussion in the ongoing IMP process. As a result, the current draft of the IMP for Haseldorfer Marsch proposes moving back the existing land protection dike to improve flood protection and develop foreland open to the tide as well as tidal areas, e.g. for the Elbe water dropwort, which occurs worldwide only in the freshwater section of the tidal Elbe.

Restoration of the tidal influence and thus connection to the Elbe estuary ecological system have been included as a proposed measure in the IMP because of its advantages for the entire system. This illustrates the possible synergies between the RESMC and nature conservation (and other aspects) as well as the positive steps towards management of the entire system.

**Creation of accommodation space through reconnection of side arms, etc.**

Reconnection of cut-off side arms like Borsteler Binnenelbe and Süderelbe can strengthen energy dissipation as well as create accommodation space and thus support the RESMC objectives. Its effectiveness not only depends on size, but also on location, local conditions and design and has to be examined both in individual cases and with regard to the interaction with the other measures. Such measures can be designed as managed realignment and are then linked to the challenges indicated in that context. However, they can also basically be carried out with appropriate structures in the dikes so that their water levels can be controlled in the event of storm surges. These measures may additionally have positive impacts for ecological functions and adaptability to climate change and should therefore be developed jointly with the respective parties responsible and affected as applicable.

However, the measures may also conflict with protection and conservation objectives of Natura 2000 sites. This should be examined and evaluated in an overall estuarine perspective, as with the other measures (see below).

**Conclusion**

- Approach basically correct, but uncertainty regarding economic efficiency
- Extensive measure(s) necessary
- Synergies with nature conservation, coastal protection and adaptation to climate possible
- FFH compatibility for the most part~~presumably~~ does not exist as things stand now

**References to further development**

- Examine additional tidal volume upstream from Hamburg for possible reinforcement of sediment input into port of Hamburg
- Possibly utilize measures for creating tidal volume as sediment traps at the same time
- Integrate all responsible parties and possibly parties affected at an early stage, particularly when dikes are moved back
- Compare effects of different methods of implementation
- Specify structural requirements and possibilities in detail
- Develop and evaluate measures in an overall perspective
- Consider possible "side effects"
- Plan in conjunction with nature conservation, coastal protection and adaptation to climate to fully develop synergies

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**Kommentar [PAW6]:** Not sure what you meabn by this?

## 6.7 How are the measures for optimizing sediment relocation assessed?

The aim of the measures for optimizing sediment relocation is to reduce the dredged volumes and improve the economic efficiency of sediment relocation while at the same time reducing environmental impairments. For this purpose the RESMC envisages different types of measures that are examined in the following. Some of these measures have already been implemented or are being applied so that results from monitoring the impacts are available in some cases.

**Relocation of dredged sand fractions in erosion section of the mouth area**

The RESMC provides for measures to counteract the development of erosion in the mouth by means of a suitable relocation strategy that makes it possible to counteract erosion tendencies on some banks in this area at the same time. This is not detailed further in the RESMC. Section 6.4 shows that the very pronounced sediment deficiency in this area can only be effectively reduced by means of very extensive measures. The advantages and disadvantages have already been discussed ~~there~~. Regardless of that, it is meaningful in terms of morphological and economic aspects to leave dredged material that has accumulated in the mouth area where it is and relocate it in such a way that local erosion is counteracted. This reduces travel times and costs at the same time. Dumping should be made as flexible as possible such that adaptation to altered boundary conditions within this morphodynamically very active area is possible.

**Sediment traps in side arms of the Elbe and other side areas (fine sediment)**

The RESMC envisages use of suitable areas in the side arms of the Elbe and other side areas as summer sediment traps for fine sediment by maintaining them to the extent necessary in winter and relocating the material in the section dominated by the ebb tide, given adequate winter discharges. Among other things, this is aimed at reducing further upstream transport and mixing with contaminated sediment in the port of Hamburg.

In principle, this approach is feasible, though its effectiveness has to be evaluated in the overall framework of all measures. However, maintenance dredging in side areas that are not otherwise maintained and transformation of eulittoral into sublittoral areas conflict with nature conservation objectives and possibly with Natura 2000 protection and conservation objectives. At the same time shallow-water areas result that are especially important in ecological terms. These measures, too, thus have to be developed in conjunction with nature conservation in an overall perspective.

