THE SEDIMENT MANAGEMENT CONCEPT OF THE ICPER

Recommendations for a good sediment management practice in the Elbe

All over the world, river basins are under pressure from human activities that affect their chemical and ecological statuses and exhaust available natural resources. Sediment as an essential, integral and dynamic part of the river basins may affect various environmental, social and legal objectives pursued there. Sediment management becomes necessary if the intensity of anthropogenic interventions in the sediment status overwhelms the resilience of ecologic endpoints of the river system or if sediment dynamics and/or sediment status strongly affect human uses. Despite the progress that has been made in the knowledge of sediment management during the last 20 years, practical examples of comprehensive river-basin-scale sediment management concepts are by no means state-of-the-art, and even concepts that focus on only one of the sediment issues are sparse. In Europe, approaches to the management of waters have been radically altered with the introduction of the European Water Framework Directive (WFD). The International Commission for the Protection of the Elbe River (ICPER) had already declared good sediment quality as one of its key targets in its first Action Programme (IKSE 1991). The first Elbe management plan prepared under the WFD (2010-2015) highlights contamination and insufficient hydromorphological conditions as two of the most important supra-regional issues in water resources management (IKSE 2009). The plan underlines that contaminated sediments and unbalanced sediment conditions are among the main reasons for the failure to meet the WFD management objectives. As a consequence, the member states in the ICPER decided to develop a sediment management concept in preparation for the management cycle from 2016 to 2021. For the first time, an integrated sediment management concept was developed in support of management planning in a large international river basin.

The view on the Elbe catchment in the context of river basin sediment management

The sediment management concept focuses on sediment quality, sediment budget, hydromorphology, and navigation related sediment aspects from a supra-regional perspective. It omits phenomena of merely local or regional occurrence. The following five components were defined to analyse the Elbe system in terms of river basin sediment management *(cf. Figure 1)*:

- the impounded inland reach of the Elbe between Němčice and Ústí n. L.;
- the free-flowing inland reach of the Elbe from Ústí n. L. to the impoundment weir at Geesthacht;
- the tidal reach of the Elbe between the weir Geesthacht and the mouth into the North Sea;
- relevant tributaries;
- reference monitoring sites.

Reference monitoring sites *(Figure 1)* are used to characterize a sub-basin that is relevant for the interregional sediment management in qualitative and/or quantitative terms. These stations usually provide long-term time series of data from quality-assured monitoring programmes.

When relevant tributaries are selected, one distinguishes two categories. The significance of the influence of Category 1 tributaries stems from their basic characteristics. Criteria for the selection are a share in the catchment area, streamflow, and – most relevant – a share of at least 10% of the suspended sediment load at the closest reference monitoring site in the Elbe downstream. Relevant tributaries of this category are the rivers Orlice, Jizera, Moldau (Vltava), Eger (Ohře), Schwarze Elster, Mulde, Saale, and Havel *(Figure 1)*.

Tributaries of Category 2 are relevant under the aspect of quality. They themselves do not significantly influence the balances of water and solids in the Elbe, but due to their load of (at least one of) the relevant contaminants they contribute significantly to the supra-regional contamination balance. The quantitative criterion for this selection was fixed at a minimum 10% share in the total load of a contaminant measured at the respective reference station. These are either direct tributaries to the Elbe (Bílina and Triebisch in *Figure 1*) or tributaries to rivers of Category 1 (Sázava, Berounka, Zwickauer/Freiberger Mulde, Spittelwasser, Weiße Elster, Schlenze, Bode, Spree).

