Case Studies

The River Elbe

A Case Study for the Ecological and Economical Chain of Sediments*

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Abstract. Industrial activities in the river basin of the Elbe have a very long tradition, and have been resulting in the contamination of sediments for centuries. Contamination lasted until the fall of the iron curtain; since then, the situation has improved significantly. In the transition zone between freshwater systems and the marine environment, ports like Hamburg still have to bear this burden of history. An overall (contaminated) management strategy should be developed in the context of the European Water Framework Directive with the emphasis on source control.

Keywords: Contamination; Czech Republic; dredged material; Elbe; Hamburg; sediments; Spittelwasser; Water Framework Directive

1 The River Basin

The River Elbe is the third largest river of Central Europe after the Danube and the Rhine, based both on length and size of the catchment area. The Labe River has its source in the Krkonoše (German: Riesengebirge), flows through the Czech Republic and then through central and northern Germany before discharging into the North Sea (**Fig. 1**). Its catchment drains some of north and central Europe's major cities, including Prague, Dresden, Berlin and Hamburg. The river's water serves several purposes: to a certain extent, it is used for drinking water production via bank filtration which makes a comprehensive treatment necessary, and it is also used for industry and agriculture.

Despite having been a heavily polluted river, the Elbe stands out among central European rivers for its natural resources. Although the upper reaches of the Elbe in the Czech Republic are characterized by a series of barrages and reservoirs, the Elbe is free flowing from the Czech-German border till the barrage at Geesthacht. These 600 km have been mostly spared by river engineering works common in other major European rivers, such as the Rhine and the Danube, mainly due to the fact that the river was part of the former German-German border. The Elbe has not been canalized, and only a few meanders have been straightened. Although it has lost a majority of its floodplains, those that remain are subject to annual floods and support wetland and floodplain forest habitats that have been internationally recognized and are unique within central Europe (after Adams et al. 2001).

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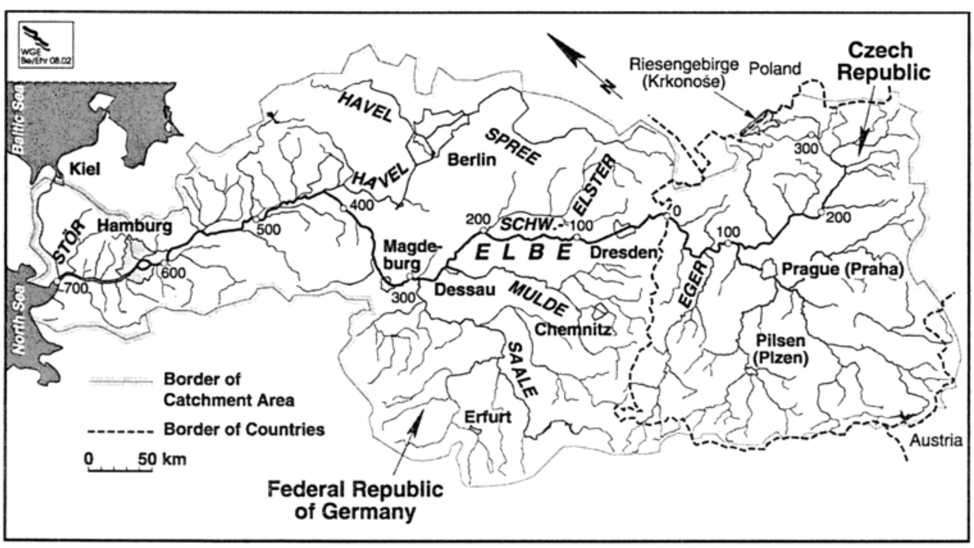

Fig. 1: Elbe River basin

Data (IKSE 1995, 2000):

Drainage basin area: 148,268 km^2, 2/3 in Germany, 1/3 in Czech Republic, less than 1% in either Austria or Poland. Important tributaries are Moldau / Vltava, Havel, and Saale, each comprising a catchment area of roughly 25,000 km^2.