**Sediment traps in the shipping channel**

By setting up sediment traps below Hamburg, the RESMC pursues two goals. On the one hand, it attempts to 'catch' marine sediments in a targeted manner before they move far upstream and mix with contaminated sediments. On the other hand, the sediment traps can function as buffers to postpone necessary dredging work and thus reduce costs and prevent ecological impairment (e.g. dredging during spawning period of twaite shad).

Experience with sediment traps is available from other estuaries, but in most cases they are small and "only" target increased sedimentation of the sand fractions and optimization of dredging. A larger sediment trap has been set up in the Caland-Beerkanaal in the port of Rotterdam (overdepth 2 m, width 1 km, length approx. 5 km). Monitoring results are not yet available.

A sediment trap near Wedel has been in operation since 2008 and initial results on its effectiveness are available, though they are not yet final. An increase in the effectiveness of dredging (campaign dredging) is evident. The effectiveness with respect to a reduction in upstream transport of fine material, both fundamentally and on the basis of the currently available results, must be viewed critically, though there are still too few monitoring results available for a final assessment.

To be able to perform the function of a trap, particularly for fine sediments, ~~better~~ and thus avoid mixing with sediment containing increased contamination, the sediment trap would have to be designed with considerably larger dimensions (also wider) and above all deeper. Whether and how this is effectively possible in the shipping channel and what further (side) effects must be expected are questions that would have to be examined.

**Note:** To trap the fine grain fraction in particular prior to mixing, peripheral sedimentation areas ("tidal polders") set up selectively might also be useful. They could make a contribution upstream and/or downstream from the port of Hamburg to reduce mixing of sediments with greater and lower contamination (among other things, the impacts on upstream transport to

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the harbours should be analyzed prior to installation upstream from the harbours). In principle, this can be done in front of or behind the dike and could be combined with the objective of creating tidal volume and possibly developing estuarine habitats. Some of the new tidal areas planned or considered above Hamburg could take on such a function. However, these areas would have to be cleared regularly. Such multifunctional measures might represent a meaningful and possibly also inexpensive form of sediment management. Recently an area located behind the dike on the Schelde was connected to the estuary via a culvert. The bottom of the area lies significantly below the lower edge of the hydraulic connection so that water remains on the area in every tide. The monthly silting there amounts to approx. 1 m.

**Kommentar [PAW7]:** I do not understand what is being said here

**Reducing sedimentation focal points through local current-controlling measures**

Influencing sedimentation focal points by means of current-controlling measures may be meaningful and effective at the local level in order to optimize maintenance dredging. However, it may happen that the focal points merely shift and then similar problems arise elsewhere. This again makes it plain that planning of individual measures should always take into account an adequately large area under study and appropriate time scales.

**Differentiated handling of different sediment fractions by means of specific equipment (primarily water injection, WI)**

From an operational and economic point of view the water injection (WI) procedure is an advantageous relocation method. The RESMC envisages its use, on the one hand, to remove fine material from side arms of the Elbe in the winter. On the other hand, it is employed in connection ~~with WI dredging~~ in order to remove sandy material by cutting the dunes.

The use of water injection (WI) in winter in branch channels is aimed at resuspending fine material in connection with high headwater discharges and thus initiating downstream transport (see above), similar to the method also used in the area of port entrances~~, for example~~. From a morphological perspective the approach is correct and the resulting temporary increase in transport of suspended matter poses no problems, particularly in situations of high upstream discharge ~~water~~. However, few investigations for the Elbe as well as for other estuaries are available to date concerning the ecological impacts of water injection both in the bottom area and the water column area, also as a comparison to the use of a hopper dredger. Investigations in this context should be initiated.

Use of the WI method for relocation of sand fractions, especially in connection with lopping off the tops of underwater dunes, is inexpensive and effective although its has to be repeated at relatively short intervals because the sand dunes grow again rapidly depending on the upstream discharge~~water~~ (an analysis of the long-term efficiency should still be carried out, however). Compared to greater smoothing of the bottom when using hopper dredgers, lopping off the crests additionally has the advantage that reduction of the tidal energy on the bottom is largely retained. Use of the WI method in sandy sediments also poses few problems from an ecological point of view since ~~presumably~~ little suspended sediment, nutrient and harmful matter is remobilized and/or enters the water column.

**Avoidance of dredging cycles through optimized relocation (local, temporal) in the Lower Elbe**

To break sediment cycles, such as those that have taken place to an increased extent in the Hamburg area since 2000, and thus reduce dredging of "the same sediment particles" again and again, reduction of upstream sediment transport should also be targeted by means of optimized relocation.

