Bundesanstalt für Wasserbau
Kompetenz für die Wasserstraßen

BAW Letter No. 5 – May 2012

G-114 G

Technical-Biological Bank Protection Measures Applied on Inland Waterways – field test on the River Rhine, km 440.600 to km 441.600 (right bank)

1 Objective

In order to prevent erosion and other negative effects due to navigation-induced hydraulic loads or flooding in the long term, the banks of inland waterways are usually protected with technical revetments such as riprap. Since the EU Water Framework Directive (WFD) came into effect in 2000, ecological aspects have become more and more important for new constructions, development and maintenance measures along German federal waterways. Thus, close-to-nature technical-biological bank protection measures should be applied more frequently as an alternative to conventional riprap revetments. However, only little experience has been gathered so far for their use along waterways, and standards do not exist at all. Therefore, the German Federal Waterways Engineering and Research Institute (BAW) and the German Federal Institute of Hydrology (BfG) have been carrying out studies on the hydraulic load-bearing capacity and the ecological effectiveness of technical-biological bank protection measures for several years now. The aim has been to develop application recommendations and dimensioning standards for their use along inland waterways. Besides theoretical analyses, laboratory and model tests, experience gathered from first practical applications on waterways is examined and a field test is performed. In the following, boundary conditions of the field test and its performance are presented.

From September to December 2011, nine different technical-biological protection measures were installed in a 1-km-long test stretch on the right bank of the River Rhine (km 440.600 - km 441.600) in the Lampertheim district near Worms, based on previously gathered knowledge. This selected river stretch is subject to high traffic; about 120 ships travel here daily. Thus, the goal of this field test is to gather experience on the load-bearing capacity of various technical-biological bank protection measures at high-traffic waterways and to assess their technical and ecological effectiveness.

The German Federal Ministry of Transport, Building and Urban Development (BMVBS) approved the test stretch at the Rhine with decree WS 11/52.05.04 on 7 April 2009. A design plan was developed by WSA Mannheim (project management), WSD (Waterways and Shipping Directorate) Südwest, BAW and BfG according to §6, VV-WSV 2107. It was submitted to the BMVBS and approved on 6 October 2010. Based on this design plan, the WSA Mannheim drafted the final planning documents, which were approved by the WSD Südwest in May 2011.

With respect to the application of alternative technical-biological bank protection measures, we

hope to draw important conclusions from this field test at the Rhine, which are transferable to other waterways as well. The technical and ecological assessment of the bank protection measures is based on a comprehensive and detailed monitoring, which is to take place over a period of five years.

2 Boundary conditions

A detailed knowledge of the boundary conditions of the test stretch and its surroundings is the precondition for the assessment and the transferability of the results. The boundary conditions were comprehensively examined by BAW and BfG and documented in a joint report "Errichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein km 440,600 bis km 441,600, rechtes Ufer – Empfehlungen für die Ausführung der Ufersicherungen" (BAW, BfG, 2010), including suggestions for the implementation of the new bank protection measures. Figure 1 shows a cross section at km 441.250, measured in 2009, with the relevant water levels. It is remarkable that the water level fluctuates enormously, i.e. about 6 m between the equivalent low water level (ELWL) and the highest navigable water level (HNWL).