Length of the River: 1,091 km, 727 km in Germany, 364 km in the Czech Republic.

Population living in the drainage basin: 25 million in Germany (31% of total population), 6 million in the Czech Republic (58% of total population).

Average discharge into the North Sea: 862 m^3/s

The running time of a water particle from the source to the tidal influence border is about 10 days for the first 942 km, but 36 days for the remaining 149 km, with tidal influence.

2 The History of the Contamination

Contamination of the river and its water has been known since the Middle Ages since, for example, the industry in Bohemia is very old. From the 14th to the 19th century silver and iron were mined extensively in the Ore Mountains (Erzgebirge). Tanning and paper-making also did not improve water quality. But of course there is no data about these times.

With industrialization, many heavy and chemical industries settled in the Elbe area. The first measurements of water quality are for chlorine, they show a sharp increase in the second half of the 19th century because of the use of sodium for industrial purposes.

In former times, domestic sewage was also a problem. There is a quotation of an unknown author from 1921 about the water quality of a river near Hamburg, "The water is so polluted that no living creature at all is able to survive in it. I believe almost certainly that a water rat, which has nevertheless a tough nature, is not capable of swimming over the Krückau because it will get the plague by crossing it and will come to its end. One must clench one's fist when one sees such destruction of the organisms living in the water." The reason for this will be insufficient sewage treatment, which led to a cholera epidemic in Hamburg in 1892, for example, with about 8,500 casualties.

Therefore, Hamburg started to build sewers and sewage treatment facilities in the 19th century, but the problem in general continued for another century. The city of Dresden in East Germany, with a population of about 500,000, released all of its sewage into the Elbe in an untreated form after its wastewater treatment plant had been severely damaged in a flood in 1987. Many communities in East Germany and Czechoslovakia didn't even have a treatment facility until the 1990s.

In 1989, when the iron curtain fell, the water quality of the Elbe was comparable to the severely polluted Rhine of the early 1970s. For decades, it had been the recipient of untreated or insufficiently treated wastewater from urban centers, industry and agriculture. During that period, 82% of the East German population lived in the Elbe's catchment area, and it encompassed over half of the East German industrial production and the entire western Czechoslovakian industrial region. Major industrial point sources included pulp and paper, chemical, and pharmaceutical facilities. For example, the chemical complex at Bitterfeld was a major source of mercury for the Elbe. It released 200,000 m^3 of untreated industrial sewage into the Elbe daily (!).

3 Development since 1989

The political change of the late 1980s led to significant improvements for the Elbe. Since 1990, the population of former East Germany has decreased by 800,000. Many industrial and agricultural complexes of the former communist regimes collapsed, and therefore didn't discharge pollutants any more. Remaining industries and farms, or those that had started since the early 1990s, are generally equipped with modern pollution control technologies.

In 1990, the treaty for the International Commission for the Protection of the Elbe (IKSE) was signed. The IKSE initiated a series of programmes in the early 1990s which mainly aimed at industrial sources considered to be the major polluters, such as the chemical, pharmaceutical, pulp and paper, and leather-processing industries.

Furthermore, in the time span from 1990–1999, 181 municipal waste-water treatment facilities were newly built, extended or reconstructed (139 in Germany and 42 in the Czech Republic). They treat the sewage of 12.9 million population equivalents in Germany and 8.5 million in the Czech Republic, respectively. The necessary investment was 3 billion Euro in Germany and 12.1 billion Kč in the Czech Republic. Elbe and North Sea are relieved annually of 83,770 tons of BOD5 (27% of the 1990's total load), 3,320 tons of phosphorus (36%), and 14,250 tons of ammonia (62%). **Table 1** shows the results of the efforts in industrial wastewater treatment.

