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Installation of a Test Stretch with Technical-Biological Bank Protection Measures River Rhine km 440.6 to km 441.6, Right Bank

First Progress Report

Boundary Conditions, Installation Documentation, Monitoring

25.01.2012

Summary

A field test is currently being carried out at the right bank of the river Rhine near Worms from km 440.600 to km 441.600 in order to test different technical-biological bank protection measures under waterway conditions. The German Federal Ministry of Transport, Building and Urban Transportation (BMVBS) approved the test stretch at the Rhine with decree WS 11/52.05.04 on 07 April 2009. A design plan was developed by the Local Waterways and Shipping Office Mannheim (WSA) and approved by the BMVBS on 06 October 2010. The basis for further planning was the joint report of the BAW and BfG "Installation of a Test Stretch with Technical-Biological Bank Protection Measures, River Rhine km 440.6 to 441.6, Right Bank – Recommendations for the Construction of Bank Protection Measures" published on 07 May 2010 [1]. It already describes the different bank protection measures recommended in a detailed manner and documents the boundary conditions in this section of the Rhine. The field test is part of the joint research and development project of the BAW and BfG "Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways" which has been underway since 2004. With the construction of a test stretch at a section of the river Rhine where about 120 ships pass daily, first experiences are to be gained at a waterway subject to high traffic.

In November 2010, the engineering offices Geitz & Partner GbR and Stowasserplan were commissioned to develop further detailed plans and to carry out the construction supervision. The draft of the final design documents No. 2003 submitted by the WSA Mannheim was approved by the Waterways and Shipping Directorate Southwest (WSD) in May 2011. In August 2011, the construction of the test stretch was commissioned to the firms Rudolph Garten- und Landschaftsbau GmbH and Grünbau GmbH und Co. KG. The on-site constructions were completed in mid-December 2011.

The present progress report documents the installed bank protection measures in detail upon completion of construction. Thus, the technical effectiveness with regard to bank protection and the ecological objective for every construction method are explained. In addition, a photo documentary and first installation experiences are available. Furthermore, boundary conditions of the test stretch and the monitoring measures first planned from 2012 to 2016 are described in detail.

The 1-km-long test stretch was divided into nine different test fields. In five fields, the existing riprap was removed and replaced by new technical-biological measures; in one of those fields the bank remained mainly unsecured. In four sections, ecological enhancements were carried out on the slope still secured with armourstones. Hydraulic loads on the bank due to shipping were considered in the selection and positioning process of the alternative construction methods. These loads decrease in the direction of flow as a result of the different bank

distances to the channel (23 m at km 440.600 and approx. 140 m at km 441.600). The strongly fluctuating water levels at the free flowing river (6 m difference between ELWL and HNWL) had to be taken into account, too.

The firm Ökon was commissioned to pre-cultivate the necessary plant mats ten months prior to construction. All construction works in the area of the test stretch were land-based. Bank stability increases with plant and root growth for the living construction methods. In the initial state bank stability must be ensured with sufficient securing material. The construction works were completed in about 3.5 months without any interruptions due to the favorable low water levels. The construction firm is responsible for the initial maintenance of the completed construction (e.g. necessary irrigation) until the next growing season (March to October 2012).

A wide-ranging monitoring is planned in order to evaluate the results and apply them to other waterways at a later point in time. The aim is to assess the tested technical-biological bank protection measures with regard to

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

The following is analyzed and documented in detail: bank stability, hydraulic bank loads, climate impacts, vegetation, fauna, maintenance measures, damages or necessary repair works. An intensive monitoring is planned until 2016, afterwards the content and intervals of further monitoring measures of the test stretch must be decided based on the then available results.

The next progress report will consist of first monitoring results, especially of first experiences on the growth of the vegetative construction methods. A prerequisite is the evaluation during the next growing season until fall 2012. In addition, the construction costs for the single test fields are documented and evaluated. This is not possible until completion of the initial maintenance measures in October 2012. The next report will, therefore, be submitted at the beginning of 2013.

In the following a brief overview of all the nine test fields is provided within this summary.

Test field 1: Riprap with willow branch cuttings, living fascines, brush and hedge layers, stone wall with shallow water zone, dead tree trunks with root plates (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:

- initiate vegetation with habitat-adapted woody plants
- establish protected bank section with shallow water zone
- enhance structural diversity
- promote fauna and flora

Test field 2: 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 top of the slope

ecological objective:

- initiate vegetation with habitat-adapted woody plants
- prevent settlement of invasive species
- enhance structural diversity
- promote flora and fauna

Test field 3: 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:

- initiate vegetation with habitat-adapted woody plants
- prevent settlement of invasive species
- enhance structural diversity
- promote fauna and flora

Test field 4: Riprap with gravel fill, groups of individual stones, dead wood fascines (Rhine-Km 440.950 to 441.000)

bank protection:

riprap remains
ecological improvement through enhancement of material and structure:
- gravel fill
- groups of individual stones
- dead wood fascines reaching into water

ecological objective:
- enhance local conditions to promote 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, plant mattresses in lower slope area, upper slope area covered with soil, hedge layer on top of slope
all measures installed on mineral granular filter

ecological objective:
- initiate habitat-adapted bank vegetation (reeds, grass species typical of softwood and hard-wood alluvial forests, woody plants typical of hardwood alluvial forests)
- enhance local conditions to promote natural succession
- create habitats

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

bank protection:

riprap remains
ecological improvement through:
- pumping of topsoil alginate blend into cavities of riprap
- hydroseeding (native grass species)
- local planting of reed bales into riprap at AZW

ecological objective:
- initiate habitat-adapted bank vegetation (reeds, grass species)
- enhance local conditions to promote natural succession
- promote 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 hydroseeding in upper slope area
TF7b and 7c: vegetation rolls at AZW (coir (TF 7b) or sheep wool (TF 7c) envelope, plant mats from AZW +0.5 m to top of slope on geotextile (TF 7b) or sheep wool fleece (TF 7c) in lower slope area, on coir mat in upper slope area (TF 7b and c)

ecological objective:

- initiate bank vegetation appropriate to habitat (reeds, grass species)
- enhance local conditions to promote natural succession
- create new habitats
- promote fauna and flora

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
- protect bank vegetation from ship-induced loads
- promote aquatic fauna

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) as transition to adjacent bank area

ecological objective:

- accept natural bank dynamics to a limited extent
- promote free succession
- promote (soil) fauna
- enhance structural diversity
- initiate vegetation of woody plants on slope edge

Contents

Annexes

1. Motivation

In the landscape conservation area "Hessische Rheinuferlandschaft" (riparian landscape at the Hessian part of the river Rhine) a field test is currently being carried out along the river Rhine near Worms from km 440.600 to 441.600 in order to test various technical-biological bank protection measures under waterway conditions. Nine different technical-biological bank protection measures are, therefore, installed in the district Lampertheim along the right bank of the river Rhine in a 1-km-long test stretch. In five sections, the riprap is completely removed and replaced with alternative measures. In one of those sections, the bank remains mostly unprotected in one section. In four sections, the existing riprap is ecologically improved. The field test is part of the ongoing research and development project of the BAW and BfG "Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways". With the construction of a test stretch at a section of the river Rhine where about 120 ships pass daily, first experiences are to be gained at a waterway subject to high traffic.