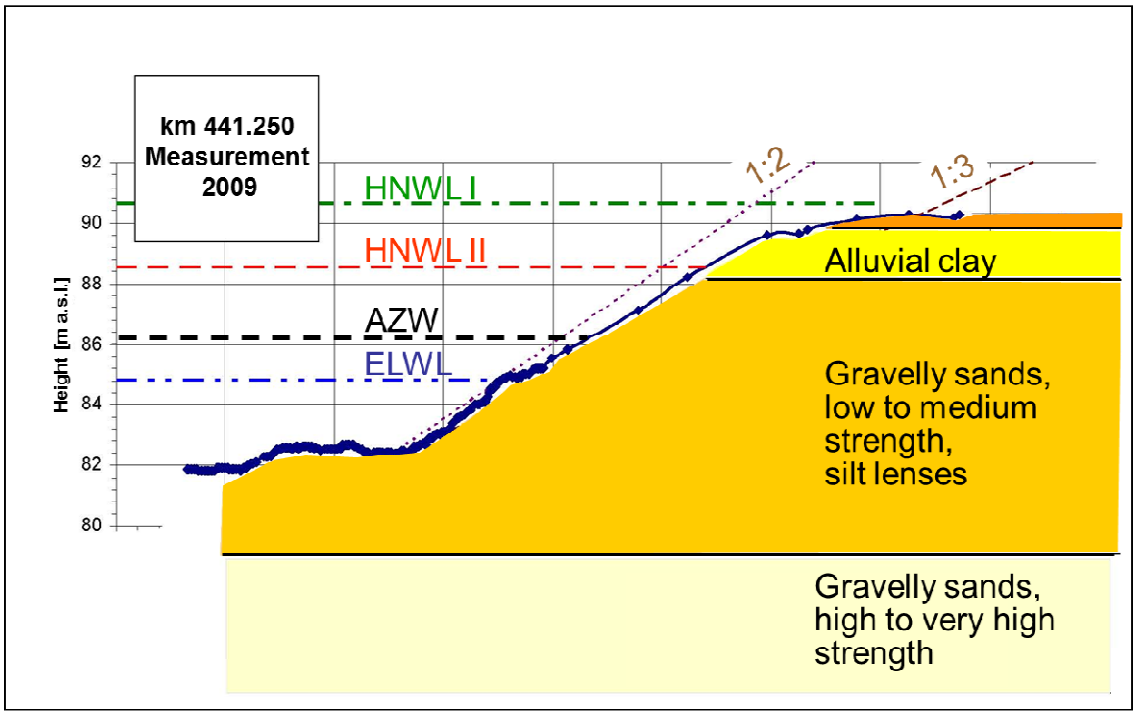


Figure 1: Cross section of bank with soil layers and relevant water levels

Ship-induced hydraulic loading is highest at km 440.600 (undercut slope) and decreases in direction of flow. In the same direction, the distance of the navigation channel to the bank increases. At km 440.600, the distance to the bank is 23 m; at km 441.600 (slip-off slope) it is 140 m. Based on theoretical calculations according to GBB (Principles for the Design of Bank and Bottom Protection for Inland Waterways) (BAW, 2010c), maximum stern waves of 0.40 m (km 441.600) to 1.00 m (km 440.600) are to be expected. On 15 January 2011, during a high water event combined with partial flooding of the adjacent terrain (gauge water level: 89.85 m above sea level), flow velocities of more than 2 m/s were measured (Schmid, 2011).

The inclination of the slopes is usually between 1:2 and 1:3. Below a 1.50 m to 2.50 m thick layer of alluvial clay, mostly gravelly sands are located (Fig. 1). The original bank protection measure was riprap (Fig. 2) made from $LMB_{5/40}$ armour stones (layer thickness approx. 60 cm to 90 cm). Underneath, a mixture of armour stones and soil can be found down to a depth of 60 cm (BAW, 2010a). At certain points, old pavement still serves as a bank protection measure.

Before the new design of the bank, there used to be only little vegetation of low biodiversity (no protected species, mostly thorny berry bushes, species that survive everywhere, invasive woody

plants such as box elder and hybrid poplars), low vegetation zonation and low structural diversity. Due to the relatively thick riprap layer and the high hydraulic loading, the bank's potential to develop vegetation used to be low. Animal diversity was also low, as observed for birds, reptiles, ground beetles, spiders, fish and macrobenthos. Among the terrestrial animals, typical bank species were missing. Instead, species which do not need specific conditions dominated. Among the aquatic animals, invasive species dominated.