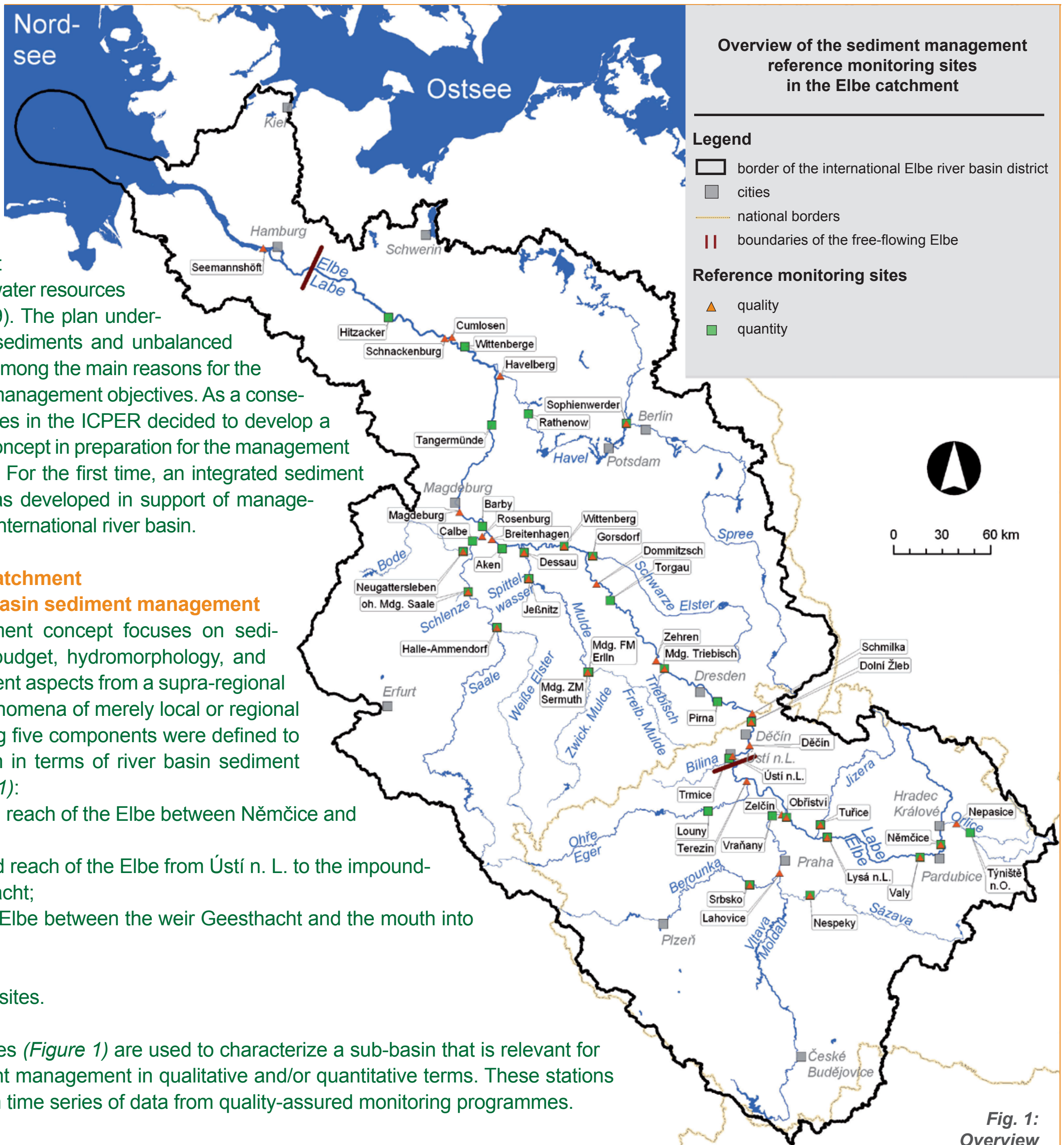

Fig. 1: Overview of the sediment management reference monitoring sites in the Elbe catchment

Figure 2 shows the fluxes of suspended sediment and cadmium. The picture illustrates the specific role small tributaries of Category 2 can have. While the contribution of the river Triebisch to the sediment load is negligible, it contributes significantly to the cadmium balance of the Elbe.

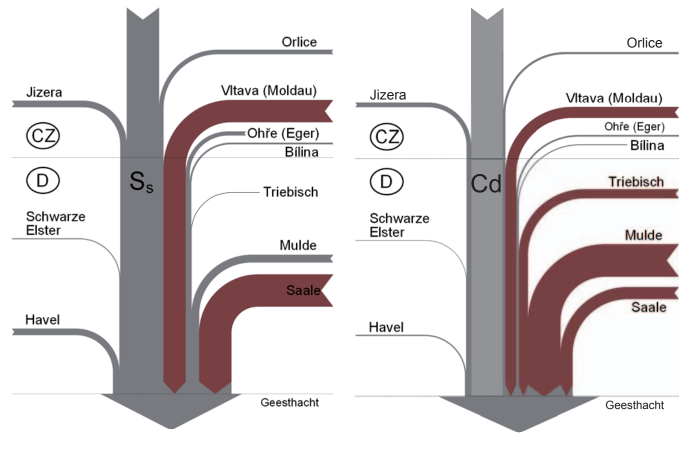

Fig. 2: Loads in the Elbe catchment: Suspended sediment (S_s) and Cadmium (Cd)

General approach to risk prioritization

Figure 3 illustrates the main steps towards the sediment management concept. The concept was elaborated in support of the general management goals as declared for the Elbe catchment according to the EU Water Framework Directive and the EU Marine Strategy Framework Directive. These are to reach and keep the good ecological and chemical status and to guarantee permanently all functions and services that are necessary for the intended human uses. The latter includes fulfilling all the criteria in order to protect human health, e.g. with respect to fish consumption or the agricultural use of floodplains. After the management goals have been defined significant indicators are selected in order to evaluate the status of the system in terms of quantity, hydromorphology, and quality *(Figure 3)*.

The risks that arise from the insufficient sediment status for the attainment of the targeted objectives are analysed. Finally, the significance of these risks is weighted, and recommendations for river basin management planning are derived. Navigation is a water use that permanently requires controlling interventions into the sediment regime of a river in order to maintain or restore defined conditions for navigability. That is why the aspect of navigability has been included in the formulation of the concept from its beginning and can serve as a model for the integration of other uses of the river. The concept complies with the following criteria:

- It is integral because it combines spatial, functional (quantity, hydromorphology, quality) as well as environmental and use-oriented (navigation) sediment aspects in one concept.
- It is related to the river basin, i.e. it considers cause-effect relations in the river basin district Elbe.
- It is risk-based, i.e. its conclusions regarding sediment budget, ecological functions, ecosystem services, and sediment-dependent uses of the river rely on the analysis of risks resulting from an insufficient sediment status.
- It has a practical orientation, i.e. it was developed in support of river basin management planning as required by the Water Framework Directive and the Marine Strategy Framework Directive. A collection of proven management practices and technical examples from the Elbe and other rivers was compiled in addition to the concept in order to encourage managers to proceed.