From a morphological viewpoint breaking dredging cycles is a sensible approach to reducing dredging volumes that is also successfully applied in other estuaries (e.g. in relocation of sediments from port of Rotterdam). On the Lower Elbe, too, this approach appears successful, as shown by the reduction in dredged volumes in the HPA area after the changes in Neßsand dumping practice. At the same time relocation within the Elbe estuary prevents, for example, material necessary in the long term for growth parallel to the accelerated rise in sea level from being removed from the system.

From an ecological perspective, too, the approach is basically sensible as it leads to a reduction in dredged volumes. For a more comprehensive evaluation, however, all measures required to reduce dredging cycles have to be taken into account in terms of their impacts since the latter may also impair the characteristics and distribution of the Natura 2000 habitats and species and/or ecological functions (possibly relevant in connection with WFD and MSFD as well).

However, in the course of further development of the RESMC it should be taken into consideration that tidal pumping as a driver of dredging cycles is to a certain extent a natural characteristic of estuaries and part of the sediment balance. Breaking dredging cycles should not lead to impairments of ecological functions due to sediment deficiency.

**Avoidance of dredging cycles by dumping material from the tidal Elbe system in the North Sea**

Dredging cycles should be reduced by dumping uncontaminated sediments from the Hamburg area at buoy E3 in the North Sea on a short-term basis.

In principle, avoidance of dredging cycles is sensible both from a morphological and an ecological point of view (see preceding section). Dumping sediment from the Elbe estuary in the North Sea at dumping site E3 may contribute to such avoidance or has already done so. However, not only does dumping at E3 involve substantial costs and $CO_2$ emissions (the aspect of pollutants is discussed in section 6.8), but the removal of sediment from the system is additionally not expedient (among other things, aspect of adaptation to climate change, though the dumped quantities, based on the sediment loads of the Elbe estuary, are small overall).

**Criteria for sediment relocation**

Specification of relocation areas within the estuary must take place within the framework of a clear strategy, on the basis of a comprehensive understanding of the system and with a clear definition of objectives that takes into account the morphodynamic, ecological and economic

aspects. The foundation laid with the RESMC basically points in the right direction, but all aspects indicated have to be further explored~~intensified~~.

The following criteria (the order does not represent any indication of priority) should be given appropriate consideration when specifying relocation areas (it is always necessary to weigh up the alternatives since the criteria are not congruent in all cases):

- No removal of material from the system
- Relocation only of sediments with little or no contamination
- Low recirculation of the relocated sediments
- Depositing of fine grain in sedimentation areas and of sand in erosion areas
- Easy accessibility of and short distances to relocation sites
- Little impairment of ecological functions
- Contribution to reduction of tidal pumping
- Little resuspension of fine sediments
- Allow material to take part in morphodynamics
- Weighing up between local impairment and possibly large-scale use
- Contribution to targeted morphological development of the estuary

**Kommentar [PAW8]:** Fines in erosion areas could also benefit intertidal areas as they disperse

**Conclusion**

- Relocation within mouth area in erosion areas correct
- Side arms of Elbe as sediment traps expedient to a limited degree
- Check effectiveness of sediment trap
- Reduction of local sedimentation focal points may be meaningful

- WI in shipping channel: weigh up short- and long-term effectiveness
- Avoidance of dredging cycles through optimized relocation is expedient and effective (dumping in the North Sea meaningful and acceptable only in short term)
- FFH compatibility of all measures not necessarily provided for

**References to further development (general)**

- Further optimize approaches
- "Overcome" administrative boundaries in daily practice
- Make approach more flexible

**References to further development (specific)**

- Intensify breaking of dredging cycles
- Leave sediment in the system
- Sediment traps bigger; but function for fine sediment is still limited
- Possibly tide-controlled peripheral sedimentation areas inside dike (sediment, accommodation space, parallel growth, habitat) above and/or below Hamburg

## 6.8 How are the measures on handling contaminated sediments assessed?

**Support of measures for reducing pollutant emissions in catchment area (work by IKSE and FGG Elbe)**

In spite of the reduction in contamination already achieved, contamination of the sediments in the Hamburg area largely restricts efficient handling of the dredged material oriented to morphological and ecological functions. At present some of the material dredged in Hamburg still exceeds the upper reference value of the directive for dredged material management in coastal waterways.

Because contamination primarily comes from upstream waters, reduction of this contamination through upstream measures has to be a priority goal. *"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"* (report by MURRAY & BREEDVELD 2011 p. 30).