Table 1: Industrial discharge reduction (IKSE 2000)

Discharge	Tons/year	Reduction 1999 to 1994
COD	37,570	50.4%
Nitrogen	8,525	65.1%
Zinc	125	60.0%
Chromium	13	84.3%
Nickel	7	89.6%
Trichloromethane	4	67.3%
AOX	427	64.1%
EDTA	85	93.3%

Despite these improvements, the Elbe still faces challenges. Legacies from the last decades, such as abandoned mines, unconfined waste disposal sites, etc., still remain. These sites pose potential threats to both ground and surface water. The most seriously polluted sites are in the BUNA industrial chemical complex and the former VEB-Leuna-Werke, the largest industrial chemical plant of East Germany. Major cleanup efforts are being directed at these sites. Non-point sources, such as agriculture, also contribute significant loads of nitrogen and phosphorus to the Elbe.

4 Survey of Water and Sediment Quality

Since the 1970's, a lot of data about the quality of water and sediments of the West German part of the Elbe River was sampled, but nothing was known about inputs east of the German-German border. In the early 1980's at that border in Schnackenburg a continuous sampling station started operation representing approximately 85% of the Elbe's watershed. Nowadays, the data gained provides a very good illustration of the development over time. Today there are more of these continuous sampling stations. Altogether the international measuring programme of the IKSE comprises 17 survey stations, 5 in the Czech Republic and 12 in Germany.

Fig. 2 shows mercury in fresh sediments in Schnackenburg. Due to very high industrial emissions, mercury was the main pollutant 20 years ago, reaching concentrations of about 75 mg/kg. For mercury the German target value is 0.8 mg/kg dm, the geogenic background concentration is 0.3 mg/kg dm. These values are not reached yet, but the development over the last 15 years is very promising. The total mercury load could be reduced from 28 tons in 1985 to 1.2 tons in 2001. Most other parameters also improved significantly.

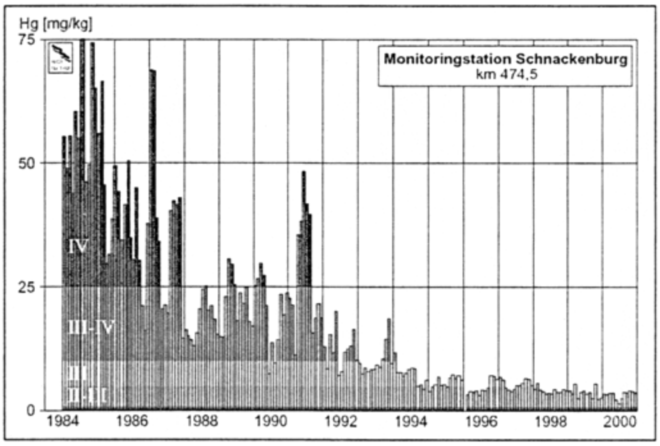

Fig. 2: Mercury concentrations in fresh sediments in Schnackenburg, former German-German border. Roman numbers are quality classes (rising contamination from I to IV)

Together with many other measuring campaigns during the last 12 years, the Elbe river basin has now become one of the best examined in Europe.

Coming to sediments, the legacy of the past is evident in sediment cores taken to determine the background concentrations for heavy metals. Samples were taken from floodplain sediments and analysed in layers which could be assigned to a certain time span.

Fig. 3 shows a core from a site in East Germany. Arsenic starts to increase nearly 100 years ago, reaches a peak with high concentrations about 1970 and has decreased since then (Prange et al. 1997). The same applies to a sediment core taken near Hamburg which shows concentration peaks of arsenic, mercury, and zinc for the mid-1970s and a steady decrease since then (Ackermann and Stammerjohann 1997).