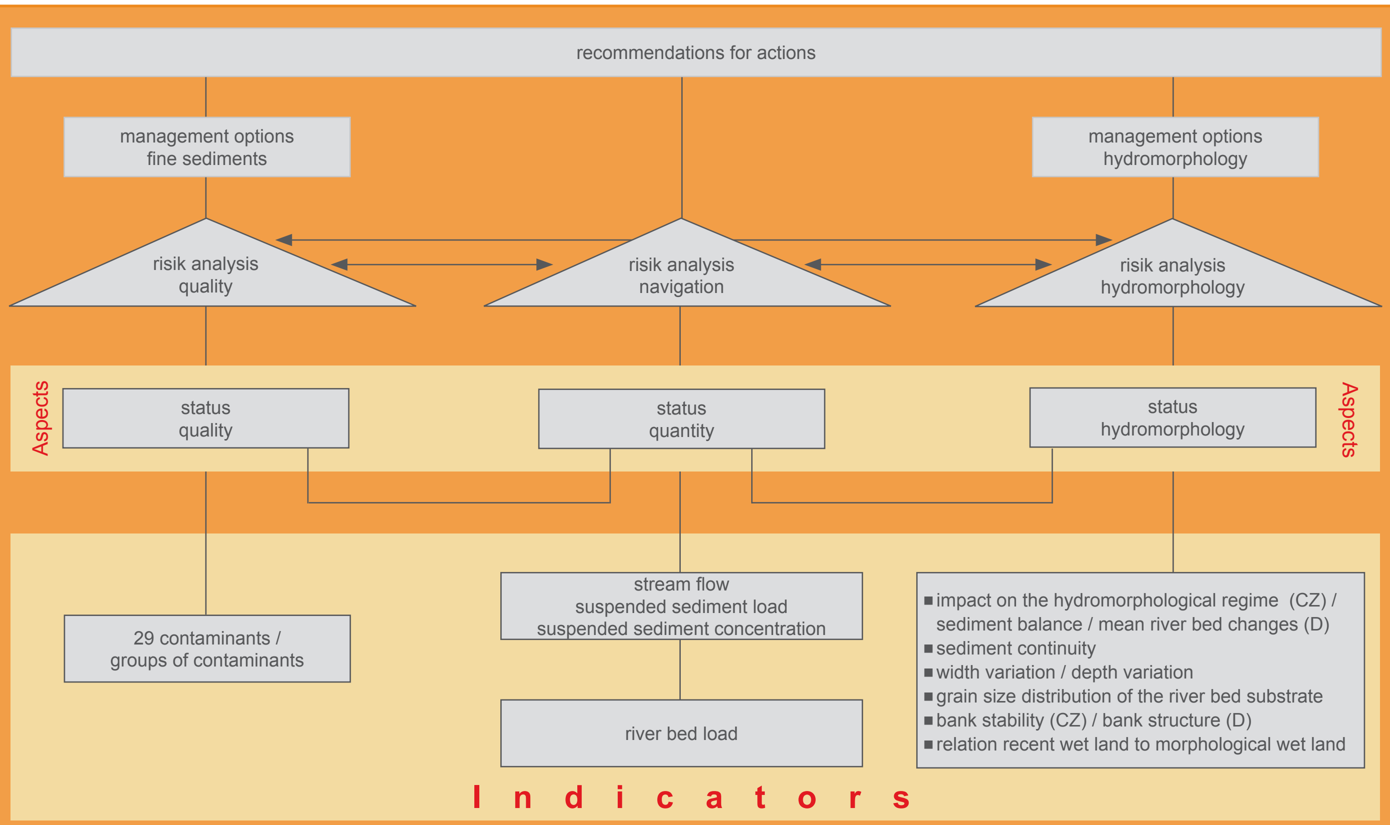

Fig. 3: General conceptual approach

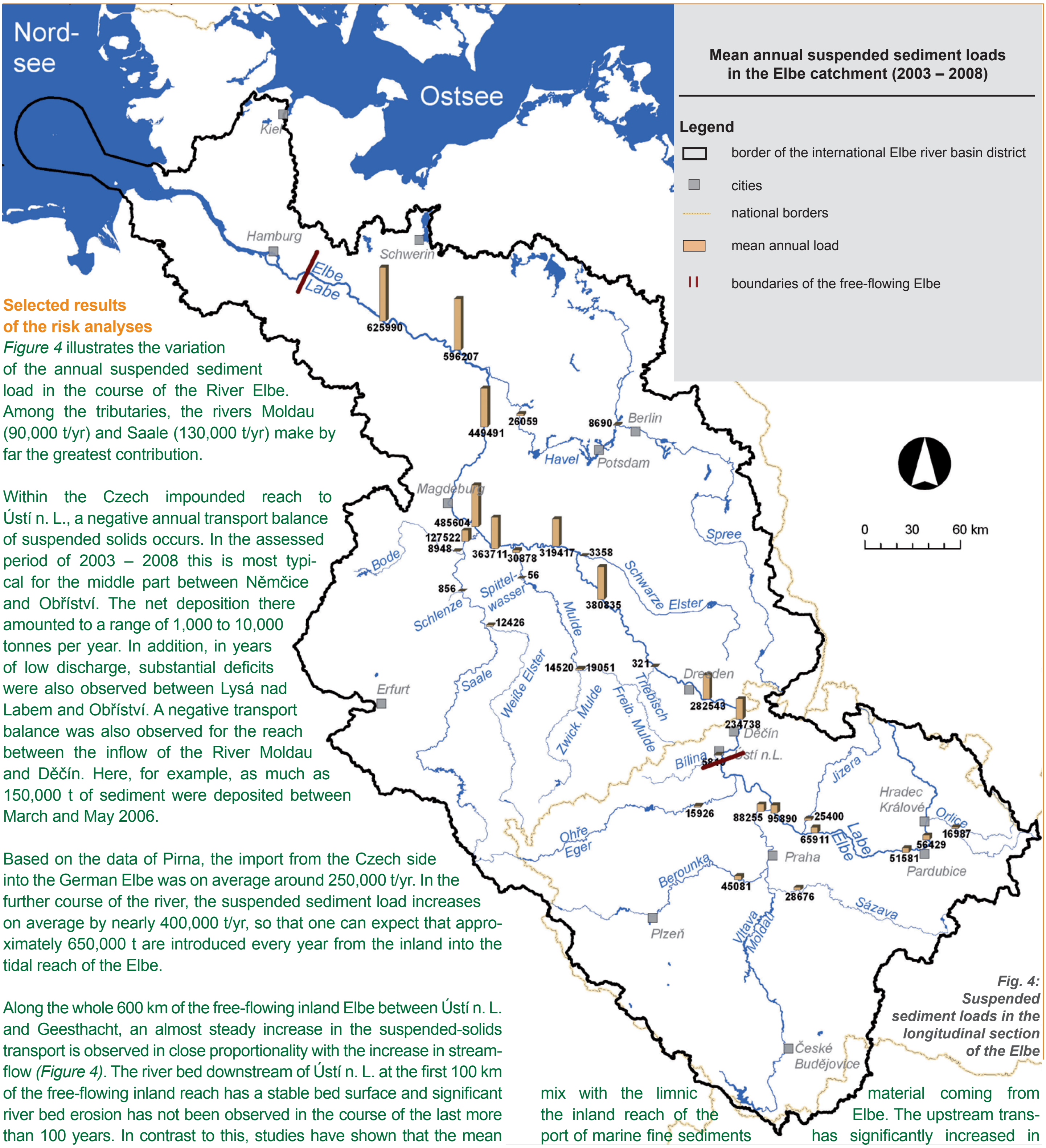

Fig. 4: ***Suspended sediment loads in the longitudinal section of the Elbe***

Selected results of the risk analyses

Figure 4 illustrates the variation of the annual suspended sediment load in the course of the River Elbe. Among the tributaries, the rivers Moldau (90,000 t/yr) and Saale (130,000 t/yr) make by far the greatest contribution.

Within the Czech impounded reach to Ústí n. L., a negative annual transport balance of suspended solids occurs. In the assessed period of 2003 – 2008 this is most typical for the middle part between Němčice and Obříství. The net deposition there amounted to a range of 1,000 to 10,000 tonnes per year. In addition, in years of low discharge, substantial deficits were also observed between Lysá nad Labem and Obříství. A negative transport balance was also observed for the reach between the inflow of the River Moldau and Děčín. Here, for example, as much as 150,000 t of sediment were deposited between March and May 2006.

Based on the data of Pirna, the import from the Czech side into the German Elbe was on average around 250,000 t/yr. In the further course of the river, the suspended sediment load increases on average by nearly 400,000 t/yr, so that one can expect that approximately 650,000 t are introduced every year from the inland into the tidal reach of the Elbe.

Along the whole 600 km of the free-flowing inland Elbe between Ústí n. L. and Geesthacht, an almost steady increase in the suspended-solids transport is observed in close proportionality with the increase in streamflow *(Figure 4)*. The river bed downstream of Ústí n. L. at the first 100 km of the free-flowing inland reach has a stable bed surface and significant river bed erosion has not been observed in the course of the last more than 100 years. In contrast to this, studies have shown that the mean bed level has dropped by maxima of around 2 m with regional variations further downstream over the period between 1898 and 2004 (e.g. around Elbe river-km 155 in the German part). Typically, mean erosion rates between 1.0 and 1.25 cm/yr occured in wider parts of the lowland reach over this period of time. This degradation tendency is continuing on a large-scale and in a long-term perspective. The focus of the erosion regime has shifted into the reaches downstream of the inflow of the Schwarze Elster in the past decades. As a whole, the mean annual sediment deficit of the German inland Elbe amounts to 0.45 mio t/yr.

