Paper 110 – Technical-biological river bank protection – a contribution to the ecological improvement of the banks of Federal waterways in Germany – First experiences from a field test along the River Rhine

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ABSTRACT: Against the background of the EC Water Framework Directive the significance of ecological aspects in all development and maintenance activities on German Federal waterways is steadily rising, particularly with regard to improvements e. g. in the structural diversity of the watercourses and thus in the living conditions of plants and animals in the rivers themselves and along their banks. In a joint research effort, the German Federal Institute of Hydrology (*BfG*) and the German Federal Waterways Engineering and Research Institute (*BAW*) want to study the effective ecological potential of riverbank construction systems using plants or combinations of plants and technical structures in a test stretch along the River Rhine. The project also comprises a long-term monitoring programme of technical, vegetational, and faunistic surveys.

1 INTRODUCTION

In recent years the scope of activities of the Federal Waterways and Shipping Administration (*WSV*) in Germany has widened beyond the management of the Federal waterways under purely navigational aspects and the preservation of the drainage function to include also ecological objectives of the rivers ("*wasserwirtschaftliche Unterhaltung*"). International and national legislation like the EC Water Framework Directive (EC WFD), the German Water Act (*WHG*), and the Federal Nature Conservation Act (*BNatSchG*) demand the pursuit of such additional aims as the conservation, enhancement, and support of sensitive habitats in and along watercourses, the preservation of ecological functions, and the improvement of the physical structure of water bodies. On the Federal waterways, this means above all the improvement of the riparian structural diversity and quality regarding the living conditions of plants and animals in the water and on the banks, including an increase in the diversity of species living there.

Since 2004, the German Federal Waterways Engineering and Research Institute (*BAW*) and the German Federal Institute of Hydrology (*BfG*) have been cooperating in the joint research and development project „Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways", setting the focus on the testing of technical-biological methods of securing embankments as an alternative to purely technical engineering methods with view to the stability and ecological potential of the banks.

Part of this project is the construction of a test reach on the River Rhine near the town of Worms, where technical-biological embankment systems are currently on trial. The purpose is the practical testing of new bank-protection systems and improvements in the physical structure of the banks on a very busy navigable waterway with widely varying water levels. A long-term monitoring programme will gather experiences with the technical and ecological effectiveness of the new embankment systems.

2 THE NEED FOR TECHNICAL-BIOLOGICAL BANK PROTECTION SYSTEMS

2.1 *The present situation on Federal waterways*

In order to prevent erosion and other negative impacts of hydraulic loads induced by navigation or flooding on the banks of German Federal waterways, they are usually protected by technical revetments such as rip-rap.

These banks are often poor in their physical diversity, with the consequence that important habitats for plants and animals are lacking in the transition zone between land and water and that the natural zoning of the banks and the diversity of species living there are lost (Figure 1).

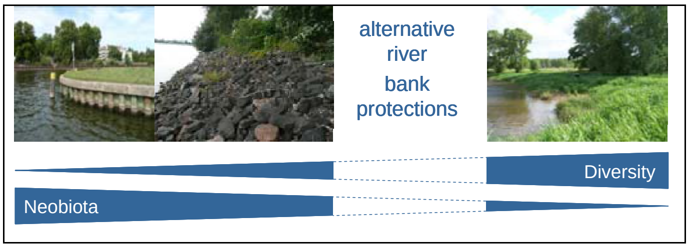

Figure 1: Technical bank revetments (on the left) are often inhabited by a higher portion of invasive alien species (neobiotics) than near-natural banks (on the right), where the species diversity is usually high, with options of compromises as combined technical-biological bank protection (centre).

2.2 *Ecological and legal requirements*

Since the EC Water Framework Directive came into effect in 2000, ecological aspects have become more and more important for new construction projects as well as development and maintenance works on German federal waterways.

