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Five years of artificial bed load feeding in the River Elbe

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Abstract

Erosion of river beds leads to various problems concerning navigation, river structures, flood dynamics, groundwater table and conditions of flora and fauna. A feasible measure to reduce this degradation process is to compensate the deficit of bed load by artificial bed load supply. Since 1996 field experiments are made by the Federal Waterways and Shipping Administration together with the Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau) and the Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde) to investigate the effectiveness of stabilizing the river bottom of the upper part of the river Elbe by artificial bed load feeding. The aim of these studies is to demonstrate the feasibility and the limits of this method of bed erosion prevention for this particular section of the river. Comprehensive measurements were carried out before, during, and after the feeding periods to get information about key parameters and about the behaviour of the dumped material. This paper presents scope, aims and results of the investigations and discusses prospects and limits of adding artificial bed load into a stream with relatively fine bed material.

1 Introduction

As a consequence of the deficit of bed load, the existence of relatively fine bed material and as an effect of regulation by men, the River Elbe between Mühlberg (km 120) and Wittenberg (km 230) (Fig. 1) suffers from a steady degradation process of serious dimension. This progressive bed erosion which is observed since the end of the 19th century leads to changes in the flood plains and adjacent catchment area as the levels of surface water and ground water follow the

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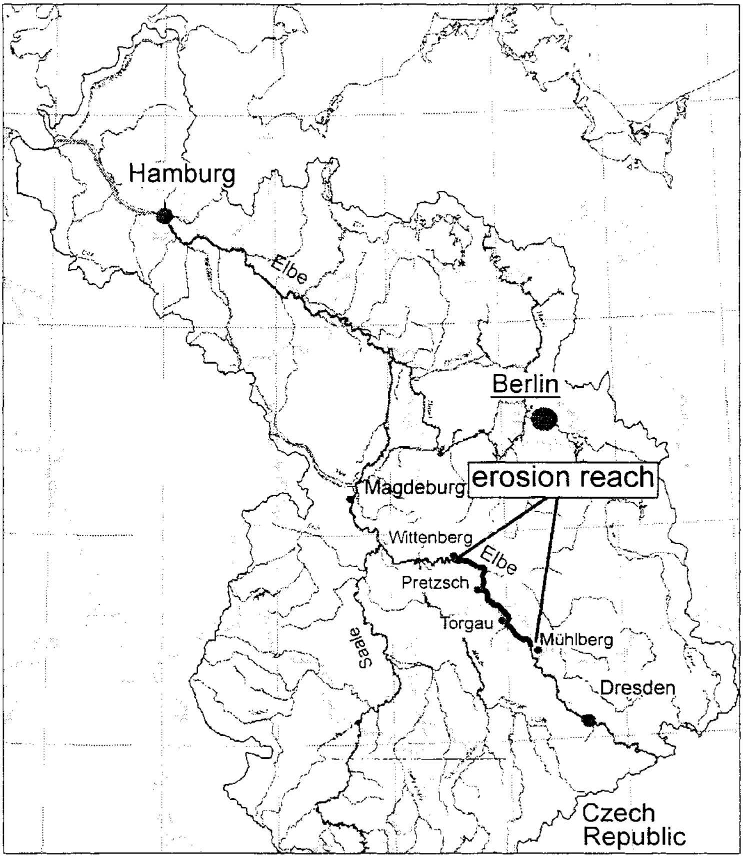

Figure 1: Catchment of the River Elbe, german part (modified map of "Forschungszentrum Jülich GmbH").

deepening river bottom. This affects the dynamics of floods (frequency, extent, duration) with impacts on flora and fauna. Another consequence of the ongoing process consists in the reduced stability of groynes and bank protection structures. Moreover, at Torgau (km 154.6) an outcropping rock is 'growing out' in relation to the gravelly and sandy bed nearby, causing unstable hydraulic conditions - a hindrance to safe navigation. To avoid further disastrous ecological as well as economical development caused by uncontrolled bed erosion, efforts are made to stop or at least to reduce this process in future.