Imports of solid matter into the tidal Elbe come from upstream via the weir of Geesthacht as well as from downstream with the flood tide from the North Sea. The tides periodically change the flow direction of the tidal river reach, and the marine solids that are transported upstream mix with the limnic material coming from the inland reach of the Elbe. The upstream transport of marine fine sediments has significantly increased in the recent past. In the emerging turbidity zone between Elbe river-km 650 and 700 the absolute amount of suspended solids in the range of maximum turbidity is around 80,000 – 100,000 t and corresponds to about 15 % of the annual suspended solids import from the river catchment. The marine imports could not have been quantified yet. An indicator may be the volumes of sediments dredged. As a rough estimate it was calculated that at the centre of dredging activities downstream of Hamburg, the portion of suspended solids originating from the German Bight of the North Sea makes up 50 % to 80 %, in dependence on streamflow. These complex conditions of sediment quantities in the tidal Elbe are also reflected in high and varying volumes dredged. As for the dry matter of fine sediment, the dredged material amounts to about the 2.5 fold of the mean annual suspended solids imported from the inland reach into the tidal Elbe of roughly 650,000 tonnes.

The sediment budget of a river is closely connected with its hydromorphology. Weakly developed hydromorphological features are indicators of a disturbed sediment budget. Vice-versa, the hydromorphological characteristics of the river have influence on the prevailing sediment conditions. The risk analysis under the aspect of hydromorphology results in a coupling of measurement and assessment of the sediment budget as a part of the hydromorphological status of the river and derived recommendations for actions to improve the hydromorphological status. The indicators `Sediment continuity` and `Mean river bed changes / Sediment balance (DE) / Impact on the hydromorphological regime (CZ)` have a key function for the sediment budget. Lacking continuity of sediment and sediment deficits adversely affect also the other hydromorphological indicator parameters. In a first step, the two key indicators are used when recommendations for action are derived. A second step is a check of the other hydromorphological indicator parameters for synergies, which may exist in a combination with Step 1, and whether specific recommendations must be given (beginning from class 3 – 'moderate').

Finally, Step 3 provides a prioritization of management options according to the criteria of Table 1. Figure 5 shows the result of the risk analysis of the key indicator "Mean river bed changes/ sediment balance/" or "Impact on the hydromorphological regime" for the entire Elbe. In contrast to the