The BMVBS approved the installation of a test stretch at the river Rhine with decree WS 11/52.05.04 on 07 April 2009. A design plan was developed by the WSD Südwest, the BAW and the BfG according to § 6, VV- WSV 2107. It was submitted to the BMVBS and approved on 06 October 2010. Based on this design plan, the WSA Mannheim drafted the final design documents, which were approved by the WSD Südwest in May 2011.

The joint report of the BAW and the BfG "Installation of a Test Stretch with Technical-Biological Bank Protection Measures, River Rhine km 440.6 to km 441.6, right bank – Recommendations for the Construction of Bank Protection Measures" from 07 May 2010 [1] is the basis for the construction works. It already describes the different construction methods recommended in detail and documents the boundary conditions in this section along the Rhine. The WSA Mannheim commissioned the engineering firms Geitz & Partner GbR and Stowasserplan to develop a detailed planning [2] and to supervise the construction works. In August 2011, the installation of the protection measures was assigned to the firms Rudolph Garten- und Landschaftsbau GmbH and Grünbau GmbH und Co. KG. The construction works were completed in mid-December 2011.

Important insights on the application of alternative technical-biological bank protection measures along the river Rhine are expected as a result of the field test, but also on the application at other waterway sections. A detailed and comprehensive monitoring is planned and will form the basis for the technical and ecological assessment of the various bank protection measures. On the one hand, this includes a pre-monitoring, i.e. studies that were carried out for comparative purposes before the redesign, and on the other hand, a post-monitoring which is initially planned for a period of 5 years after the completion of construction works. Afterwards monitoring measures will be carried out at greater time intervals. In 2016, the new intervals will be determined on the basis of the results acquired until then.

This 1st progress report includes a short summary of the boundary conditions in the area of the test stretch, a detailed documentary and description of the completed test fields 1 to 9 as well as a comprehensive monitoring program for 2012 to 2016.

2. Boundary Conditions

The boundary conditions in the area of the test stretch were extensively examined by the BAW and BfG in advance and documented in the joint report "Installation of a Test Stretch with Technical-Biological Bank Protection Measures, River Rhine km 440.6 to km 441.6, right bank – Recommendations for the Construction of Bank Protection Measures, 07 May 2010" [1]. Annex 1 depicts the most important boundary conditions in an overview. As an example, figure 1 shows a bank cross section at km 441.250 measured in 2009 with the decisive water levels of the Rhine. The water level AZW lies about 20 cm below mean water level (MW) due to the hydrograph (Worms gauge) of the last 10 years. For comparison the slope inclinations 1:2 and 1:3 are also depicted.

In April 2010, further examinations were carried out on-site in order to evaluate the existing riprap and especially to determine the layer thickness of the riprap as a basis for further plans. It was thus determined that a conglomerate of stones and in-situ soil exists even below the determined layer thickness of 60 to 90 cm, up to the explored depth of 1.20 m below the top of the riprap [5].

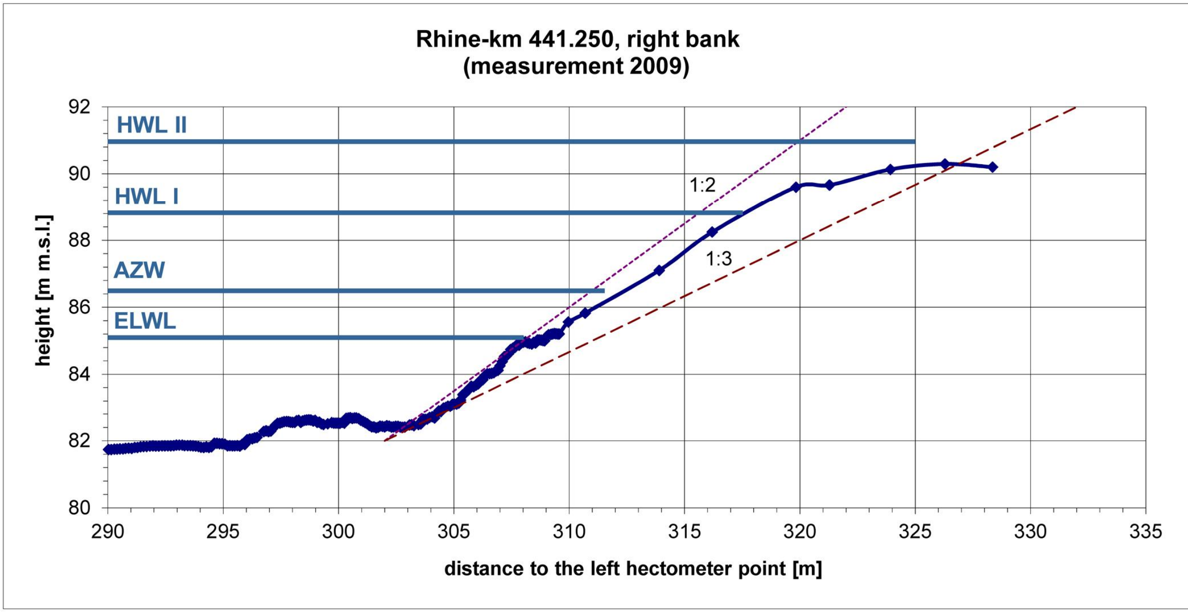

Figure 1: Bank cross section at km 441.250 with decisive water levels of the river Rhine

Additionally, the BAW performed calculations to determine the overall stability of the bank slope in the initial state with riprap and after the removal of riprap above AZW for different loading cases prior to the construction works. As the overall stability is not given at the moment and only increased in the long term through the vegetative bank protection measures after the corresponding root growth it must be sufficiently ensured without any protection measures, too. This verification was provided for the existing mean slope inclination of 1:2.5 without considering an imposed load [3]. As a result of additional calculations on the construction state, limitations with regard to admissible slope inclinations during construction and the use of a HGV 60 (total load: 600 kN) were provided [4].

3. Installation Documentation

3.1 Basic Findings

The engineering firms Rudolph Garten- und Landschaftsbau GmbH and Grünbau GmbH und Co. KG installed the technical-biological bank protection measures from September to December 2011. Land-based construction methods were chosen. The meteorological and hydrological boundary conditions for the installation were very good. During the construction period, the water levels of the Rhine were low (see Figure 2) so that the measures could mostly be installed under dry conditions. The construction works were not interrupted or delayed.

Figure 3 depicts the construction periods for the individual test fields. The riprap in the test fields 2, 3, 5 and 7 was generally removed close to the date of installation of the new bank protection measures in order to leave the slope unprotected for a short period of time only. Prior to the construction works all areas, in which measures were carried out within the ground, were systematically examined on existing explosive ordnance.