Prior to the construction measures, the overall stability of the bank with and without riprap above AZW (about 20 cm below mean water level) was determined for various load cases. As the overall stability does not increase, or increases only slowly, after relevant root growth due to the biological bank protection measures, the bank needs to be sufficiently stable even without protection measures. The same applies to the construction state. Stability could be verified for the existing mean inclination of 1:2.5 (BAW, 2010b). However, the use of heavy vehicles of type SLW 60 (weight: 60 tons) for construction works has to be limited (BAW, 2011b).

Figure 2: Old riprap revetment; picture taken on 22 February 2011

3 Technical-biological bank protection measures

The 1-km-long test stretch was divided up into nine test fields (TF). In five sections, the riprap was removed above AZW. In TF 2, 3, 5 and 7, the riprap was replaced by new technical-biological protection measures; in TF 9, the bank remained mostly unprotected. In four sections (TF 1, 4, 6, 8), the riprap remained to protect the bank but was improved with biological measures. On the underwater slope (below AZW), the riprap remained in all sections.

TF	km	New technical-biological protection measures
1	440.630 to 440.800	Riprap with willow branch cutting, living fascines, brush and hedge layers, stone wall with shallow water zone, dead wood trunks with roots
2	440.820 to 440.860	Willow brush mattresses, installed diagonally to the direction of flow (after removal of riprap)
3	440.880 to 440.950	Willow brush mattresses, installed transversally (after removal of riprap)
4	440.950 to 441.000	Riprap with gravel fill, groups of individual stones, dead wood fascines
5	441.000 to 441.110	Reed gabions and stone mattresses on granular filter, plant mats and hedge layers (after removal of riprap)
6	441.125 to 441.200	Riprap with top soil alginate blend, hydroseeding and individual plants
7	441.200 to 441.375	Pre-cultivated plant mats on different filter mats (sheep wool fleece, geotextile, coir mat), dead wood fascines, vegetation rolls and hydroseeding (after removal of riprap)
8	441.375 to 441.475	Riprap and pavement with reeds, elevation of existing stone wall
9	441.475 to 441.600	Limited free erosion and succession, wooden groyne (tree trunks arranged in the form of a Spanish fan and buried in the slope), stakes on edge of slope (after removal of riprap)

Table 1: Overview of the new bank protection measures (TF = test field) (BAW et al., 2012)

The alternative protection measures were arranged according to the ship-induced hydraulic loading,

which, due to the varying distance of channel and bank, decreases in direction of flow.

Table 1 gives an overview of the 9 test fields and their new protection measures. Detailed descriptions, including photos and ecological objectives can be found in the appendix as part of the joint report of BAW and BfG “Errichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein km 440,600 bis km 441,600, rechtes Ufer – Erster Zwischenbericht: Randbedingungen, Einbaudokumentation, Monitoring” (BAW et al., 2012).

For the technical-biological bank protection measures, which were installed after the removal of the riprap, prefabricated elements such as reed gabions (TF 5), stone mattresses (TF 5) and plant mats (TF 7) were used as well as willow brush mattresses (TF 2 and 3), which were made from local willow branches. The plant mats were pre-cultivated during one growth season. However, due to various reasons, the vitality of the plants was partially not satisfying (TF 5 and TF 7) when the protection measures were installed. How this affects the bank stability will be shown by the monitoring.

If construction methods involve living plants, the bank stabilizes only gradually with increasing plant and root growth. Thus, the initial state is the most critical one. On the one hand, the plants need to be sufficiently attached to the slope. On the other hand, bank stability has to be guaranteed by the sufficient attachment of the plants. The plants are attached to the bank mainly with stakes, cross-bars and bracing wire. The stakes need to be driven into the ground and reach a sufficient depth to absorb the tensile stress that results from submergence (heave) or currents and waves. Hydraulic loads occur immediately after and sometimes during the installation.