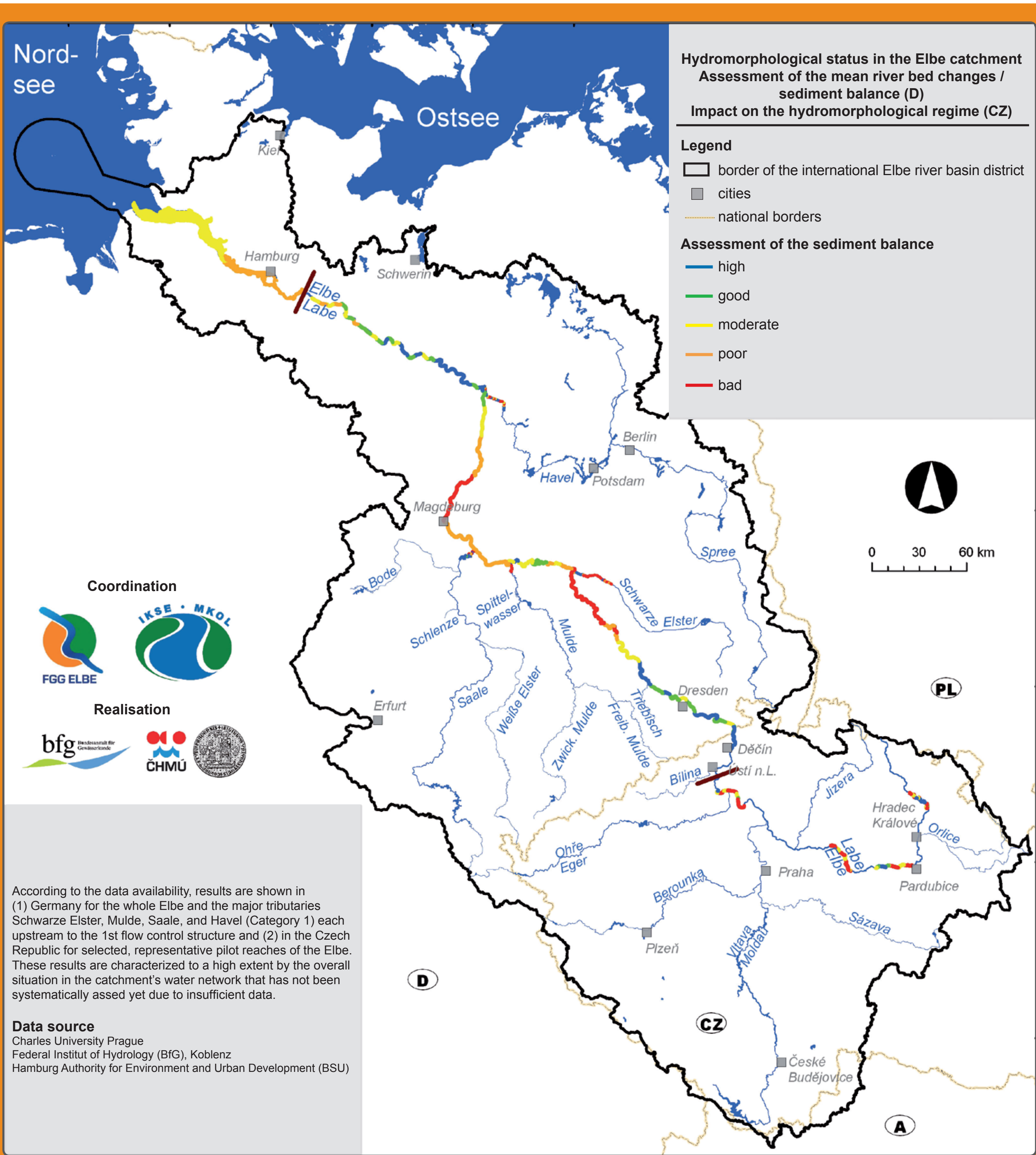

Fig. 5: Risk classification of the key indicator "Mean river bed changes/sediment balance" respectively "Impact on the hydromorphological regime"

inland reach of the Elbe, the tidal Elbe does not contain Class 1 ('high'). Over centuries, the estuary has been subject to basic morphological changes and is today designated as a „heavily modified water body".

The risk analysis under the quality aspect was done for all 29 relevant contaminants with respect to each of the identified management goals. It was performed in two stages:

1. Evaluation at the sub-basin level to identify the main source areas of particle-bound contaminants. The evaluation covers both the classification of the mean annual concentrations at the reference monitoring sites and an analysis with respect to the loads from the sub-basins. As a result, the qualitative conditions and the particulate contaminant fluxes in the catchment are described in their local and temporal development. The results are demonstrated at the examples in *Figures 6 and 7*.
2. Source-related evaluation within the source areas identified under Stage 1. The following types of sources were considered:
   (1) point sources (sewage water and point discharges from historical mining),
   (2) sediments/historical sediments,
   (3) historical contaminations such as brownfields or old mining sites in an adjacent zone to the river, from which sediment-relevant