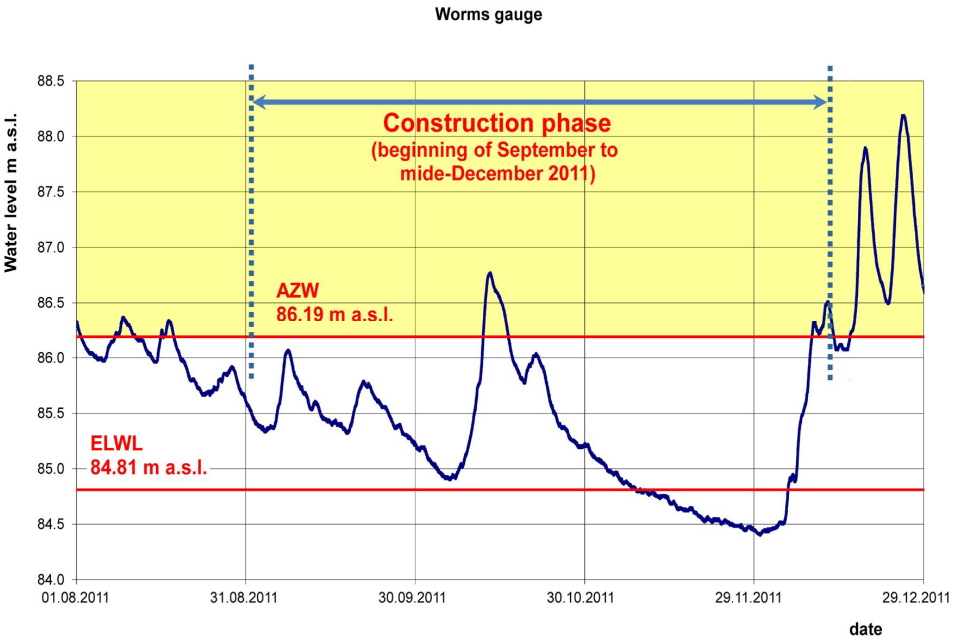

Figure 2: Hydrograph of the river Rhine at the Worms gauge (August to December 2011)

The transitional areas between the different test fields were separately established after completion of the test fields especially focusing on smooth and safe transitions.

The WSA Mannheim set up signs for ships during the construction period. Ships had to adapt their way of travelling to avoid wave action at the bank. However, it was not controlled whether or not masters actually adhered to these instructions.

Construction timetable Test stretch river Rhine km 440.600 to km 441.600																				
measure	**August**				**September**			**October**				**November**				**December**				
	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
setup of construction site			■	■																
protection measures / gravel road				■	■															
pruning / mowing			■	■																
TF 9 removal					■	■														
TF 8 construction of stone wall					■															
TF 4 dead wood fascines / stones / gravel								■		■	■		■							
TF 9 wooden groyne / riprap												■		■						
TF 7 removal						■	■													
TF 7 reed mats / reed bales / dead wood fascine											■	■	■	■						
TF 5 removal							■													
TF 5 stone mattresses / reed gabions / reed mats									■	■			■	■						
TF 5 hedge layers														■						
TF 6 reed bales								■	■											
TF 6 top soil alginate blend / hydroseeding						■		■	■		■									
TF 1 construction of stone wall											■			■						
TF 1 living fascine / willow branch cuttings / planting															■	■				
TF 9 log branch cuttings														■						
TF 2 removal											■	■								
TF 2 installation of willow brush mattresses / hedge layers													■	■	■					
TF 3 removal												■	■							
TF 3 installation of willow brush mattresses														■	■					
TF 9/6/7/5/1-3/4 site clearance														■	■					
removal / maintenance path construction															■					

Figure 3: Overview of construction periods

3.2 Technical-Biological Bank Protection Measures in Detail

3.2.1 Test field 1: Riprap with willow branch cuttings, living fascines, brush and hedge layers, stone wall with shallow water zone, dead tree trunks with root plates (Rhine-Km 440.630 to 440.800 – 170 m TF-length)

3.2.1.1 Description

This area at the upstream beginning of the test stretch is subject to the largest hydraulic loads as an undercut slope prevails and the navigation channel runs very closely to the bank. The existing riprap remains as bank protection. It consists of loose armourstones of the stone size class $LMB_{5/40}$ /TLW, 2003/ and has a layer thickness of approx. 60 to 80 cm without an additional filter layer. The test field was ecologically improved through

- willow branch cuttings
- living fascines
- brush layers
- hedge layers

Not only willow branch cuttings and living fascines, but also brush and hedge layers were installed in single rows in the dip direction of the slope in a total of 17 pits with a depth of 0.80 to 1.20 m. These pits were excavated within the existing riprap with a length of 7.50 to 8.00 m, a width of 2 m and at a distance of approx. 5 m. The pits were divided into 3 sections of each 2.50 m length. Hedge layers were installed in the upper slope area, willow branch cuttings, living fascines and brush layers were alternately installed in the middle and lower slope area. Prior to the installation of plants, sands of a layer thickness of approx. 50 cm were filled into the excavated pits first, in order to ensure good contact to the subsoil. The willow branch cuttings were installed into the in-situ soil below the riprap after a predrilling. The height of the upper end of the cuttings above the riprap varied in order to examine the influence of different flooding heights. The plant material was silt up (willow branch cuttings) or covered with fine grains (hedge and brush layers, living fascines) after installation. The pits were then filled with armourstones again to guarantee area wide bank protection.

To improve the conditions for aquatic fauna, a stone wall was built as an extension of the bank line. This measure was possible as the bank is set back a little in this test field. Thus a narrow shallow water zone with upstream and downstream connection to the Rhine was developed due to the wall, in which a water depth of about 2 m is obtained at AZW. Ship-induced loads such as wave impact and current can be reduced by the wall in the area of the shallow water zone. Additionally, three dead tree trunks with root plates were installed in the lower slope area at distances of approx. 25 m inclined riverward. These can be populated by macrozoobenthos and offer fish hiding places as well as potential spawning and feeding habitats. Table 1 presents details on the single elements. Figure 4 shows excerpts of the detailed design [2].