The filter stability of the bank may also cause problems in the initial state. Thus, reed gabions and stone mattresses were installed on top of a granular filter (TF 5) (BAW, 2011a). Different filter mats (TF 7) – sheep wool fleeces, coir mats, geotextile fleeces – were installed under the plant mats, however, none of them could meet all the demands – filter stability, strength, permeability to roots, and if possible, biodegradability. Future experience will show which products are suitable. Since the branch cuttings (TF 2 and 3) were installed as closely together as possible and covered with auxiliary brushwood, no additional filter was installed in these test fields.

For the ecological improvement of the riprap revetment, materials such as log branch cuttings, brush and hedge layers as well as living fascines (TF1) and methods such as hydroseeding on alginate (TF 6) were used. Moreover, the bank structure was enhanced through dead wood fascines and individual stones (TF 4). In these three fields, riprap is still the main protection measure, whereas additional elements were only installed for ecological reasons. Testing these measures is important for waterway sections which are subject to high hydraulic loading and still require a riprap revetment. The assessment of these three improvement measures will focus on the ecological effectiveness.

In TF 9, the test field with the lowest hydraulic loads, the riprap was removed and not replaced by any new measure, so that free erosion can be assessed. How is the bank changing due to hydraulic loads and flooding? Will conditions stabilize in the long term? A wooden groyne (tree trunks arranged in the form of a Spanish fan and buried in the slope) guarantees a safe transition to the existing revetment behind the end of the test stretch. The maintenance path is to be protected by willow cuttings.

4 Planning and implementation

The Local Waterways and Shipping Office (WSA) Mannheim commissioned the engineering firms Geitz & Partner GbR and Stowasserplan to develop a detailed planning for the new bank protection measures based on the preliminary planning of BAW and BfG (Stowasser, Geitz 2011). They were also in charge of the construction supervision. In August 2011, the installation of the protection measures was commissioned to the firms Rudolph Garten- und Landschaftsbau GmbH and Grünbau GmbH und Co.KG. For the pre-growing of plant material (reed gabions, plant mats, and individual plants), the firm Ökon Vegetationstechnik GmbH was commissioned ten months prior the construction.

The technical-biological bank protection measures were installed from September to December 2011. A land-based construction method was chosen. Meteorological and hydrological conditions were good. During the construction phase, the water levels of the Rhine were low (cf. Fig. 3), so that the measures could mostly be installed under dry conditions. The construction works were not interrupted or delayed. A quality check on 14 December 2011 confirmed that the measures were installed properly. The acceptance of the entire construction is scheduled for October 2012 after the first vegetation period. Until then, the construction firm is in charge of the maintenance.