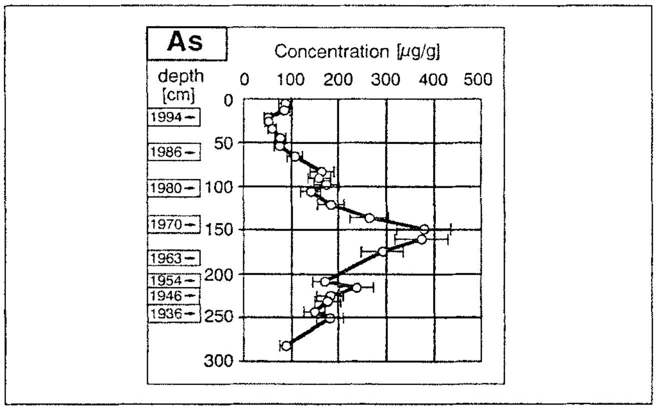

Fig. 3: Sediment core from 'Bucher Brack', Tangermünde (from Prange et al. 1997)

5 Sediments – Problems and Solutions

5.1 Port of Hamburg

In the Port of Hamburg, dredging has to be undertaken to secure a sufficient water depth for vessel traffic. Here, dredging has a century long tradition. Traditionally, the dredged sediments were used beneficially for land reclamation or agriculture. About 20 years ago – as in other places as well – the contamination of dredged sediments and the resulting negative effect for the environment came into public focus. This led to a broad political discussion in Hamburg. But there was no quick solution available. A Dredged Material Research Programme was initiated. Soon it could be seen, although it was the same problem compared to other ports due to the special circumstances, that local solutions had to be found.

In comparison to Rotterdam, Hamburg, for example, could not act upstream to prevent further emissions into the river Elbe. Only the immense pollutant load coming with the river through the iron curtain could be measured, but nothing was known about their origins; not to even talk about the possibility of discussing efforts to reduce them.

Hamburg had to find a solution of disposing the dredged sediments in its limited city borders. The solution consists of pre-treatment, i.e. separation into sand and (contaminated) silt and the environmentally safe disposal of the silt in two specially constructed silt mounds. Of course this is a costly solution, but it was not thought to be a long-term solution.

Pre-treatment is done in the large scale METHA plant (Fig. 4). It has a throughput capacity of 1 million m^3 sediments per

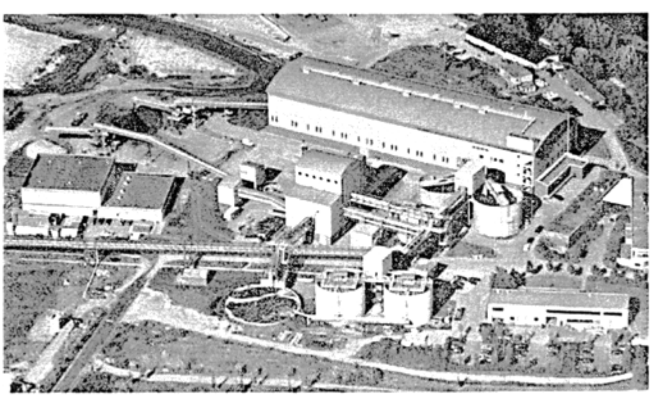

Fig. 4: METHA Treatment plant in Hamburg

year. Its products, besides smaller amounts of coarse materials, are sand, fine sand and silt. The sand is used as construction material and nearly contaminant free. The fine sand can be used in the industry as a raw material or additive.

Trials have shown, part of the silt is used beneficially as a sealing material in the construction of the dredged material disposal sites or was built into former harbour basins for backfilling. It was also used as raw material in brick fabrication. Trials have showed that this is a feasible possibility which now has to be decided upon, also under consideration of the relatively high additional payments.

Since the mid 1990s, dredged material fulfilling certain criteria developed for the Elbe system has been relocated into the river. With this technology, sediment coming from the river is given back into the aquatic system. The effects of relocation on the environment are minimised following a concept of sustainable relocation.