New legislation on the consideration of the interests of nature conservation calls for rethinking in matters of river-bank design. This means primarily that in waterway development and maintenance the options of near-natural technical-biological bank protection must be taken into consideration. However, when the above-mentioned ecological targets are attained, the stability of the banks under hydraulic stress and the safety and ease of navigation must be preserved.

Although considerable progress has been made over the past few years in the systematic scientific study of technical-biological bank-engineering methods regarding their functionality, effectiveness, applicability, maintenance and repair (e.g. Begemann & Schiechtl 2000, Florineth 2004, Patt et al. 2011, Hacker & Johannsen 2012), only little practical experience has been gathered so far in their application along waterways. Technical regulations and standards do not exist at all yet, so that uncertainty and arguments about the planning, dimensioning, and the execution of such projects occur frequently.

One of the achievements in the ongoing joint research and development project is the preparation of research-based argumentation-aids and recommendations for the application of combined technical-biological bank protection along navigable inland waterways.

3 FIELD TEST ON THE RIVER RHINE

3.1 *(Pre-) Conditions*

Commissioned by the German Federal Ministry of Transport, Building and Urban Development (*BMVBS*), the planning for a 1-km-long test stretch with several technical-biological bank protection measures on the River Rhine near Worms was initiated. Different measures should be tested under real-life conditions on a highly frequented Federal waterway.

The project was executed under the responsibility of the Federal Waterways and Shipping Administration (*WSV*), represented by the Waterways and Shipping Office (*WSA*) Mannheim.

The test stretch was installed on the right bank of the river (km 440.6 to km 441.6) in the Lampertheim district near Worms. The selected stretch is a very busy waterway with about 120 ships passing here on an average day, making the River Rhine one of the most frequented Federal waterways in Germany.

It is remarkable that the water level can fluctuate enormously at this site: there is a difference of about 6 m between the equivalent low-flow level and the highest navigable water level. The inclination of the bank slopes is usually between 1:2 and 1:3. The original bank protection was rip-rap (layer thickness approx. 60 cm to 90 cm). (See also Paper 111: Fleischer & Soyeaux).

The potential for the settlement of plants and animals was generally poor on this bank before the beginning of the project. Especially the zone between the low and the high water level was nearly bare of any vegetation due to the ship-induced wave impacts. The fish community in the rip-rap lined river stretch was nearly everywhere dominated by invasive alien species (neozoa), while the portion of river-type-specific species indicative of the good ecological quality pursuant to WFD was small. There was no natural zoning of the river banks (pondweed zone, reed zone, softwood and hardwood floodplain), because of the massive stone cover, lacking space, and heavy wave impacts. On the whole, this river stretch was poor in its physical diversity (Fleischer et al. 2012).

3.2 *Technical biological bank protection*

The test stretch was prepared in winter 2011 under optimum hydrological and meteorological conditions (cf. BAW/BfG 2010). It is divided into nine test fields. In four test fields, the rip-rap was removed above the *AZW* water level and was replaced by new technical-biological protection systems (AZW from German "*Ausbauzentralwasserstand*" was defined by the Waterways and Shipping Directorate (WSV) South-West for water levels in the freeflowing River Rhine (river-km 334-640) and was derived from the mean streamflow (ZQ) in a time series. It is usually about 20 cm below the mean water level). In another four test fields, the rip-rap was left in place to protect the bank, but was ecologically upgraded with plants or other structural elements.

In one test field, the bank remained mostly unprotected. Only at the top of the slope sets of willows were inserted to muffle the impact of the tolerated wave dynamics and thus prevent advancing bank erosion towards the hinterland.

On the underwater slope (below the *AZW* water level), the rip-rap was left in place in all sections. When the locations of the alternative protection structures within the test stretch were selected, the hydraulic impacts of navigation, that are decreasing in flow direction because of wider distances between the bank and the fairway, were duly considered (cf. BAW/BfG/WSA-MA 2012).