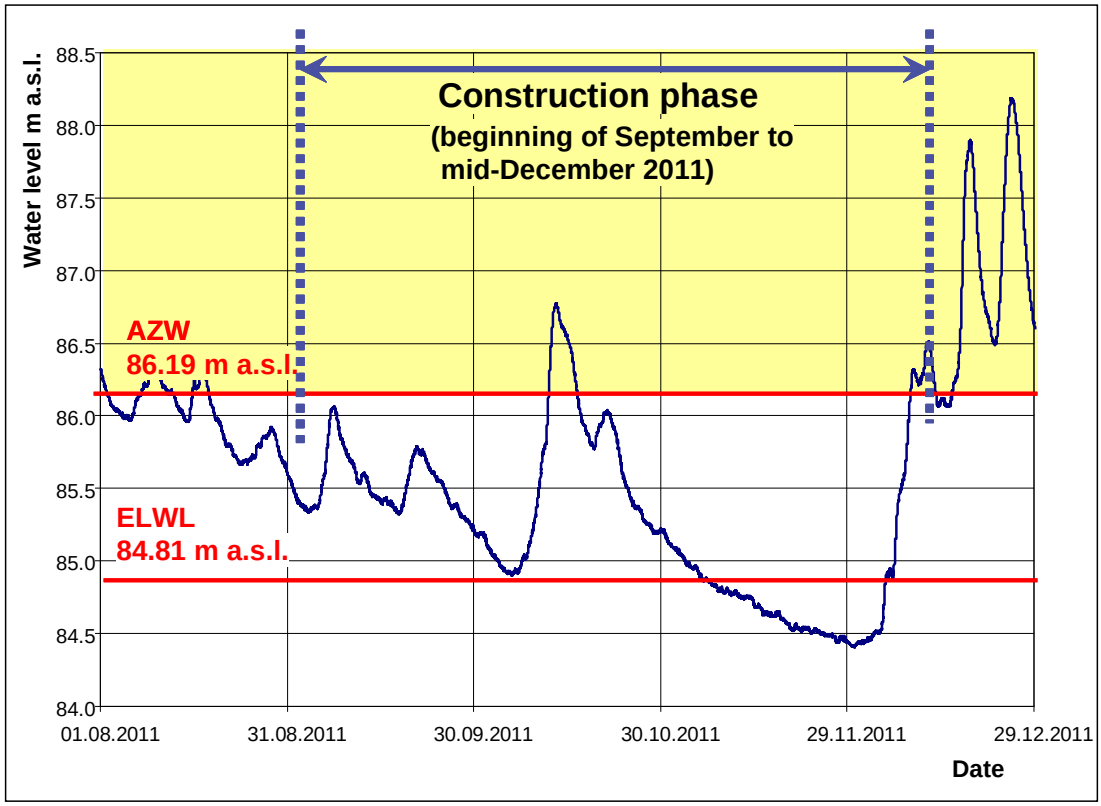


Figure 3: Hydrograph of the River Rhine at the Worms gauge

5 Monitoring

A comprehensive monitoring is planned to analyze the results and subsequently transfer them to other waterways. Its objective is to assess the implemented technical-biological bank protection measures regarding

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

The following parameters will be measured, analyzed and documented:

- bank geometry, bank stability
- excessive pore water pressure in the soil
- hydraulic loads on the banks
- meteorological influences and impact from Rhine water levels
- vegetation
- fauna
- ecology
- maintenance measures
- damage and rehabilitation measures.

Until 2016, a detailed and comprehensive monitoring will be performed at short intervals. To properly assess the biological measures, they need to be observed during at least four or five vegetation periods. Depending on the results in 2016, the tasks and intervals of the monitoring will be redefined.

The monitoring started already in 2009/2010 with the assessment of biological indicators. In the first year of the completion of the test stretch (2012), the focus lies on the experiences which were made during the construction and on the critical initial state of the technical-biological bank protection measures when they are only kept in place by their fixations. The progress of the roots and the vitality of the plants also need to be observed and assessed. Were the attachment measures sufficient? What effect did hydraulic loads and periods of submergence have immediately after the installation? Do the different measures sufficiently protect against surface erosion and provide slope stability even in the initial state? If applicable, for what reasons did rehabilitation measures have to be performed?

To assess the ecological effectiveness of the test stretch, reference stretches with conventional riprap are being observed as well.

The various analyses will be continued starting 2013. It will be assessed whether the roots of the plants, which will have developed by then, can take over the protection of the bank. How do temporary protection measures, such as biodegradable sheep wool fleeces, correlate with root growth without causing temporary stability problems? How does the roughness at the bank change due to increasing plant growth? At the same time, the bank protection measures will be assessed more and more from an ecological point of view based on the development of vegetation and fauna. Can ecological improvement be observed? Can the demands of the EU Water Framework Directive be met?

Simultaneously, hydraulic loads will be measured for different water levels, especially above AZW, as well as soil reactions (excessive pore water pressure) in the test stretch to quantify the load-bearing capacity of the protection measures. Important boundary conditions such as water levels of the Rhine and meteorological data will be continuously documented.

All data are documented in annual progress reports. Detailed evaluations of the technical-biological bank protection measures regarding bank protection and ecology will not be possible until 2016, after several vegetation periods. The same applies to the maintenance of the measures.