The management at the river basin level initiated by the WFD and the resulting increased co-operation, both between the German federal states and at the international level, are positive for this process. The measures provided for the management plan for the Elbe catchment area (FGG ELBE 2009) are of special importance for optimized sediment management in the Lower and Outer Elbe. However, implementation is only possible in the long term.

Hamburg itself is a major source region for certain harmful substances in the sediments, above all organotin compounds (TBT and its decomposition products) and to a lesser extent with regard to individual heavy metals. Because of the ban on use of TBT, further improvement can be expected here in the short to medium term. However, the distribution of contamination in 2010 indicates that enforcement of the ban on use as well as handling of existing coatings have to be improved further. Other local input pathways from industry and municipal sewer systems can presumably also be reduced further.

Overall, considerable further progress in the reduction of harmful substances has to take place in order to meet the demands of European and national water, marine and nature conservation. However, it can be assumed that a reduction in sediment contamination to concentrations enabling unrestricted relocation in the water body will take a long time.

**Continuation of removal of contaminated dredged material from the system (storage/treatment on shore)**

As long as the necessary further reduction in contamination of the dredged material (see above) does not lead to a situation in which relocation in the water body is safe in ecotoxicological terms, onshore disposal of the exceptionally contaminated sediments will remain necessary.

The ongoing separation of the sand fractions containing little contamination during onshore treatment appears meaningful. Whether recycling suitable material, e.g. for building purposes, is feasible and meaningful is a question that should be examined further. The conditioning of dredged material as applied in Bremen and its subsequent use, e.g. in dike construction, as well as the possibilities indicated in the report "Dredged material as a resource: Options and constraints" (PIANC 2009) point out additional options.

In the long term, onshore treatment and disposal cannot be regarded as sustainable handling of dredged material~~, however,~~ because sediment should fundamentally remain in the system and onshore treatment involves substantial consumption of resources.

**Note:** Storage of (moderately) contaminated sediments in the water body in a way that extensively rules out release of the harmful substances is carried out in various *Länder* in the coastal region. This may also be a meaningful method for the Elbe estuary for a transitional period until the measures for reduction of sediment contamination successfully take effect. So-called capping, i.e. covering contaminated sediments with uncontaminated material in less energy-rich areas or in deepened areas created for this purpose, appears conceivable. However, such

measures have numerous ecological and other implications that require comprehensive examination (including system-related monitoring).

**Avoidance of mixing contaminated with uncontaminated sediment by means of sediment traps and reduced tidal pumping**

Because more contaminated dredged material has to be treated and disposed of at great expense and with substantial resource consumption, reduction of the quantity of contaminated dredged material is basically meaningful. The RESMC focuses on reducing the mixing of contaminated with uncontaminated dredged material in this context with the aim of lowering dredging requirements overall (though then possibly including sediment with higher contamination) and removing material from the system. Measures for reducing contamination from the~~increased~~ upstream sediment transport as a possible option are part of the RESMC (including sediment traps, reduction of tidal pumping). This approach seems basically sensible. It could be supplemented by allowing targeted sedimentation of the more contaminated sediments deposited from upstream waters in special sediment traps upstream from Hamburg (the creation of additional tidal volume upstream from Hamburg should be examined with an eye to possible boosting of sediment input from downstream reaches into the port of Hamburg, however). These sediment traps would have to accumulate fine sediments and suspended matter in a targeted manner so that the latter could then be removed from the system and disposed of on shore. This means that very low-energy environments with longer residence times would have to be created. HPA already worked out such possible methods conceptually a long time ago, but did not regard them as practicable. If, however, such measures are employed at the same time as measures for creating accommodation space and could also perform certain ecological functions (restricted by contamination), such an assessment may lead to a different result.

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**Kommentar [PAW9]:** Not sure what is being said here

**Temporary dumping of dredged material at buoy E3**

Dumping contaminated sediments from the Hamburg area at buoy E3 in the German Bight is aimed at helping to break dredging cycles and has been carried out since 2005. The dumping strategy is limited until 2011 and is supported by extensive monitoring.

As a measure with a set time limit, dumping at buoy E3 is compatible with the guidelines of the London and OSPAR conventions in spite of the references to local biological and ecotoxicological impacts. However, these conventions, like the WFD and MSFD, target further reduction and, in the end, elimination of contamination due to harmful substances. For this reason measures for reducing contamination, particularly upstream from Hamburg, are still urgently necessary. Temporary dumping at buoy E3 in the North Sea has to be linked to a specific programme for reducing the contamination of dredged material and a monitoring programme.