2 Causes and extent of the erosion process

There are a variety of reasons for the progressive depth erosion in this river reach: besides regulations by men (i.e. restriction of discharge area by dykes, restriction of bank erosion by bank protection structures, restriction of bed load supply by transverse structures upstream in the main river as well as in tributaries, increase of slope by shortening the course of the river), the geological and morphological character of this part of the Elbe is predominantly responsible for the development. Concerning the composition of the bed material, this reach has the character of a transition zone with dominating coarse gravel at the upstream end (85 % gravel, 15 % sand; 25 % < 6.3 mm; $d_m \approx 25$ mm) in contrast to fine gravel and sand at the downstream end of the reach (35 % sand; 60 % < 6.3 mm; $d_m \approx 6$ mm). Fine sand (d<0,2 mm) or silt are not found in the river bed surface [1]. In this part the course of the Elbe is regulated by river engineering structures (mainly groynes and longitudinal training walls). Mean low water discharge is about 130 m³/s, the average annual flood is about 1300 m³/s, the flood with a recurrence interval of 100 years is about 3410 m³/s. At mean discharge conditions the water level slope is 23 cm per kilometre and the mean velocity is about 1.2 m/s with a mean water depth of 2.8 m.

Erosion rates have been quantified for different sections and different periods of time by analysing the spatial and temporal development of water levels and of bed geometry (records of cross sectional soundings). The changes of the surface water level between 1888 and 1996 (Fig. 2) show that the extent of the depth erosion increases from the entry to the erosion reach up to Pretzsch (about km 185), but clearly decreases from here to Wittenberg (about km 220), with a temporally and regionally varying erosion rate. Since 1888 a maximum water level decline of 1,7 m occurred between Torgau and Pretzsch (km 155 - km 185) [2]. In addition, measurements of sediment transport (bed load and suspended load) have been carried out at various sites since 1994 to get detailed knowledge

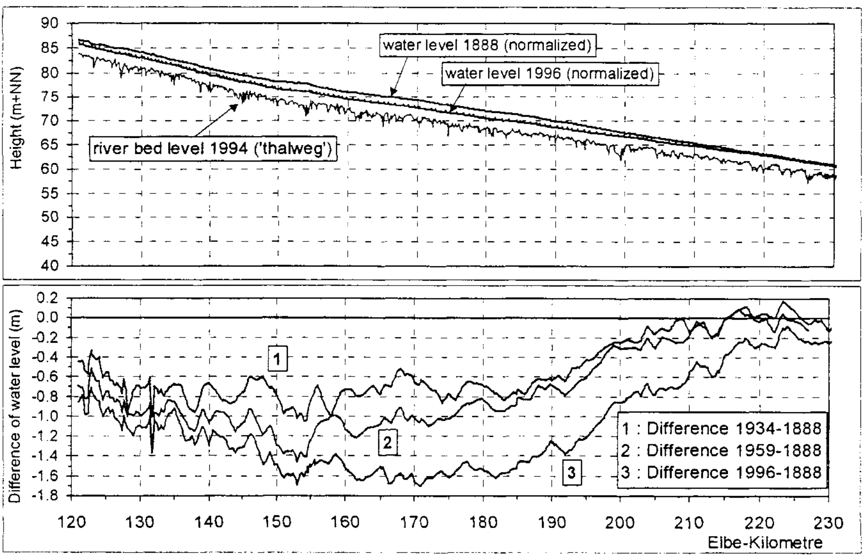

Figure 2: Changes of water level and river bed in the upper part of the river Elbe.

of the present transport situation along the reach. Mean annual loads have been calculated applying bed load transport-discharge-functions to mean daily discharge values. As no significant amount of bed load is delivered by tributaries, the differences of these loads are due to erosion and represent the deficits of bed load for the specific river sections. The results of these measurements have shown that at present the entrance to the erosion reach has to be localized close to Belgern (km 141). From upstream no significant quantity of bed load is supplied. At Wittenberg (km 214.8) about 55,000 tons of bed load are transported per year as an average reflecting the increasing quantity of smaller grain sizes between both sites. Though the bottom shear stress decreases between these sites the critical shear stress (defined by the grain sizes of the river bed material) reduces more along this river reach.