3.3 *Replacement of the purely technical bank protection by new technical-biological bank protection measures*

In two test fields, willow brush mattresses were installed – once perpendicularly (Figure 2), and once diagonally to the direction of flow – densely packed and fixed with wire, wood beams, and pegs. The brush mattresses were made of native, site-typical willow species (predominantly *Salix purpurea* and *S. alba*) from the nearer surroundings.

Figure 2: Construction of willow brush mattresses (perpendicular to the direction of flow)

In a next test field, reed gabions with pre-cultivated species for two different plant zones were installed from the toe to the middle bank slope (in one half of this test field). Towards the upper margin of the slope and on the remaining half of the test field stone mattresses without plants were spread. They consist of crushed, little stones filled into a polypropylene net. Their thickness is up to 30 cm (Figure 3).

Figure 3: Test field with reed gabions (at the water-line) and stone mattresses on a granular filter layer on the upper slope

In another test field, different filter mats (of sheep wool, synthetic fleece material, or coir) were combined with overlaying, peg-fixed plant mats (Figure 4). A suitable site-typical natural floodplain species composition (predominantly *Carex acuta, C. acutiformis, C. riparia, Festuca arundinacea, Phalaris arundinacea, Iris pseudacorus, Agrostis stolonifera)* was pre-cultivated over one year on plant mats. For several reasons, the vitality of individual plants in the mats was not satisfactory when the test stretch was prepared.

Figure 4: Test field with plant mats arranged on different filter mats

3.4 *Measures for the ecological upgrading of purely technical river-bank protection*

The rip-rap was ecologically upgraded, on the one hand, by willow-branch cuttings, brush and hedge layers as well as living fascines and, on the other hand, by hydroseeding on soil alginate and structural improvement with (dead) wood fascines and groups of individual stones (Figure 5). Here too, native site-typical species were used for seeding and planting, for example hardwood floodplain shrubs (*Cornus sanguinea, Viburnum opulus, Euonymus europaeus, Crataegus monogyna, Acer campestre, Prunus avium*).

Figure 5: (Dead) wood fascines at low-flow water level

In two test fields, a breakwater-like stone wall was built in the river in front of the bank, so that a shallow-water zone protected against hydraulic impacts was created (Figure 6).

Figure 6: Stone wall with shallow-water zone and structural elements in the water and slope zones (dead wood trunks with roots, willow branch cuttings)

In these test fields, the rip-rap continues to protect the stability of the bank. The additional components were inserted purely for ecological reasons. The testing of these designs is of special relevance for waterway reaches, where the protection with rip-rap is indispensable due to heavy hydraulic impacts. Here, the main purpose of the tests is to prove the ecological effectiveness.

3.5 *Monitoring*

Until 2016, a detailed and comprehensive monitoring programme will be performed with technical, vegetational, and faunistic surveys in short intervals (cf. BAW/BfG/WSA-MA 2012, 2013). To assess the ecological effectiveness of the test stretch, river reaches with conventional rip-rap embankments serve as reference.

The objective is to assess the implemented technical-biological bank protection systems regarding

- their technical effectiveness to guarantee bank stability,
- their ecological effectiveness, and
- their maintenance requirements.

The following parameters will be measured, analysed and documented:

- Bank geometry, bank stability	BAW
- Excessive pore-water pressure in the soil of the bank	
- Hydraulic loads on the banks	
- Meteorological influences and impacts of water-level fluctuations	BAW/BfG, third parties
- Vegetation	BfG
- Fauna	
- Maintenance requirements	BAW/BfG/ WSA Mannheim
- Damage and rehabilitation/repair	
- Costs	WSA Mannheim

The monitoring had started already in 2009/2010 with an assessment of biological indicators. In 2012, two vegetation surveys (June and October) and two electro-fishing campaigns (Mai and September) examined ecological issues. The vegetation mapping of the different bank slope zones was based on surveys performed according to the method by Braun-Blanquet (1964). The plant-species inventory of each slope zone was surveyed in full area coverage as completely as possible and the number of individuals and the dominance of the individual species was estimated. Moreover, the vitality of the introduced plants was examined and parameters of the physical structure were determined.