**Note:** Long-term handling of sediments of low to moderate contamination, such as those currently dumped at buoy E3, represents a special challenge for further development of the RESMC (assumption: the pressing measures for reducing contamination take effect only in the long term) because it is necessary to weigh up between the legal aspects of marine and water protection, ecological impacts in the coastal sea and in the estuary, resource consumption due to long transport distances and costs. To establish a viable long-term approach, it appears

meaningful in a first step to analyze and intensify the various known options (see also in this connection the proposals formulated in the various expert reports) and any further possibilities as an extension of the BfG (Federal Institute of Hydrology) system study (BFG 2008) in such a way that a comprehensive comparison can then take place on a similar information base.

**Conclusion**

The contamination of the dredged material from the Hamburg area in particular restricts efficient (and also inexpensive) sediment management geared predominantly to morphological and ecological aspects (see below). Measures for reducing contamination are therefore of considerable significance. It is important that the HPA and WSV support the international river basin community in remediation of the sources, strengthen their cooperation with national and international administrations and draft or further develop transregional objectives and programmes concerning measures for reducing harmful substances.

- Approach basically correct
- Paramount objective must remain remediation of contamination sources; but can only be reached in long term
- In the medium term the RESMC has to give further consideration to handling contaminated sediments

**References to further development**

- Boost national and international cooperation with the aim of remediation of contamination upstream
- Examine sediment trap for contaminated sediments between Hamburg and tidal weir with possible synergies (check additional tidal volume upstream from Hamburg for possible increase in sediment input into port of Hamburg, however)
- Compare ways of relocating sediments of low to moderate contamination from the Hamburg area taking account of the estuary ~~oriented to~~ cross-section (i.e. taking into account all advantages and disadvantages)

**Kommentar [PAW10]:** Is this what you mean?

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# 7. Final overall assessment and recommendations

## 7.1 Overall assessment

The evaluation of the RESMC and the measures it specifies based on the criteria indicated in section 6.1 shows that the approach of the RESMC is generally expedient, innovative and geared to the problems. However, it has to be further developed, as already mentioned in the RESMC itself, so as to be able to meet the criteria in full. The extent to which the individual criteria are met is assessed as follows:

**(1) Does implementation of the RESMC make it possible to secure the shipping channel depths specified in the approval procedure for the tidal Elbe?**

This key task of WSD and HPA is and will continue to be guaranteed. The RESMC does not provide for any measures that make this task difficult or hinder its performance, but aims at optimization.

**(2) Does implementation of the RESMC enable a reduction in dredged volumes and dredging costs?**

This is the central objective indicated in the RESMC and it can be assumed that implementation of the RESMC, primarily through optimization of the relocation strategy, will lead to a reduction both in dredged volumes and in dredging costs. Thus far no cost-benefit estimates are available for implementation of the river engineering measures and their effectiveness has not been adequately documented to date. The necessary scope of the measure for reducing tidal pumping may be quite substantial so investment and maintenance costs could also be high.

An assessment of the costs for implementation of the measures proposed in the RESMC is not yet possible at the moment as the measures will not be specified in sufficient detail until the next step.

**(3) Does implementation of the RESMC enable a reduction in the impairment of the environment related to maintenance?**

Key objectives of the RESMC include a reduction in dredged volumes and in sediment contamination so that the related impairment of the environment is also fundamentally reduced. However, the effects on the environment related to the various measures specified in the RESMC and with regard to protection and conservation objectives have not been completely analyzed yet and integrated management objectives necessary to be able to give adequate consideration of conflicts in objectives are lacking.

**(4) Is implementation of the RESMC compatible with the regional objectives of nature and marine conservation as well as water management?**

Implementation of the RESMC can support certain regional objectives of nature and marine conservation as well as water management for the Lower and Outer Elbe or sections of the latter, but may also quite conceivably lead to conflicts. Especially protection and conservation objectives of specific Natura 2000 sites may not necessarily be compatible with river engineering measures in particular. The legal situation requires an examination at the level of the individual sites. The question of whether and how this can be supplemented with an analysis focusing on the entire system should be clarified (the current IMP process is also currently working on establishment of an overall perspective). Further development and implementation of the RESMC should in any case be incorporated into a higher-level management plan like the IMP.