However, a complete quantification of the material eroded needs to consider the bed material transported in suspension as well. According to numerous measurements [3] the increase of this portion along this river reach amounts to about 25,000 tons per year, giving an estimated total of about 80,000 tons of bed material eroded in this reach per year on average. Comparisons of cross sectional soundings carried out between 1961 and 1965 and between 1993 and 1995 confirm these results.

3 Countermeasures

Because of the heterogeneity of this river reach artificial bed load supply will be only one of various adequate measures to prevent bed erosion in future. Basing on the analysis of the morphodynamic character of the river reach, of the causes of the erosion process and of the experiences from the field experiments an integrated concept for erosion prevention will be developed which consists of the following principle measures:

increase of bed load supply:
- artificial bed load feeding,

increase of bed resistance to hydraulic forces:
- static bed protections (local armouring and paving),
- coarsening the bed material (feeding a mixture coarser than that of the existing bed material),

reduction of transport capacity:
- modification of the river structures (e.g. adjustment of groynes),
- measures in the flood plains (e.g. repositioning or breaching of dykes; incorporation of side branches, flood channels and backwaters; lowering of banks).

Although it is evident, that only a well adapted combination of some of these approaches will successfully reduce the erosion process for such a long and heterogeneous river reach, the feeding of bed load will definitely be one essential measure.

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4 Bed load feeding

Since 1996 field experiments are made by the Federal Waterways and Shipping Administration (Wasser- und Schifffahrtsverwaltung des Bundes - WSV) together with the Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau - BAW) and the Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde - BfG) to investigate the effectiveness of stabilizing the river bed of the upper part of the river Elbe by artificial bed load feeding [4] [5].

4.1 Aims and scope

The aim of these studies is to demonstrate the feasibility and the limits of stabilizing the river bottom dynamically by feeding bed load without impeding the navigation for this particular section of the Elbe. This approach is directed to the long-term stabilization of the whole reach in order to get a constant mean bed level, even if some local and short-term variation occurs.

The main tasks of these field experiments are careful measurements to obtain reliable data about key parameters, such as suitable places for pouring out, required masses, optimal feeding rates, appropriate sand-gravel-mixture, feeding technology (e.g. bottom-dump scows), behaviour of the material after dumping (e.g. transport velocities and distances, grain-sorting by transport, areas of sedimentation, mixing with natural bed material). Reliable data on these parameters are essential for an operation in the everyday routine according to the hydraulic and morphological character of the river section.

4.2 Realization

Starting in 1996 at only one feeding site with first assumptions about feeding rates the design of the field experiments in the following years based on the experience gained before.

Besides important aspects of practicability and safety (vicinity to the supervising local office and to the gravel pit; no impediment to the navigation) the selection of appropriate feeding sites depended mainly on their suitability for answering questions regarding the operation in future. In Table 1 the chosen areas are listed together with their principal characteristic and the main objectives of the investigations. The grain size distribution of the added material (75 % gravel, 25 % sand; $d_m \approx 12$ mm; $d_{95} \approx 34$ mm) was chosen to be slightly more coarse than the natural grain-mixture of the river bed in the area with the highest erosion rates. This distribution was taken for all the years because it was not desired to vary all the parameters. The feeding rates have been defined to vary with discharge (consistent with the transport capacity of the river) and in accordance with calculations regarding the allowed elevation of the river bed without obstructing the navigation. The various feeding rates shown in Table 2 are considered as upper limits.

Table 1: Characteristics of the feeding areas.