6 Outlook

From the analyses and assessments of the test stretch, we expect to draw valuable conclusions on how technical-biological bank protection measures can be implemented on large rivers such as the Rhine, but also on waterways in general. The different bank protection measures tested in this project are assessed, amongst others, regarding their installation conditions, initial and long-term load-bearing capacity, construction and maintenance costs and ecological effectiveness. Based on this and other experiences, e.g. from the test stretch Stolzenau on the River Weser (BAW, 2011c), a smaller, impounded river, as well as on results from laboratory and model tests and theoretical analyses, recommendations will be developed for future projects.

As a first step, we intend to publish specification sheets with the results of the measures which have so far been tested on our website (http://ufersicherung.baw.de/de/index.html). The website was initiated a few years ago by BAW and BfG to continuously offer profound information on close-to-nature technical-biological bank protection measures and provide assistance with further applications on German federal waterways.

7 Literature

BAW (2010a): Versuchsstrecke am Rhein, km 440,600 bis km 441,600, rechtes Ufer; Untersuchungen vor Ort zum vorhandenen Deckwerk am 14. April 2010 (BAW note, 26 July 2010)

BAW (2010b): Versuchsstrecke Rhein, km 440,600 bis km 441,600, rechtes Ufer; Studie zur Gesamtstandsicherheit der Uferböschung im Bereich der Versuchsstrecke, (BAW letter, 7 December 2010) (Az.: 2410/A39520410151)

BAW (2010c): Grundlagen zur Bemessung von Böschungs- und Sohlensicherungen an Binnenwasserstraßen, 2010, available at http://www.baw.de/de/die_baw/publikationen/merkblaetter/index.php.html

BAW (2011a): Versuchsstrecke Rhein, km 440,600 bis km 441,600, rechtes Ufer; Dimensionierung Kornfilter für Versuchsabschnitt 5, (BAW letter, 15 March 2011) (Az.: 2410/A39520410151)

BAW (2011b): Versuchsstrecke Rhein, km 440,600 bis km 441,600, rechtes Ufer; Ergänzende Untersuchungen zur Gesamtstandsicherheit der Uferböschung im Bereich der Versuchsstrecke unter Berücksichtigung einer Verkehrslast, (BAW letter, 27 July 2011) (Az.: 2410/A39520410151)

BAW (2011c): Untersuchungen zu alternativen technisch-biologischen Ufersicherungen an Binnenwasserstraßen (Gemeinsames FuE-Projekt der BAW und BfG), Ergebnisse aus der Versuchsstrecke Stolzenau an der Weser, km 241,550 – 242,300, rechtes Ufer; (BAW Letter 1/2011)

BAW, BfG (2010): Errichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein km 440,600 bis km 441,600, rechtes Ufer - Empfehlungen für die Ausführung der Ufersicherungen, 7. Mai 2010

BAW, BfG, WSA (2012): Errichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein km 440,600 bis km 441,600, rechtes Ufer – Erster Zwischenbericht: Randbedingungen, Einbaudokumentation, Monitoring, 25. Januar 2012

Schmid (2011): Bericht zu den hydraulischen Untersuchungen auf dem Rhein bei HW im Bereich Rhein-km 440,600 bis km 441,600, Messungen vom 15. Januar 2011, Ingenieurbüro Schmid Kapsweyer, 19. April 2011

Stowasser, Geitz (2011): Errichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen; Rhein km 440,600 bis km 441,600, rechtes Ufer – Ausführungsplanung, 21. Juni 2011

Abbreviations:

BAW:
Bundesanstalt für Wasserbau (Federal Waterways Engineering and Research Institute)

BfG:
Bundesanstalt für Gewässerkunde (Federal Institute of Hydrology)

WSA:
Wasser- und Schifffahrtsamt Mannheim (Local Waterways and Shipping Office Mannheim)