The fish communities in the test stretch and in the reference stretch were determined by going by boat against the flow along the bank using the random -point abundance sampling method. This method is based on an accidental choice of numerous points for fishing in order to gain a representative picture of the unevenly distributed swarms of young fish. Altogether, fish was caught at about 150 points in distances of 0.5 to 3.5 m to the bank. The stunned fishes were identified, sized, and returned into the river. Additionally, parameters such as distance to the bank, water depth, dominant substrate material, and special structures were recorded.

The results of the vegetation and fish surveys in the first year of the study after the completion of the test sites are shown below. They are published in the report BAW/BfG/WSA-MA 2013 (in German language). The final assessment of the tests can be made only after several growth periods.

3.6 *First Results – Vegetation*

In the first year, the banks protected by plant systems had to face sometimes very unfavourable conditions. Several flood events (highest water levels around 1 m below the top of the bank slope) occurred already after the completion of the test site in December 2011 and January 2012, followed by prolonged frost, with short intervals of very low temperatures without protection by snow cover in February 2012. There were also sometimes persistent low-water levels, especially from early February to mid-April at the beginning of the growth season and in the summer months from mid-July to early October. This summer brought more flood events that kept the bank slopes for more than six weeks continuously under water (from *AZW* -0.5 m to *AZW* +1.0 m) stressing the bank structures trough uplift, natural currents, and the hydraulic impacts from passing ships.

This was the time when the bank-protecting plants had to grow sufficient roots to become firmly anchored in the ground. Here, the fixing elements (cross beams, pegs, wires, armour stones) showed their special importance, especially when the protection layers are rather lightweight and may become afloat, as it may happen with willow-brush mattresses, plant mats and filter mats. Such layers do not remain stable in their place under hydraulic impacts and must be fixed to the ground surface so that they have close contact to the soil and can grow roots.

The vitality of the pre-cultivated plants at the time of the installation has also great influence on the successful rooting and growth. The plots, where the pre-cultivated plants were less vital and the systems were lightweight, suffered most losses. Thus, most repairs were needed in the test field with the plant mats, because the anti-erosion geotextiles and the plant mats themselves became damaged, and erosion set in at some places. Finally, the slope had to be covered again with armour stones in the critical zone between low water level and roughly up to *AZW* +1.7 m.

Nevertheless, one can state that the inserted plants have generally resisted the diverse stresses and have grown well so far. Single failures and losses in vitality that occurred, for instance, after prolonged flood events were soon compensated; a fact that indicates that the inserted plant species are well tolerating the prevailing dynamic conditions on these banks.

The good growth of the willow-brush mattresses (Figure 7) initiates the establishment of typical softwood floodplain vegetation.

Figure 7: Growth of willow-brush mattresses (six months after construction)

A site-typical riverbank vegetation of reeds, moisture-loving tall perennial herbs, grass and herb species has established here from the reed gabions and the plant mats. In the first year, dense spontaneous growth emerged besides the inserted pre-cultivated species, consisting mainly of ruderal and nitrogen-indicator vegetation that is typical of construction sites and is less adapted to floodplain site conditions. The natural succession has set in on all test fields, and some species constitute already the transition to the next stage of succession. Except on the test field „plant mats on erosion-control geotextile", where the larger repairs had to be made, the plant-based bank protection systems have well ensured the stability of the bank so far.

The plants that were inserted into the rip-rap fields are also growing well. Single losses of structural elements, like some reed ball plantings, occurred in one test field mainly in the wave-impact zone around the *AZW* water level. Generally, the inserted elements developed into habitat components (woody plants – single or in groups, grass and herb growth) and thus improved the structural diversity of the vegetation on this technical bank stabilization system considerably. Moreover, in the bank zones that are protected by a stone wall, the first Potamogeton species could settle and first reed stands began to evolve (Figure 8).