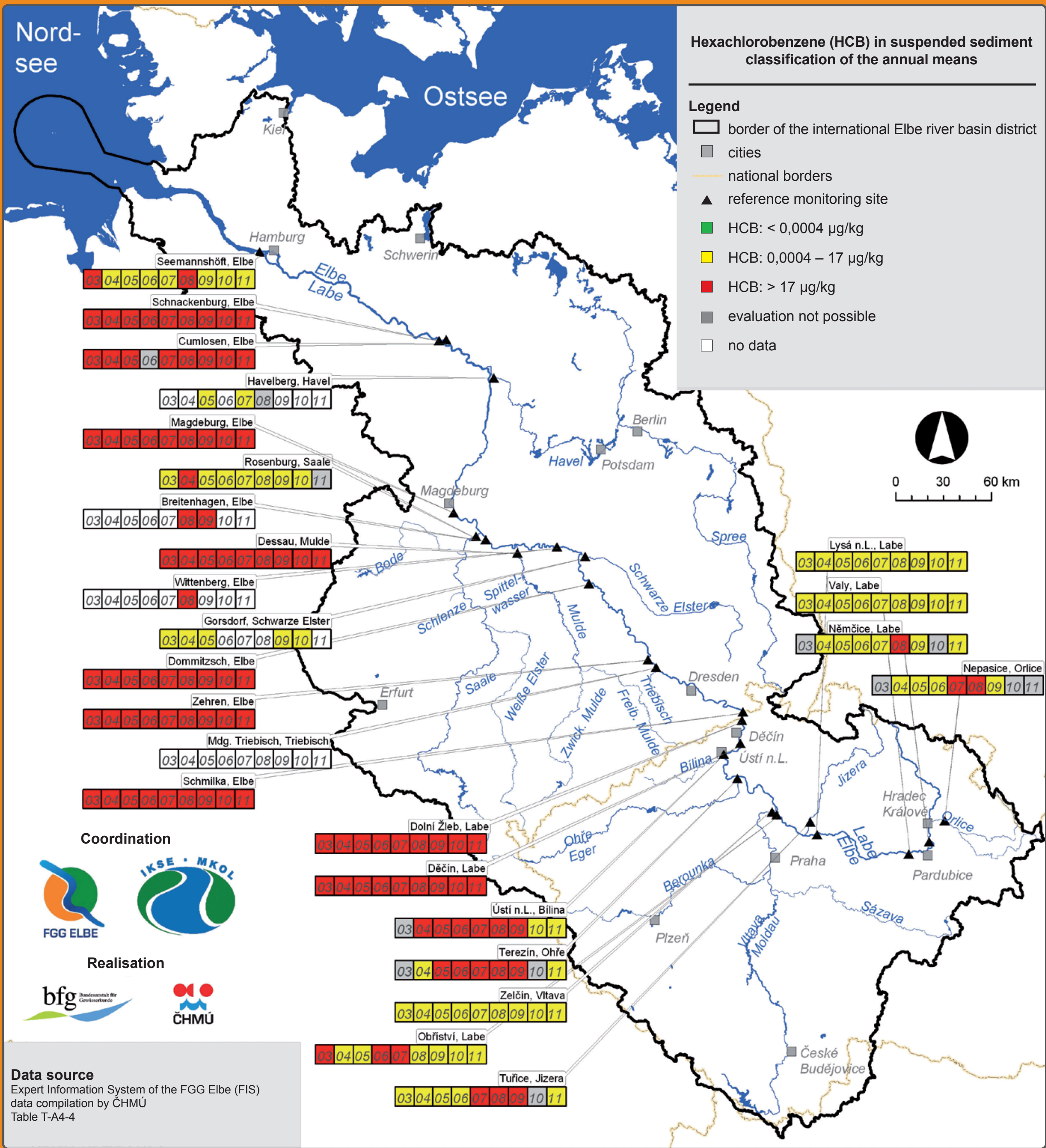

Fig.: 6: Hexachlorobenzene in suspended sediment – Classification of the annual means

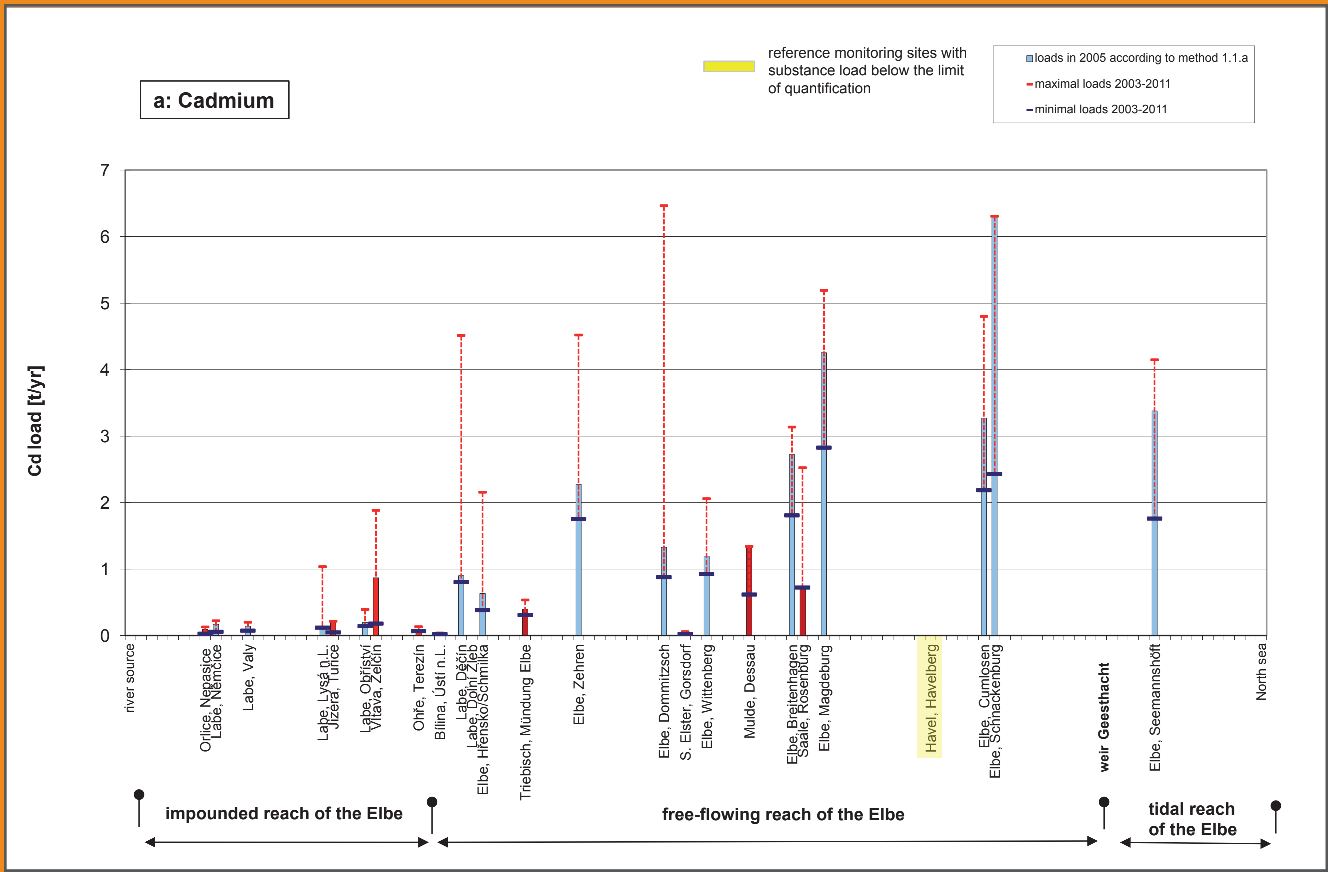

Fig.: 7: Cd loads in the longitudinal section of the Elbe

contaminants are emitted regularly or may be emitted episodically, e.g. due to enhanced streamflow, potential sources are such contaminated sites within the inundation areas of the River Elbe and its relevant tributaries, and

(4) other sources (e.g. emissions from urban systems).