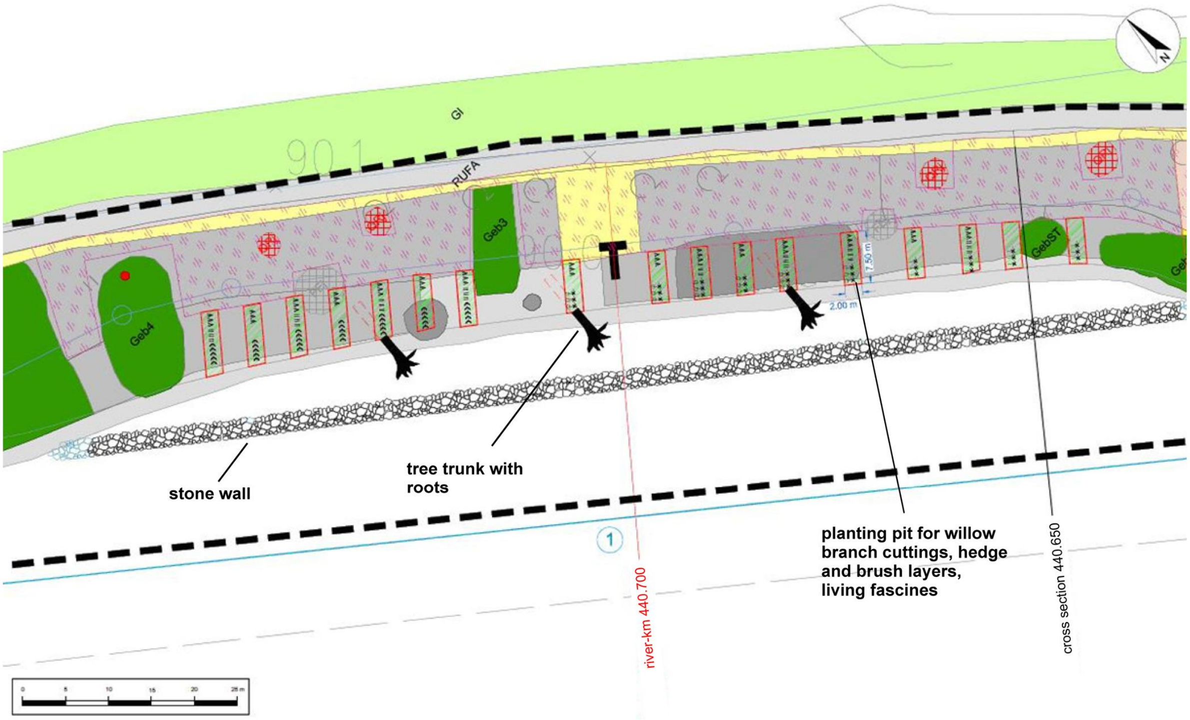

Figure 4: Graphic overview of test field 1 (modified according to [2])

Tab. 1: Details test field 1

element	plant species/ material	dimensions
willow branch cuttings	white and basket willow (living willow branches grown as straight and as consistently as possible)	diameter: 10 to 12 cm length: min. 1.80 to 2.00 m embedment depth: approx. 1.30 to 1.60 m head of cutting 20 to 40 cm / 1.30 m above the upper edge of the riprap
living fascines	of min. 70% living, i.e. shoot-forming willow branches (purple, basket or almond willow), and of max. 30% dead branch material, i.e. non shoot-forming branch material from deciduous woody plants	diameter: 2 to 5 cm (single branches of living material) diameter of total fascine: 45 to 55 cm along the entire length length: 2 to 4 m (single branches of living and dead material) length of total fascine: 5 m
brush layers	white willow, hybrid crack-willow, silky-leaf osier, purple willow (living willow branches grown as straight and as consistently as possible)	diameter: 2 to 4 cm (single branches) length: min. 70 to 100 cm
hedge layers	hawthorn, field maple, common hazel, dogwood, spindle tree, guelder-rose (bare rooted young woody plants)	length: 60 to 100 cm
stone wall	armourstones of $LMB_{5/40}$	approx. 2 m wide inlet and outlet openings (at AZW) top: AZW + 0.5 m
dead tree trunks	native deciduous woody plants (e.g. beech) with extensive root plates	trunk diameter: 80 to 120 cm root diameter: 1.50 to 2.00 m length: 5 to 6 m

3.2.1.2 Objective

In general:

- examine possibilities to ecologically improve an existing loose riprap by increasing the structural diversity for those waterway sections, in which technical bank protections are indispensable due to high hydraulic loads
- test various possibilities of subsequent planting of a riprap with woody plants
- test possibilities to improve the conditions for aquatic fauna in bank areas with high hydraulic loads through a riverward stone wall and dead wood trunks

Bank protection:

- the existing riprap continues to ensure the bank protection
- all other measures serve as ecological enhancements of the bank area. The installed willow branch cuttings as well as brush and hedge layers additionally increase the bank stability for the long term after root growth in the subsoil
- constructing a riverward stone wall reduces the wave load on the bank area

Ecological enhancement:

- initiate habitat-adapted vegetation of woody plants (woody plants in the alluvial softwood and hardwood forest zone)
- create a protected bank area with natural structure elements for aquatic fauna
- promote animals preferring woody plants (e.g. birds and insects)

3.2.1.3 Construction Period

From week 43 to 48 (24.10. to 30.11.2011)

3.2.1.4 Photo Documentary

The pictures in figures 5 and 6 show the completed test field 1, taken on 14.12.2011 at about AZW (Worms gauge: 86.19 m a.s.l.). The shallow water zone that was developed is clearly visible. Within this zone the flow velocity is reduced. The root plates of the installed dead tree trunks lie below the water level and are therefore available as habitat and structural elements for the aquatic fauna. The pictures of figures 7 and 8 were taken at the end of the construction period on 29.11.2011. At this point in time the river Rhine had extremely low water levels (see Figure 2). A water level of 84.44 m a.s.l. was measured at the Worms gauge, i.e. a water level of approx. 40 cm below ELWL. Details are depicted, such as the log branch cuttings (Figures 5 and 6) and the installation of brush and hedge layers (Figure 8).

Figure 5: Finished test field 1 with shallow water zone (picture taken on 14.12.2011 at about AZW)

Figure 6: Log branch cuttings in the completed test field (picture taken on 14.12.2011 at about AZW)

Figure 7: dead tree trunk with visible root plate (picture taken on 29.11.2011 at about ELWL-40cm)

Figure 8: Installation of brush and hedge layers (picture taken on 29.11.2011 at about ELWL-40cm)

3.2.1.5 First Installation Experiences

Placing individual log branch cuttings in an existing loose riprap of 60 to 80 cm thickness is not possible without damaging the log branch cuttings. Thus, it was already determined in the planning process that the log branch cuttings are to be installed in previously excavated pits in the riprap. Since a conglomerate of soil and stones of a greater layer thickness is in place (see note of the BAW [5]) below the riprap, however, the installation of the log branch cuttings turned out to be problematic nonetheless. In order to sufficiently embed the log branch cuttings in the subsoil, some pre-drillings had to be carried out as a result.

Ordering planting material with an appropriate certificate of origin (native) turned out to be difficult. Despite an early request at the tree nurseries, some changes in the region of origin had to be accepted.

3.2.2 Test field 2: Willow brush mattresses with branches orientated diagonally to the direction of flow (Rhine-Km 440.820 to 440.860 – 40 m TF-length)

3.2.2.1 Description

The existing riprap was completely removed from AZW to the top of the slope between km 440.820 to 440.860 along the river Rhine. The riprap consisted of loose armourstones of the stone size class $LMB_{5/40}$ and had a layer thickness of approx. 60 to 80 cm. The present slope inclination was flattened to 1:3 and the willow brush mattresses were installed with branches orientated diagonally in a 45° angle to the dip direction of the slope.