Dipl.-Ing. Petra Fleischer
Federal Waterways Engineering
and Research Institute
Geotechnical Engineering Department
Earthworks and Bank Protection Section
Phone: +49-(0)721-9726-3570
Fax: +49-(0)721 9726-4830
E-Mail: petra.fleischer@baw.de

Dr.-Ing. Renald Soyeaux
Federal Waterways Engineering
and Research Institute
Geotechnical Engineering Department
Earthworks and Bank Protection Section
Phone: +49-(0)721 9726-3650
Fax: +49-(0)721 9726-5740
E-Mail: renald.soyeaux@baw.de

Dr. rer. nat. Meike Kleinwächter
Federal Institute of Hydrology
Ecology Division
Fauna and Ecology Department
Phone: +49-(0)261 1306-5954
Fax: +49-(0)261 1306-5152
E-Mail: kleinwaechter@bafg.de

Dipl.-Biogeogr. Katja Schilling
Federal Institute of Hydrology
Ecology Division Vegetation Studies,
Landscape Management Department
Phone: +49-(0)261 1306-5975
Fax: +49-(0)261 1306-5152
E-Mail: schilling@bafg.de

Appendix: Description of the bank protection measures and their ecological objectives

Test field 1: Riprap with willow branch cuttings, living fascines, brush and hedge layers, stone wall with shallow water zone, dead tree trunks with roots (Rhine-km 440.630 to 440.800)

Bank protection:
Riprap remains
Ecological improvement through:

- Willow branch cuttings
- Living fascines (various willow species)
- Hedge layers (native woody plants)
- Brush layers (various willow species)
- Stone wall
- Dead tree trunks with roots

Ecological objective:

- Enhance structural diversity and promote flora and fauna
- Promote native woody plants
- Create protected shallow water zone for aquatic fauna
- Promote animals with wood habitats (e.g. birds and insects)

Test field 2: Removal of riprap, willow brush mattresses with branches orientated diagonally to the direction of flow (Rhine-km 440.820 to 440.860)

Bank protection:
Removal of riprap, spreading out of willow brush mattresses on the bank with branches orientated diagonally to the direction of flow of the Rhine, hedge layers at the upper edge of the slope

Ecological objective:

- Enhance structural diversity and promote flora and fauna
- Promote native woody plants
- Prevent settlement of invasive species
- Promote animals with wood habitats (e.g. birds and insects.)

Test field 3: Removal of riprap, willow brush mattresses with branches orientated transversally to the direction of flow (Rhine-km 440.880 to 440.950)

Bank protection:
Removal of riprap, spreading out of willow brush mattresses on the bank with branches orientated transversally to the direction of flow of the Rhine

Ecological objective:

- Increase structural diversity and promote flora and fauna
- Promote native woody plants
- Prevent settlement of invasive species
- Promote animals with wood habitats (e.g. birds and insects.)

Test field 4: Riprap with gravel fill, groups of individual stones, dead wood fascines

Bank protection:
Riprap remains
Ecological improvement through enhancement of material and structure:

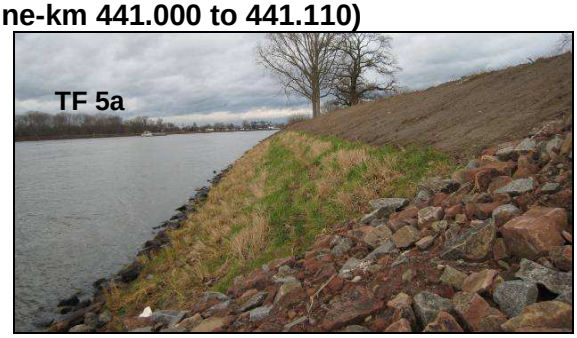
- Gravel fill
- Groups of individual stones
- Dead wood fascines reaching into the water

Ecological objective:

- Enhance conditions for natural succession
- Create habitats for aquatic and terrestrial fauna