No.	Area	Characteristic of the area	Main objectives
I	km 131-143	Entrance to the erosion reach, armoured bed surface, no bed load supply from upstream	Information about the transport capacity of the stream
II	km 173-191	Highest erosion rates at present, bed load transport takes place already at very low discharges, region with a very dynamic river bed	Experiences with feeding operation as in everyday routine (feeding rates as required in future)
III	km 153.8-154.4	Region with great scours above the rock at Torgau	Experiences regarding: - feeding at low water discharges, - temporary storage in scours, - transport of the stored material at higher water levels
IV	km 157.0-157.4	Downstream of the rock at Torgau, upper end of the section with highest erosion rates at present, bed load transport starts at about 2 MQ, no scours	Experiences with feeding operation as in everyday routine (feeding rates as required in future)

Table 2: Feeding rates for different water levels.

Water level (cm) at gauging station Torgau	Water discharge (m^3/s)	Feeding rate (tons/day)
< 180	< 255	no feeding
180 – 229	255 – 338	300
230 – 299	339 – 471	600
300 – 620	472 – 1560	900
> 620 (> highest navigable water level)	> 1560	no feeding

Table 3 summarizes the quantities added at the various feeding sites during the last five years. Insertion of the sand-gravel-mixture was realized according to the defined feeding rates using two bottom-dump scows (carrying-capacity of 160 tons and 300 tons respectively) moving upstream (Fig. 3).

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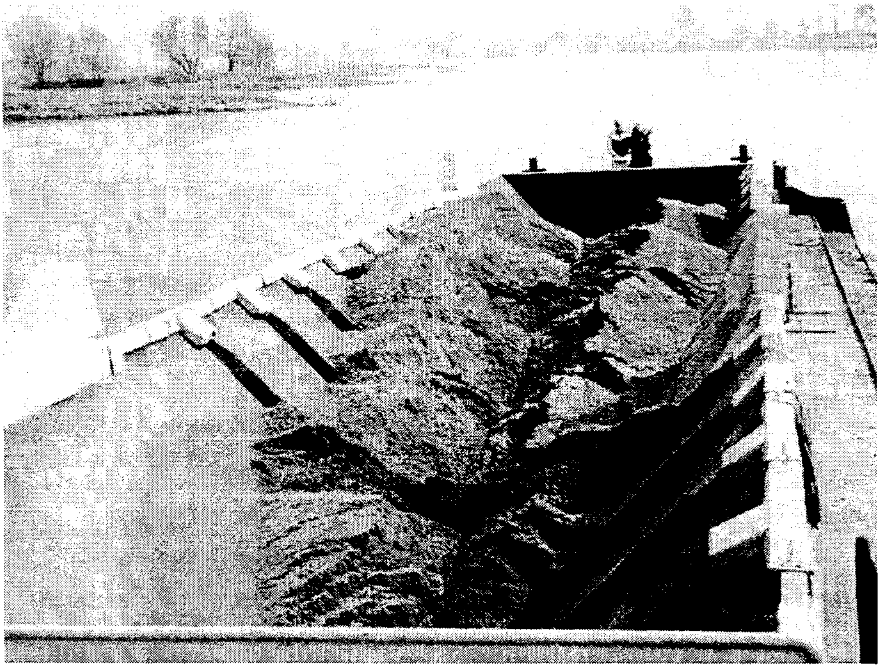

Figure 3: Bed load feeding with a bottom-dump scow (~300 t).

Table 3: Added masses, field experiments from 1996 to 2000.

year	area	Feeding area (Elbe-km)	gravel (tons)	tracer (tons)	total (tons/year)
1996	I	142.5-142.9	9,100	2,100	11,200
1997	I	131.5-132.0	7,000		31,200
	II	173.5-174.7	4,100	20,100	
1998	I	131.5-132.0	16,300		51,300
	II	176.9-178.3	35,000		
1999	I	131.5-132.0	1,440		36,480
	I	142.7-142.9	1,440		
	III	153.8-154.4	16,700		
	II	174.0-174.5	16,900		
2000	III	153.8-154.4	6,600		30,600
	IV	157.0-157.4	15,000		
	II	190.2-190.7	9,000		