The resulting costs of treatment are immense. Depending on the river flow, between 2 and 5 million m^3 have to be dredged annually. 1.4 Million m^3 thereof are treated on land. The city of Hamburg has to spend roughly 30 million Euro annually for this, not including personal and capital costs.

5.2 Spittelwasser

The creek Spittelwasser is a tributary into the Mulde and has been used as a channel for industrial effluents for decades. It is situated in the Bitterfeld district, the so-called Chemical Triangle, one of the largest industrial complexes of Eastern Germany with chlorine, film and pulp production. Since the beginning of the chemical industry at the end of the 19th century, industrial process water had never been treated until 1994. The low gradient of the Spittelwasser favours sedimentation. Today the Spittelwasser contains about 20,000 tons of sediments with organics, heavy metals, pesticides, etc. For example, dioxin concentrations of up to 23,000 ng/kg and mercury concentrations with a peak of 740 mg/kg were found. At the same time, the Spittelwasser is part of a nature protection area. Chemical analyses show that the Bitterfeld chemistry polluted the Mulde and Elbe sediments down to the Hamburg harbour, a distance of about 350 kilometres.

Evaluation of remediation of the Spittelwasser was also part of the NICOLE and CLARINET projects.

6 Handling of Sediments and Dredged Material

Sediments are an integral constituent of the aquatic system. Due to their special properties, they bind a more or less large part of contaminants being discharged into this system. The development over time and distance can be seen in fresh Elbe sediments taken in the above-mentioned sampling stations along the river. **Fig. 5** shows the decreasing contamination of fresh sediments along the river from the Czech border to the sea in 1997, a clear indication of inputs in the upper part of the river basin.

Many point and non-point sources accumulate along the river. Contaminants are spread and diluted at the same time. In Hamburg, upstream sediments near the sea mix with marine sediments transported with the tide. The contamination is low, compared to upstream concentrations, and still high compared with North Sea standards. The

	Cuxhaven	Grauerort	Seemannshöft	Bunthaus	Schnackenburg	Magdeburg	Schmilka
mercury	II-III	II-III	II-III	II-III	III	III	III
cadmium	II	II-III	III	III-IV	III-IV	III	III-IV
lead	II	II-III	II-III	II-III	III	III	II-III
copper	I-II	II-III	II-III	III	III	III	II-III
arsenic	II-III	II-III	III	III	III	III	III
α-HCH	I-II	I-II	I-II	II-III	II-III	II	II
β-HCH	I-II	I-II	II	II-III	III	III	II-III
γ-HCH	I-II	I-II	I-II	II	II	I-II	II
HCB	I-II	II-III	II-III	III-IV	III-IV	III-IV	IV
p,p'-DDT	I-II	I-II	II	IV	III	III-IV	IV
p,p'-DDD	I-II	I-II	I-II	III	III	II-III	IV
PCB No. 153	I-II	II	II-III	III	III	III	III-IV
AOX	-	II-III	III	III	III	III	III
Tributyltin	-	III	IV	-	II-III	II-III	II
Tetrabutyltin	-	I-II	II	-	II-III	II	I

Fig. 5: Contamination of fresh sediments (monthly samples) from the Czech-German border in Schmilka (right) to the sea in Cuxhaven (left) in 1997. Class I is the least, class IV the most contaminated

amount of sediments is large, the amount of different contaminants as well.

Parts of these sediments have to be dredged for nautical reasons. Still the larger part of contaminants is being transported with suspended matter further to the sea, 'only' about 1/3 of the heavy metal load is withdrawn from the aquatic system with the dredged material. Following current regulations, a considerable share of the dredged sediments has to be specially treated, thereby resulting in high expenses. Nevertheless, the influence of the city to reduce the inputs of these contaminants is still limited. Therefore, in an individual case, Hamburg gave financial support to a Czech chemical company. Spending 150,000 Euro, two settling basins could be built to reduce the mercury load being emitting from this factory from 1.7 to 0.8 tons per year and, thus, cutting the total load of the river in 1995 by half! This is not the *polluter pays* principle, but it's a pragmatic approach to get things done. Available funds for ecological measures are still limited in Eastern Europe.