The willow branches were placed between the previously installed stakes on the slope in layers inclined in the direction of flow so that their thick basal ends are pointing downwards to the river. Several overlapping willow brush mattresses had to be installed due to the slope length of about 12 m. Every layer was buried 1 m deep into the slope at their lower end. The bottom layer of willow branches embeds 1 m into the remaining riprap below AZW as a toe protection. Thus, a transition to the existing revetment is achieved at the same time. In order to improve erosion control the willow brush mattresses were covered with coniferous brushwood up to AZW + 1.7 m in the initial phase. The brush mattresses including coniferous brushwood were secured with crossbars between the stakes and were tied down with wire (see Figure 11). The coniferous brushwood layers were additionally secured with coarse-meshed wire (game fence) (Figure 12). Finally, the brush mattresses were covered with sandy-gravelly material in a layer of approx. 3 cm thickness.

Since willow rods with a diameter of only 1 to 3 cm were installed (as these could be cut in the vicinity) instead of willow rods with a thickness of 3 to 5 cm as demanded in the specifications, a section wide coverage of the slope was not achieved due to only 30 willow rods per running meter. This will probably have a negative impact on erosion stability in the initial state.

At the top of the bank slope hedge layers were installed at the end of the brush mattresses. For this purpose, plants were placed into the pits inclined in an angle of 90° to the slope. Only one third of the plants protruded beyond the slope surface (see Figure 13).

Figures 9 and 10 show excerpts of the detailed design [2]. Details on the single elements are listed in table 2 and 3.

Tab. 2: Details test field 2 – willow brush mattresses (diagonally)

element	plant species / material	details/ dimensions	installation area
willow branches	purple willow (shrubby willow) white willow (willow tree)	diameter: 1 to 3 cm (planned in specifica-tions: 3 to 5 cm) length: 3 to 4 m number: 30 Qty./m orientated diagonally to direction of flow	AZW - 0.5 m to AZW + 1.70 m
	purple willow (shrubby willow) basket willow (shrubby willow and willow tree) white willow (willow tree)	diameter: 1 to 3 cm (planned in specifica-tions: 3 to 5 cm) length: 3 to 4 m number: 30 Qty./m orientated diagonally to direction of flow	AZW + 1.7 m to top of slope
coniferous brushwood	common spruce	length: 1.50 to 2.50 m	AZW to AZW + 1.7 m
stakes	non shoot-forming	diameter: 4 to 6 cm length: 0.80 to 1.00 m number: 1 Qty./m	AZW to top of slope
crossbars	white willow, living material	diameter: 10 to 12 cm	AZW to top of slope
bracing wire	annealed wire for brush mat-tresses coarse-meshed game fence to fix coniferous brushwood	diameter: 3 mm mesh size approx. 10 cm	AZW to top of slope AZW to AZW + 1.70 m
topsoil	gravel available on-site (5/32)		AZW to top of slope

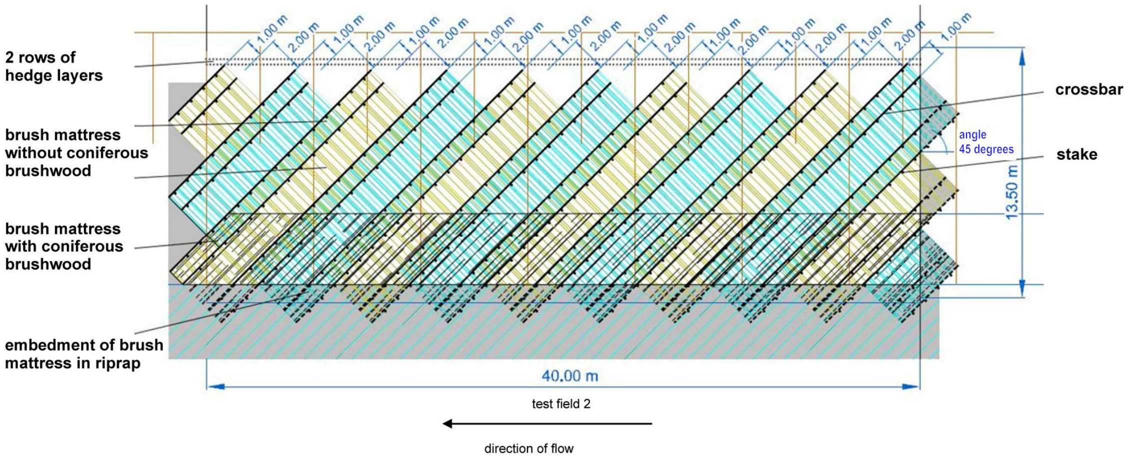

Figure 9: Ground plan test field 2 - willow brush mattresses orientated diagonally (modified according to [2])

Tab. 3: Details test field 2 – hedge layer

element	plant species / material	details/ dimen-sions	installation area
hedge layer	common hazel - seedling common hawthorn - seedling and bare rooted young woody plants spindle tree - seedling and bare rooted young woody plants common dogwood - shrub each in equal proportions	length: 0.60 to 1.00 m number: 3 Qty./m	top of slope

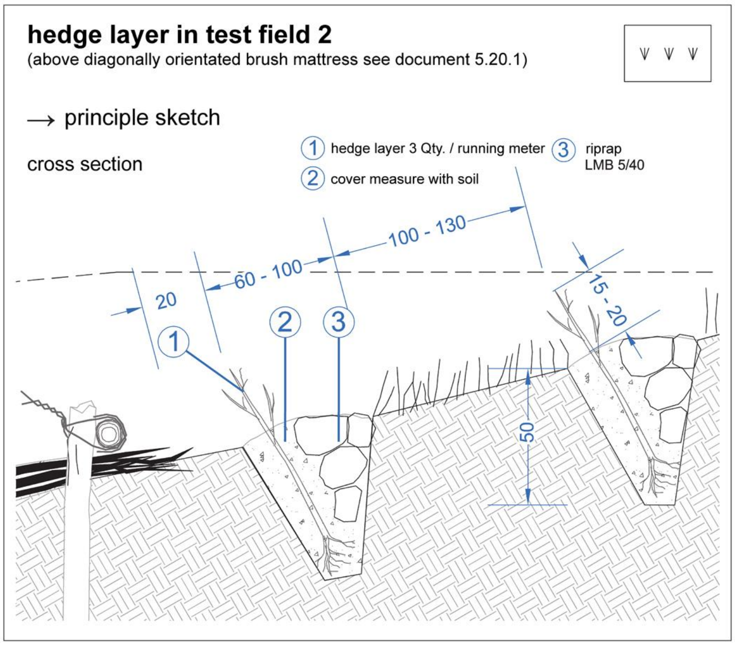

Figure 10: Cross section of test field 2 – hedge layer [2]

3.2.2.2 Objective

In general:

- test willow brush mattresses as bank protection aimed at ensuring sufficient slope stability at waterways subject to ship-induced hydraulic loads