In the years 1996 and 1997 red granite (natural-coloured) from a gravel pit nearby was used as tracer to observe the dynamics of the gravel fractions of the dumped material - mainly medium and coarse gravel due to supply restrictions, thus having a coarser mixture than the other material. As no experience existed with regard to tracer detection in the river Elbe for any grain fraction the use of mainly coarse material in these field experiments was reasonable due to the problems being faced with the detection of fine tracer material. Since 1998 original gravel from the Elbe coated with luminophors is used as an alternative sort of tracer. The use of two different tracer methods gives the opportunity to assess the suitability of such methods for the investigation of bed load transport. In order to get information about transport velocities tracer detection is performed for both methods by bottom sampling.

4.3 Results of the field measurements

In general, any short-term proof of erosion prevention measures is difficult, if the erosion rate is small in comparison to the attainable precision of the measuring methods. Used in rivers with a movable bed, water level control as well as soundings are methods with precision of about 5 to 10 cm, thus faced with an erosion rate of 1.5 mm per year it needs about 4 to 7 years to identify changes unambiguously and to give answers to the effect of the measure. On the other hand, if the artificially added material is well adapted to the grain size characteristic of the bed material and it substitutes the material otherwise eroded from the river bed (i.e. the measure is successful), measurements of bed material load will indicate no change at all. For these reasons short-term proofs mainly have to rely on soundings in the vicinity of the feeding areas (to monitor the transportation of the added material out of the feeding area) and on the tracking of tracers.

The investigations carried out in the last years showed that mainly because of the hydrological situation in the river Elbe (usually long periods of low discharge) the material could not be added to the intended extent (about 80,000 tons in a year having a mean discharge volume). Only in 1998, a comparatively dry year, the input could be realized as planned, thus the field experiment in that year was close to a realistic simulation of an operation in the everyday routine. The results of that year give a reliable estimation regarding the transport capacity of the river. Simulations with a series of 30 years of mean daily discharge (1971-2000) show that on a long-term mean bed load feeding in this part of the river Elbe is theoretically possible at 180 days per year assuming the feeding rates in context with the water levels (Table 2). However, from a practical point of view a number of only 88 days seems to be realistic for feeding operation. Till now, max. 78 days of feeding could be realized in a single year (1997).

The cross sectional soundings carried out before, during, and after the feeding periods proved to be a suitable way to calculate the effects of the feeding in the vicinity to the feeding areas. The results demonstrate that the accumulations due to the feeding operations are limited both in time as well as in

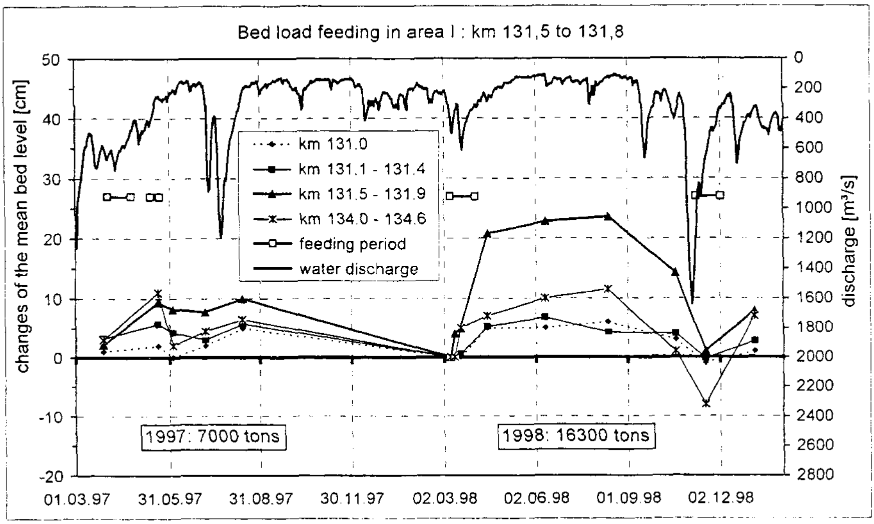

Figure 4: Development of the mean bed level in and downstream of the uppermost feeding area.