Test field 5: Removal of riprap, installation of reed gabions, stone mattresses, plant mattresses and hedge layers (Rhine-km 441.000 to 441.110)

Bank protection:
Removal of riprap
TF 5a: Reed gabions composed of various species in lower slope area, soil-covered stone mattresses in upper slope area
TF 5b: Stone mattresses, combined with plant mattresses in lower slope area and covered with soil in upper slope area, hedge layers on upper edge of slope
All measures installed on granular filter



Ecological objective:

- Initiate bank vegetation appropriate to the habitat (reed, grass species typical of hardwood and softwood floodplain forests, woody plants typical of hardwood floodplain forests)
- Enhance conditions for natural succession
- Enhance structural diversity to promote flora and fauna

Test field 6: Riprap with top soil alginate blend, hydroseeding and individual plants (Rhine-km 441.125 to 441.200)

Bank protection:
Riprap remains
Ecological improvement through:

- Pumping of top soil alginate blend into cavities of riprap
- Hydroseeding (native grass species)
- Local planting of reed bales into riprap at AZW

Ecological objective:

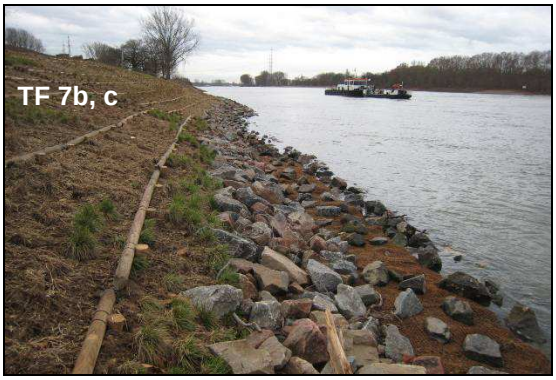
- Initiate bank vegetation appropriate to the habitat (reed, grass species)
- Enhance conditions to promote natural succession
- Promote fauna (especially animals living in reed habitats and soil fauna) and flora

Test field 7: Removal of riprap, installation of different filter mats (sheep wool fleece, geotextile, coir) and plant mats, dead wood fascines, vegetation rolls, hydroseeding (Rhine-km 441.200 to 441.375)

Bank protection:
Removal of riprap
TF 7a: Reed mats (common reed) in lower and middle slope area on sheep wool fleece (7a1) or geotextile (7a2), dead wood fascines in middle slope area, coir-covered hydroseed in upper slope area
TF7b and 7c: Vegetation rolls at AZW (coir (TF7b) or sheep wool (TF7c) envelope), plant mats from AZW +0.5 m to upper edge of slope on geotextile (TF7b) or sheep wool fleece (TF7c) in lower slope area, on coir mat in upper slope area (TF7b and c).

Ecological objective:

- Initiate bank vegetation appropriate to the habitat (reed, grass species)
- Enhance local conditions to promote natural succession
- Create new habitats
- Promote flora and fauna



Test field 8: Riprap and pavement with reeds, elevation of existing stone wall (Rhine-km 441.375 to 441.475)

Bank protection:
Riprap and old pavement remain
Ecological improvement through elevation of stone wall in order to protect existing reeds

Ecological objective

- Promote reed succession and animals living in reed habitats
- Protect bank vegetation and, in case of high water levels, aquatic fauna from ship-induced loads

Test field 9: Removal of riprap, acceptance of free erosion and succession, wooden groyne (tree trunks arranged in the form of a Spanish fan and buried in the slope), log branch cuttings (Rhine-km 441.475 to 441.600)

Bank protection:
Removal of riprap, no installation of new protection measures, log branch cuttings on slope edge to protect maintenance path, wooden groyne (tree trunks arranged in the form of a Spanish fan and buried in the slope) at transition to adjacent bank area

Ecological objective:

- Accept natural bank dynamics to a limited extent
- Promote free succession
- Promote (soil) fauna and species
- Enhance structural diversity
- Promote woody plants on slope edge