Bank protection:

- in the initial state bank protection and filter stability are ensured through complete coverage of the slope with willow brush mattresses firmly attached to the ground, additional protection is given through planar placement of coniferous brushwood
- sufficient securing which presses the brush mattresses firmly onto the ground, a prerequisite for bank protection in the initial state
- anchoring brush mattresses to the in-situ soil with increasing root growth, increase in shear strength of the soil, increase in slope stability
- mitigation of hydraulic impacts on the slope area with growing willow shoots

Ecological enhancement:

- initiate a habitat-adapted vegetation of woody plants in the alluvial softwood and alluvial hardwood forest zones
- medium- to long-term improvement of the temperature balance

- introduced habitat-adapted woody plants can prevent the growth of non-native woody plants and invasive species if maintenance is carried out properly
- increase structural diversity in comparison to riprap
- create habitats for animals preferring woody plants (e.g. birds and insects), at higher water levels also for aquatic fauna
- promote soil fauna

3.2.2.3 Construction Period

From week 43 to 44 (24.10. to 06.11.2011) – removal of riprap
From week 45 to 47 (07.11. to 27.11.2011) – construction of willow brush mattresses

3.2.2.4 Photo Documentary

Figure 11: Finished willow brush mattresses covered with coniferous brushwood in the lower slope area (picture taken on 14.12.2011)

Figure 12: Additional securing of coniferous brushwood layers with mesh wire (picture taken on 14.12.2011)

Figure 13: Hedge layer at the top of the slope (picture taken on 29.11.2011)

3.2.2.5 First Installation Experiences

Despite a professional installation of the willow brush mattresses the following difficulties occurred:

- the crossbars made of white willows have an irregular form due to the natural bend of the branches. Thus, it was difficult to establish a tight connection between crossbars, brush mattresses and soil.
- it became clear that an additional planar securing of the coniferous brushwood through mesh wire was necessary (Figure 12).
- it was difficult to drive the stakes into the ground to the necessary depth due to the rocky subsoil. Preparing plant holes with a dibble was partially necessary
- for the installation of living construction material great care and specialized staff are generally important

3.2.3 Test field 3: Willow brush mattresses with branches orientated transversally to the direction of flow (Rhine-Km 440.880 to 440.950 – 70 m TF-length)

3.2.3.1 Description

The existing riprap was completely removed from AZW to the top of the slope between km 440.880 to 440.950 along the river Rhine. This riprap consisted of loose armourstones of the stone size class $LMB_{5/40}$ and had a layer thickness of approx. 60 to 80 cm. The existing slope inclination was flattened to 1:3 and willow brush mattresses were installed in dip direction of the slope.

The willow branches were placed in layers between the previously installed stakes on the slope and were orientated transversally to the direction of flow so that their thick, basal ends point downwards to the water. Several overlapping willow brush mattresses had to be installed due to the slope length of about 12 m. The bottom of every layer was buried 1 m deep into the slope. At the height of AZW, the lowest willow layer embeds into the riprap, which remains under water and thus functions as toe protection. Thus, a transition to the existing revetment is established at the same time. In the initial phase, the willow brush mattresses were covered with coniferous brushwood up to AZW + 1.7 m in order to enhance erosion control. The brush mattresses including coniferous brushwood were secured with crossbars between the stakes and were tied down with wire (Figure 17). The coniferous brushwood layers were additionally secured with coarse-meshed wire (game fence). Finally, the brush mattresses were covered with sandy-gravelly material of approx. 3 cm thickness.

Since willow rods with a diameter of only 1 to 3 cm were installed (as these could be cut in the direct vicinity) instead of willow rods with a diameter of 3 to 5 cm as listed in the specifications, planar coverage of the slope was not achieved due to only 20 or 40 willow rods per running meter. This will probably have a negative effect on the erosion stability in the initial state.

At the top of the bank slope hedge layers were installed at the end of the brush mattresses. For this purpose, plants were installed into pits inclined in an angle of 90°to the slope. Only one third of the plants protruded beyond the slope surface.

Figure 14 shows excerpts of the detailed design [2]. Details on the single elements are listed in table 4.

Tab. 4: Details Test field 3

element	plant species/ material	details/ dimensions	installation area
willow branches	purple willow (shrubby willow) white willow (willow tree)	diameter: 1 to 3 cm (planned in specifications: 3 to 5 cm) length: 3 to 4 m number: 40 Qty./m orientated transversally to direction of flow (in dip direction of the slope)	AZW - 0.5 m to AZW +1.7 m
	purple willow (shrubby willow) basket willow white willow (willow tree)	diameter: 1 to 3 cm (planned in specifications: 3 to 5 cm) length: 3 to 4 m number: 20 Qty./m orientated transversally to direction of flow	AZW +1.7 m to top of slope
coniferous brushwood	common spruce	length: 1.50 to 2.50 m	AZW to AZW +1.7 m
stakes	non shoot-forming	diameter: 4 to 6 cm length: 0.80 to 1.00 m number: 1 Qty./m	AZW to top of slope
crossbars	white willow, living mate-rial	diameter: 10 to 12 cm	AZW to top of slope
bracing wire	annealed wire for brush mattresses coarse-meshed game fence to fix coniferous brushwood	diameter: 3 mm mesh size approx. 10 cm	AZW to top of slope AZW to AZW + 1.70 m
topsoil	gravel available on-site (5/32)		AZW to top of slope