In *Figure 8*, examples of the source types 1 – 3 are shown. As a result, the relevant sources in the basin districts are described and ranked. Altogether, 38 source-related recommendations are given in the concept.

Depending on hydraulic conditions, sediments may be sources or sinks of contaminants. Therefore, besides the source function (mainly induced by floods), the sink function was also included in the analysis. This refers first of all to the role of floodplains and also to the Mulde reservoir as an example for further types of sinks such as natural and artificial river lakes, storage reservoirs, and harbour basins. Consequently, recommendations in the concept refer also to the potential sink functions.

Fig. 8: Examples of sources of sediment contamination in the Elbe catchment
a – Sewage water discharge into the Elbe from the chemical industry below Pardubice
b – Old mining water discharge into the Triebisch river via the 'Rothschönberger Stollen'

Fig. 8: ***Examples of sources of sediment contamination in the Elbe catchment***
c – Historical sediments: training structures in the Czech lower Elbe river near Nebočady
d – Historical sediments: example of a regional clustering of groyne fields, for which the relevant content of fine sediments was modelled (red spots)

Conclusions on recommendations for action

Recommendations for the river basin management make up the final step in the sediment management concept *(Figure 3)*. Criteria for prioritization had to be defined in this context. *Table 1* gives an overview. While aspect-specific criteria are listed in the upper section, the lower section comprises such of general character. Recommendations given under each of the three aspects – quality, hydromorphology, and navigation – have to be assessed also for their effects on the two other criteria ("resonance effect"), which is reflected by the general criterion No 3. On the whole, the concept discusses 22 types of recommendations for action in this way.

From the qualitative perspective, source-related recommendations are given in the fields of

(1) reduction/restoration of point sources,

Table 1: Criteria of prioritization of management actions

Aspect		
Quality	Hydromorphology	Navigation
1. Quantitative significance of a source (load / potential load) 2. Number of relevant contaminants per source. Here, two groups are considered, one including priority dangerous substances (water framework direktive) and substances of specific concern for human health and the other comprising the rest.	1. Positive influence on one or both key indicators 2. Positive influence on further indicator parameters 3. Effect potential for long river reaches 4. Orientation at areas of classes 3, 4, 5	Inland Elbe: 1. Maintain, optimize, adapt the regulating system (free-flowing reaches) / stabilize the river bed in the longitudinal section and river constructions (impounded reaches) 2. Relocate or add sediment 3. Dredge Tidal Elbe: 1. Reduce the contaminant import from upstream 2. Establish an adaptive dredged material management
General criteria: 1. Solving a problem at source or elimination of the underlying cause. 2. If the underlying cause (source) does not exist anymore, the problem should be solved as close to the source as possible ("sweeping the stairs from the top down"). 3. The recommendation has a positive effect on one or both of the other aspects. 4. A single investment causes lower follow-up costs in the long run. 5. Degree of difficulty/costs of implementation. 6. Safety/uncertainty in the assessment of success, e.g. because of variability of the system. 7. The criterion for exclusion "Absence of appropriate options for solution" is applied only in exceptional cases when the level of knowledge is very well-based/substantiated		

(2) reduction/restoration of historical contaminations,
(3) removal of historical sediment deposits sensitive to remobilization,
(4) management of fine sediments in the river combined with the optimization of maintenance strategies,
(5) reduction of imports of contaminated fine sediment from urban areas, and
(6) utilization and management of contamination sinks.

Recommendations for actions from a hydromorphological perspective are primarily directed at the dominating causes of the unsatisfactory situation and thus at the key factors “Sediment continuity”, or “Mean river bed changes / sediment balance” (D) and ”Impact on the morphological regime” (CZ)”. The trends of reduced sediment supply as a result either of retention in the entire river basin in storage reservoirs and impoundments, or due to cross structures, bank stabilization and sealing, or an increased transport capacity of the river due to river-training, as well as dyke construction must be stopped and reversed. In the tidal Elbe, hydromorphologically effective river-training measures should have primary influence on the tidal characteristic with the aim of reducing the “tidal pumping“ and thus the upstream transports of fine sediments in the estuary.

From a navigational perspective, actions for the long-term monitoring and stabilization of the river bed longitudinal section have priority in the impounded inland reach. In the free-flowing reaches, the regulating system has to be adapted in its regulation parameters in order to ensure again a regulated sediment transport, wherever possible. An active sediment management practice is advisable wherever there are navigation-hindering deposits in the defined fairway channel, e.g. after flood events or as a consequence of a regulation system with restricted functionality. In the tidal Elbe, sediment management for waterway maintenance rests upon three pillars (HPA and WSV, 2008). These are (1) an adaptive management of the sediment budget according to the upstream flow conditions, (2) a significant reduction of the contaminant load in sediments from upstream, which can only be reached by the entire river basin community, and (3) river-training measures.

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