Figure 8: Growth of reed and tall forbs protected by a stone wall (June 2012).

In the test field that was left without any bank protection the prevailing hydraulic stresses caused – as expected – erosion and slope slips. Whether the hinterland can be sufficiently protected by establishing vegetation-based systems at the transition to the slope top will have to be tested in future studies. In the first year after the removal of the rip-rap, the bank formed here a variety of structures like break-off edges, accumulations of flotsam, and a rich diversity of substrate materials (Figure 9).

Maintenance work was not needed at any of the test fields to date.

Figure 9: Structural diversity (floating wood debris, different substrates (sand, gravel fill, stones), and break-off edges after flooding in the test field left without bank protection.

3.7 *First results – Fishes*

The fish fauna that had been surveyed by electrofishing campaigns in late May and late September 2012, could not reach most of the bank-protection test fields that were built above the *AZW* water level. Exceptions were the test fields where woody structures (especially fascines, tree trunks with roots) had been placed into the water. In comparison with full rip-rap bank covers, where alien species were found to be predominant, these (dead) wood structures were favoured by river-type-specific species indicative of the good ecological quality pursuant to WFD such as perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) which was especially true for fascines (Figure 10). In the shallow-water zone behind the stone wall, swarms of young fish were observed between the (dead) wood trunks with roots.

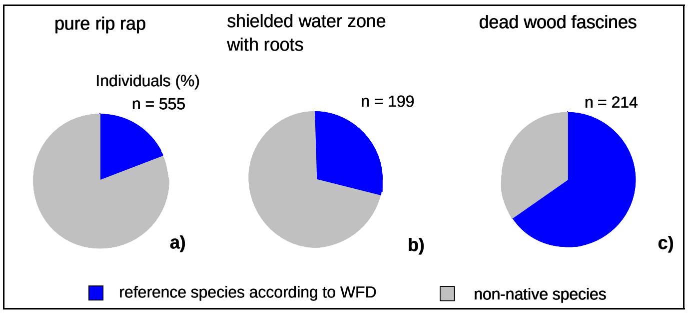

Figure 10: Portions of fish species indicative of good ecological quality according to WFD and invasive (non-native) per test field, (a) reference field with full rip-rap cover, (b) shielded water zone with rip rap and fallen trees with roots, (c) rip-rap with (dead) wood fascines. n= individuals caught by electrofishing in May and September 2012.

4 CONCLUSION

One year after the completion of a test stretch with systems of technical-biological bank protection and the enhancement of the physical bank structures, the results of the first phase of the monitoring programme showed that vegetation-based bank protection systems have generally developed well – even under conditions of hydraulic stress and after repeated flooding. Especially in the critical phase of root-taking and growing, the fixtures have a decisive role, particularly when the vegetation elements themselves, like mats of plant material, are light-weight and tend to float-up. Larger repairs were necessary in the plant-mats plots. At some places armour stones had to be built in again. The stability of the systems could be secured in all test fields so far. The plants are growing well; brief spells of weakened vitality were soon compensated, and the plants recovered. The natural succession is advancing. At present, ruderal and nitrogen-loving species still witness the construction phase, while at some places the transition to the next succession stages is setting in. The installed bank-protection systems have already developed into different habitat components (woody plants – single or in groups, grass and herb growth).

Even the structures that were built-in without having bank-protecting functions initiate secondary positive effects. So it was found that in the submerged (dead) wood fascines, the portion of invasive alien fish species was significantly lower than in waters in front of the rip-rap embankments.

The results of this field-test study on the River Rhine were published on the website (http://ufersicherung.baw.de). This website was initiated by the *BAW* and the *BfG* to offer updated information on technical-biological bank protection and to provide assistance in the application of such methods on other Federal waterways. The results from the ongoing monitoring (until 2016) in the test fields on the River Rhine will be supplemented and published in forthcoming reports.

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