It should become evident that treating dredged material from maintenance works in general is not a sustainable, at least not a primary element of aquatic protection politics. Emphasis has to be put on source control, which is also a central argument in international conventions. When it comes to dredged material – mainly occurring in the estuaries – the contaminants are already diluted and spread over large areas or amounts of sediments. One may ask "Why only treat this material?" while all other sediments around with the same degree of contamination which are not caught hold of remain untreated?

Of course this does not apply to local contamination of sediments. The Spittelwasser sediments, which have their origin at that very site, for example, pose a threat to the environment already where they actually are. When they are transported with the current downstream they lead to a deterioration of the whole system beyond that.

7 Outlook

Handling (contaminated) dredged sediments is very dependent on the specific local circumstances. Now, the European Water Framework Directive demands a holistic river basin approach when considering the water resources. However, it is not yet clear how sediments will be incorporated into the new regulations which have to be developed. For example, it has to be made clear what is meant by the fact that Annex VIII names 'Materials in suspension' in the list of main pollutants, which become sediments when they settle. As already stated 'Materials in suspension' are an integral part of the aquatic system, so why are they generally pollutants? Sediments are the 'memory of a river', they are a common ownership from the past. Therefore, common solutions have to be found.

When standards for the assessment of dredged material are set, these should be in accordance with the necessary measures of source control in the entire river basin. Goals, and therefore also sediment standards for marine environment protection, are rather demanding; when formulating them, riverine inputs seem to be taken into account insufficiently. It is hardly to be understood why ports in the transition zone between fresh water systems and the marine environment shall exclusively bare the financial and also ecological burden of insufficient measures upstream.

It should be kept in mind, when sediments are taken out of the river or sea, that the problem is not at an end. Also treating them on land may have negative ecological effects, aside from the enormous funds needed due to the large amounts of dredged material. Inadequate regulations or high demands may limit the possibilities of beneficial use or disposal, aside from the fact that the market for beneficial use products may be limited. For example, the European Landfill Directive (1999) does not acknowledge the fact that subaqeous disposal of dredged material is an appropriate and cost-effective solution for contaminated sediments.

Sediments do not fit well into the, until now, rather defined environmental regulations. They are in water as well as on land (governed by different guidelines), they behave differently in different environments, they pass boundaries without permit, they spread contaminants over wide areas, they are an integral part of the environment and, at the same time, are regarded as waste when being dredged.

Therefore, a management concept for sediments has to be developed and integrated into an overall concept which may fit into the context of the European Water Framework Directive. The Thematic Network SedNet will be an adequate European forum to discuss this topic, which is crucial for those responsible for ports and waterways, but also for all those who feel responsible for river basin and marine environments.

References

Adams M-S, Ballin U, Gaumert T, Hale B-W, Kausch H, Kruse R (2001): Monitoring selected indicators of ecological change in the River Elbe since the fall of the Iron Curtain. Environmental Conservation 28 (4) 333–344

Ackermann F, Stammerjohann D (1997): History of heavy metal contamination in the sediment of the Mühlenberger Loch. Bundesanstalt für Gewässerkunde, 7 pp, Koblenz

Internationale Kommission zum Schutz der Elbe (IKSE):
- Die Elbe und ihr Einzugsgebiet (1995)
- Gewässergütebericht Elbe 1997 mit Zahlentafeln der physikalischen, chemischen und biologischen Parameter des Internationalen Messprogramms der IKSE (1999)
- Die Elbe von 1990 bis 2000 – 10 Jahre erfolgreiche Zusammenarbeit in der IKSE (2000)

Prange A et al. (1997): Geogene Hintergrundbelastung und zeitliche Belastungsentwicklung. GKSS Forschungszentrum, Geesthacht

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