**(5) Is implementation of the RESMC compatible with the requirements of European and national water, marine protection and nature conservation?**

The RESMC also targets reduction of impairment of the environment and thus supports in particular the objectives of the WFD and MSD. Although a number of synergies with the objectives of European nature conservation are possible, formal conflicts that cannot easily be overcome must also be expected at the level of individual sites. However, the possible synergies as well as the possible conflicts have not been adequately analyzed yet and can therefore only be evaluated to a limited extent.

**(6) Can the RESMC be implemented with broad social acceptance?**

The RESMC measures have not been analyzed yet in terms of their potential for conflict, but it can be assumed that the latter is significant since different interests of third parties are affected. Both further development and implementation of the RESMC should therefore take place in an open and transparent fashion.

## 7.2 Central recommendations

The references to further development of the RESMC mentioned in section 5 and 6 can be developed into the following central recommendations, some of which are already incorporated~~designated~~ in the RESMC itself as necessary in the future:

**Technical recommendations**

- The feasibility, effectiveness, interaction and relative importance of the various approaches should be worked on and taken into account more intensively
- Documentation of the effectiveness of the river engineering measures in particular, as ~~well as sediment traps regarding tidal pumping should be improved~~

- The contamination of the dredged material restricts the opportunities for efficient handling of dredged material; measures for reducing contamination are therefore pressing

- Different ways of relocating sediments with little to moderate contamination from the Hamburg area should take account of the morphodynamic and sedimentary processes ~~be compared with a cross-sectional orientation~~

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**Kommentar [PAW11]:** Aqgain not sure what is being said or whether I have interpreted correctly

**Strategic recommendations**

- It is urgently necessary to analyze the possible synergy effects, especially of the river engineering measures, and further develop them jointly with other relevant fields (such as nature conservation, adaptation to climate, coastal protection)

- The form in which the cooperation and any joint responsibility regarding sediment management can be further developed by HPA and WSV should be examined

- Further development of the RESMC should take place jointly with the *Länder* within the scope of overall management of the tidal Elbe with clearly formulated and structured priority objectives

- The nature conservation perspective and the influence on ecological functions has to be taken into account appropriately in the further developed RESMC

- The overall approach of the RESMC and/or the individual measures should be examined in terms of their FFH compatibility; this must take place formally for the individual sites. As regards content, it appears more meaningful to gear the approach to cross-site conservation objectives for the entire estuary, though this is legally not possible as things stand now. It should be examined here whether an initiative directed at the EU Commission may be meaningful.

## 7.3 Conclusion

As an overall approach, the RESMC is innovative and suitable for tackling the problems and it points out prospects for a "viable Elbe estuary". Given appropriate further development, it can make a major long-term contribution to securing the target depths of the shipping channel specified in the approval procedure, regenerating ecological functions, improving adaptability to climate change and improving coastal protection.

It is urgently necessary to work out and further develop the (potential) synergies jointly with the other responsible parties, interest groups and parties concerned.

Implementation requires joint long-term efforts on the part of the federal and state governments in Germany for which the prerequisites are presumably favourable due to the existing

situation regarding the problems (for example, as a result of the required long-term adaptation to climate change). In accordance with the order, however, the evaluation does not take into account current planning for further deepening of the shipping channel in the Lower and Outer Elbe. At this juncture it should be pointed out that acceptance and implementation of the RESMC will presumably not be facilitated by the overlapping of the two processes.

On the basis of the long-term prospects for full implementation, a two-pronged approach appears meaningful. On the one hand, WSD and HPA should specify the RESMC in greater detail as well as analyze synergies and impediments. The necessary measures should be further developed and the ecological impacts (risks and opportunities) as well as compatibility with the FFH Directive assessed.

On the other hand, communication with the other parties, possibly in the framework of the structures created through the IMP process, regarding the concept and its further development should be intensified and parallel to that political support sought. Implementation of the further developed RESMC and/or overall management of the tidal Elbe can only be realized together with all decision-makers, responsible players and parties concerned.

Because of the challenges, particularly with regard to the river engineering measures, implementability appears possible only if the (potential) synergies especially with nature conservation and coastal protection are developed jointly in such a way that implementation of the further developed RESMC and/or of an emerging overall management becomes the common interest of different parties.

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**Maps provided**

HPA: Map of RESMC measures

WSA: Sediment maps of the Tidal Elbe (6 documents)

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**Further literature for Lindsay Murray and Gijs Breedveld**

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**Further literature for Patrick Meire**

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