space; significant accumulations could be observed only very close to the feeding areas. Navigation was not hindered by accumulations. Figure 4 shows that in the upmost area the gravel was not completely removed when discharge was less than 800 m³/s. However, after a flood the mean bed level reached the height it had before. The fact, that downstream of the feeding area (km 134.0-134.6) the river bed is eroded during the flood in November 1998 to such an extent, obviously shows that in the feeding area itself the added material has prevented this consequence.

The results of the tracer observations indicate at which quantity and at which speed the different tracer fractions move downstream. As expected, the coarse gravel fraction moves downstream very slowly. In the case of the first experiment in 1996 the added tracer had its maximum of quantity at or nearby the feeding site still eight months after termination of feeding. The extensive bottom sampling showed that already some kilometres downstream of the feeding sites the tracer material is spread over the whole movable part of the cross section.

Transport velocities of the tracer-front are calculated for different time periods and are listed in Table 4. These results of course have to be interpreted in view of the hydrologic situation for the period of grain migration. As the longest period (April 1997 to May 2000) reflects the average hydrologic situation very well, these results can be taken as reliable estimates of the maximal speed at which these fractions will move. This means that the medium and the course gravel fraction need at least about 11 years and 19 years respectively to move through the whole reach (90 km) when added at the entrance of this reach. This of course is an important hint to manage the feeding with several sites along the reach if success is expected in the near future.

Table 4: Mean transport velocities of the tracer-front.

start of the experiment; feeding site	time of sampling	time of transport (days)	medium gravel (6.3-20 mm)	coarse gravel (20-63 mm)
4/1996; area I	Sep. 1996	141	40 m/d	20 m/d
	March 1997	327	22 m/d	13 m/d
4/1997; area II	April 1998	357	32 m/d	21 m/d
	May 1999	777	24 m/d	13 m/d
	May 2000	1116	22 m/d	13 m/d

5 Conclusions

Valuable experiences were gained in the last years concerning the problems of artificial bed load feeding in the River Elbe. However, if bed load feeding is proceeded, statements regarding the long-term development of this river reach need observations of about ten years because of the high variance in hydrology.

The future investigations will focus on the specification of the feeding rates to the character of the reach and the different discharge situations, and on the optimization of the sand-gravel-mixture. In particular, the knowledge about the natural variance of bed level in connection with the different hydrologic situation has to be extended for the various parts of the reach. Presently, investigations with a hydraulic-numerical model are carried out to simulate the feeding experiments and to determine proper threshold values of feeding rates. In future feeding operation will be supported by simulations with numerical models.

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References

[1] Schmidt, A., Ergebnisse neuerer Untersuchungen zu Gewässersohle und Feststofftransport in der Erosionsstrecke. *Mitteilungsblatt der BAW*, Nr.74, 51-62, Karlsruhe, 1996.

[2] Faulhaber, P., Flußbauliche Analyse und Bewertung der Erosionsstrecke der Elbe. *Mitteilungsblatt der BAW*, Nr.74, 33-49, Karlsruhe, 1996.

[3] Sauer, W. & Schmidt, A., Die Bedeutung suspendierten Sandes für die Sohlhöhenentwicklung der Elbe. *Wasserwirtschaft* (submitted 05/2001).

[4] Schmidt, A. & Faulhaber, P., Geschiebezugabe in der Erosionsstrecke der Elbe. *Zeitschrift für Binnenschiffahrt,* Nr. 23, S. 41-45, 1998.

[5] Kühne, E. & Schoßig, R., Geschiebezugabe zur Sohlstabilisierung der Elbestrecke unterhalb Dresden, *Wasserbaukolloquium des Instituts für Wasserbau und Technische Hydromechanik, 16. bis 17.3.2000,* S. 57-67, Dresden, 2000.