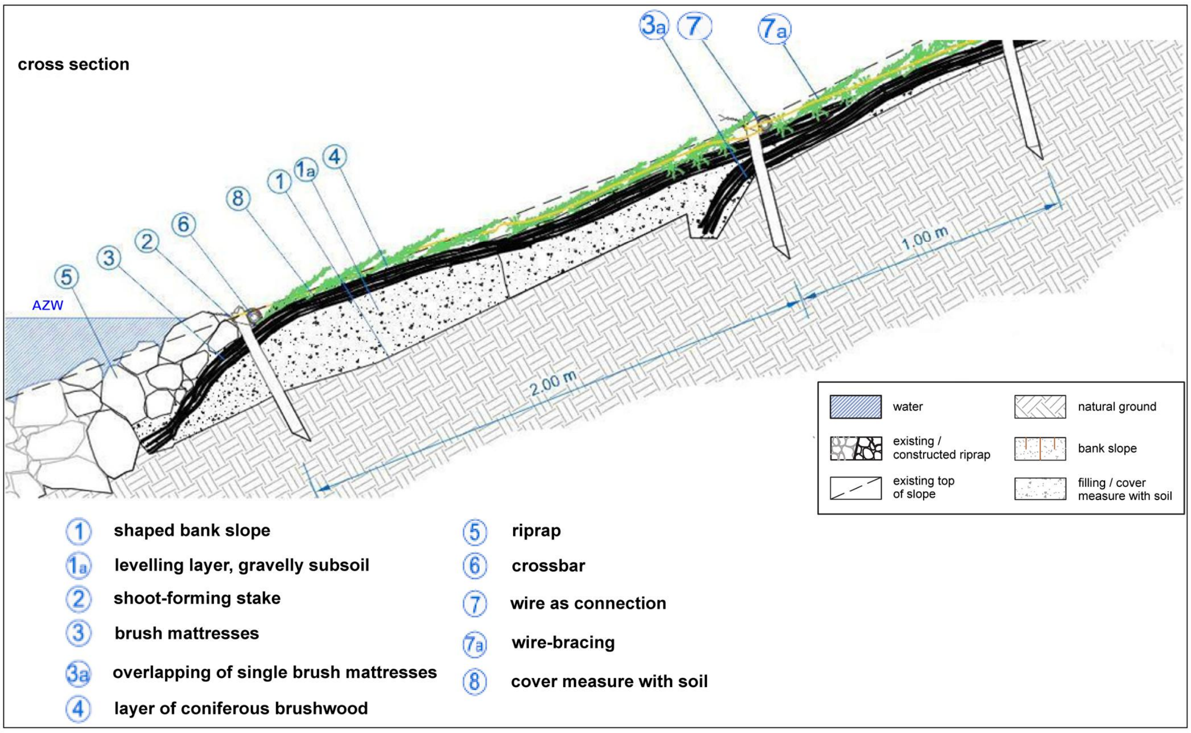

Figure 14: Cross section of test field 3 (modified according to [2])

3.2.3.2 Objective

In general:

- test willow brush mattresses as bank protection measure at waterways with ship-induced hydraulic loads on guaranteeing sufficient slope stability
- measure excess pore water pressures below brush mattresses in the soil during ships‘ passages (examine influence of roots on development of excess pore water pressures in the soil)

Bank protection:

- in the initial state bank protection is ensured through complete coverage of the slope with willow brush mattresses firmly attached to the ground, additional protection is given through planar placement of coniferous brushwood
- sufficient securing which presses the brush mattresses firmly onto the ground, a pre-requisite for bank protection in the initial state
- anchoring brush mattresses to the in-situ soil with increasing root growth, increase in shear strength of the soil, increase in slope stability

- in the initial state the filter stability is guaranteed through planar placement of brush mattresses and additional coniferous brushwood, later through a deep-reaching network of roots
- mitigation of hydraulic impacts on the slope area with growing willow shoots

Ecological enhancement:
- initiate vegetation of habitat-adapted woody plants in the alluvial softwood and alluvial hardwood forest zones
- medium- to long-term improvement of temperature balance
- introduced habitat-adapted woody plants can prevent the growth of non-native woody plants and neophytes provided they are cared for properly
- increase in structural diversity in comparison to riprap
- create habitats for animals preferring woody plants (e. g. birds and insects)
- promote soil fauna
- create habitats for aquatic fauna at higher water levels

3.2.3.3 Construction Period

From week 44 to 45 (31.10. to 13.11.2011) – removal of riprap
From week 46 to 47 (14.11. to 27.11.2011) – installation of willow brush mattresses

3.2.1.4 Photo Documentary

Figure 15: Placed willow branches, before securing (picture taken on 16.11.2011)

Figure 16: Willow brush mattresses after securing and with bracing wire (picture taken on 14.12.2011)

Figure 17: Lower layers of willow brush mattresses covered with secured coniferous brushwood (picture taken on 14.12.2011)

3.2.3.5 First Installation Experiences

Despite the professional installation of willow brush mattresses the following difficulties occurred:

- the crossbars made of white willows have an irregular form due to the natural bend of the branches. Thus, it was difficult to establish a tight connection between crossbars, brush mattresses and soil.
- it became clear that an additional planar securing of the coniferous brushwood through mesh wire was necessary.
- it was difficult to drive the stakes into the ground to the necessary depth due to the rocky subsoil. Preparing plant holes with a dibble was partially necessary.
- for the installation of living construction material great care and specialized staff are generally important.

3.2.4 Test field 4: Riprap with gravel fill, groups of individual stones, dead wood fascines (Rhine-Km 440.950 to 441.000 – 50 m TF-length)

3.2.4.1 Description

The existing riprap in test field 4 remains as bank protection. It is made of loose armour-stones of stone size class $LMB_{5/40}$ /TLW, 2003/ and has a layer thickness of approx. 60 to 80 cm without an additional filter layer. Test field 4 was ecologically improved by

- filling the riprap cavities with gravel which is a prerequisite for natural succession
- arranging groups of individual stones as structural elements made of granite armour-stones with a maximum edge length of approx. 1 m
- dead wood fascines as fish shelters and potential habitats for macrozoobenthos

First, fine gravel (0/32) was filled into the voids of the riprap and was silt up afterwards. Above this coarser gravel (0/36) was filled to the top of the revetment. 6 bundles of dead wood fascines were installed into the riprap with a declination towards the direction of flow and a protrusion of ½ or ¼ the length so that their ends reach into the water below AZW. They were secured with wooden stakes and bracing wire, additionally. In a final step, the area was covered with gravel (Figure 19). The large granite stones were placed on the riprap above AZW in an irregular manner. Figure 18 shows the plan view of the measure (excerpts of the detailed design [2]) and table 5 lists details on the individual securing elements.

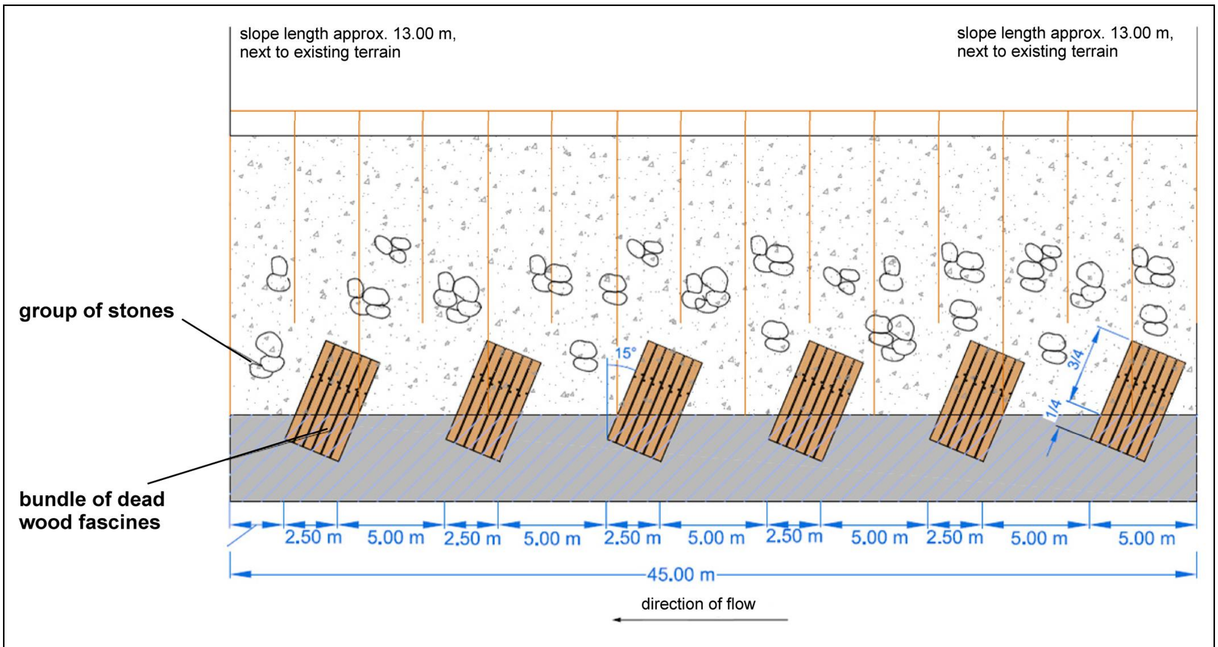

Figure 18: Plan view of test field 4 (modified according to [2])

Tab. 5: Details test field 4

element	plant species/ material	dimensions
gravel		grain sizes 0/32, 0/63
groups of individual stones	granite	maximum edge length: approx. 1 m density: 2.65 t/m^3
bundles of dead wood fascines	birch (dead, non shoot-forming material, bound with wire)	number: 6 (each consisting of 5 single fascines) length: 5 m inclination: 45° inclined in direction of flow (declined)
stakes	non shoot-forming material	diameter: 10 to 12 cm length: 1.20 to 1.50 m

3.2.4.2 Objective

In general:

- test possibilities to ecologically enhance an existing loose riprap for waterway sections at which technical bank protection measures are inevitable due to high hydraulic loads
- test various possibilities to initiate natural succession in the revetment area
- test area on suitability for habitats for animal species preferring open habitats (e. g. special species of ground beetles and spiders, sunny places for reptiles)
- test possibilities to improve conditions for aquatic fauna

Bank protection:

- existing riprap continues to ensure the bank protection
- all other measures are to ecologically enhance the bank area

Ecological enhancement:

- improve local conditions to promote natural succession (placing of fine gravel material)
- create habitats for aquatic and terrestrial fauna, promote species of open bank areas, place dead wood as natural habitat

3.2.4.3 Construction Period

From week 40 to 45 (04.10. to 11.11.2011) with interruptions

3.2.4.4 Photo Documentary

Figure 19 depicts the completed test field 4 on 14.12.2011 at AZW (Worms gauge: 86.19 m a.s.l.). Figure 20 shows the dead wood fascines as fish shelters in detail at a very low water level of approx. 40 cm below ELWL (Worms gauge: 84.44 m a.s.l.).

Figure 19: Test field 4 completed (picture taken on 14.12.2011 at about AZW)

Figure 20: Dead wood fascines, picture taken on 16.11.2011 at about ELWL

3.2.4.5 First Installation Experiences

The stakes to secure the dead wood fascines had to be driven through the riprap into the subsoil. The installation of stakes and thus securing the fascines turned out to be difficult as a conglomerate of soil and stones of a greater layer thickness (see BAW-note [5]) was in place instead of the natural ground.

3.2.5 Test field 5: Removal of riprap, installation of reed gabions, stone mattresses, plant mattresses and hedge layers (Rhine-Km 441.000 to 441.110 – 110 m TF-length)

3.2.5.1 Description

In test field 5, the existing riprap was completely removed from AZW - 0.5 m to the top of the slope over a length of 110 m. It consisted of armourstones of the stone size class $LMB_{5/40}$ /TLW, 2003/. Two different construction methods (reed gabions, pre-cultivated plant mats) are tested on their technical effectiveness with regard to guaranteeing bank stability and on their ecological effectiveness.

The test field is divided into two sections TF 5a and TF 5b (Figure 21). After the riprap was removed, a mineral granular filter (chippings) [6] in a layer thickness of 30 cm was installed on the prepared subgrade (slope inclination 1:2.5) in both sections. This filter was dimensioned for the existing boundary conditions and had the purpose to guarantee filter stability in the slope area (Figure 24).

In TF 5a reed gabions are used (Figure 22, 24). They were installed longitudinally in direction of flow in the area of AZW - 0.5 m to AZW +1.70 m and are divided in two planting zones. In April 2011 already, the firm Ökon Vegetationstechnik GmbH prepared the reed gabions and pre-cultivated them with various species for two planting zones during one vegetation period so that they were completely covered and rooted at the time of installation. The gabions of the type planting zone 1 were installed in the area of AZW - 0.5 m to AZW + 0.5 m. The gabions of the type planting zone 2 (see each Tab. 6) were installed connecting thereto in the area of AZW + 0.5 m to AZW + 1.70 m. Stone mattresses were installed next to the reed gabions from AZW + 1.70 m to the top of the slope. They consist of a plastic network structure which was filled with quarried natural stones on-site (Figure 23). In comparison to the traditional riprap revetment, it is expected that over time fine material will settle in the cavities of the stone mattresses due to the thin layer thickness and the smaller and denser cavities. Thus, conditions for plant growth will be improved. In a last step, the stone mattresses were covered with soil of approx. 10 cm thickness and are thus left to natural succession.

In TF 5b stone mattresses were placed on the complete area from AZW - 0.5 m to the top of the slope on the mineral filter layer. Additionally, they were silt up with mineral filter material in the lower slope area (first three layers). In the area AZW - 0.5 m to AZW +1.70 m pre-cultivated plant mats were tied onto the stone mattresses with cable ties. These, too, were pre-cultivated during one vegetation period according to species composition and zonation of the reed gabions by the firm Ökon Vegetationstechnik GmbH. On delivery, however, the mats partially did not have the demanded width of 100 cm (mainly 90 cm, partially 80 cm) which were planned for the installation scheme. Thus, a shortage of materials occurred during construction. An additional strip of mats had to be installed in order to ensure sufficient embedment of the plant mats in the stone mattresses. Furthermore, the plant mats of planting zone 2 had partially very little vegetation, especially the dominant species reed fescue and reed canary grass were poorly developed or were completely missing in some sections. The loss of plants during installation amounted to about 15 % (result of an inventory on 22.11.2011) in relation to the entire area (TF 5b). The vegetation growth on the plant mats of planting zone 1 was mostly satisfying.

A poor connection between the coir tissue and the underlying 3D lattice tissue within the mats was also noticed and seen as a deficiency as reduced stability of the plant mats during wave and flow load is thus to be expected from the start.

In order to secure the plant mats on the stone mattresses timber battens (Figure 25) were additionally used which were attached with wire knotters and single armourstones that shall weigh down and further stabilize the mats. The stone mattresses in the upper slope area (without plant mats) were also covered with soil such as in TF 5a. This soil cover also serves as a protection against vandalism as it covers the abovementioned plastic network structure otherwise visible from the maintenance path. The construction method concludes with a single-row hedge layer of native shrubs that were planted in order to stabilize the edge of the slope (Figure 26).

Reed gabions and stone mattresses were closely butt together, single elements were not connected.

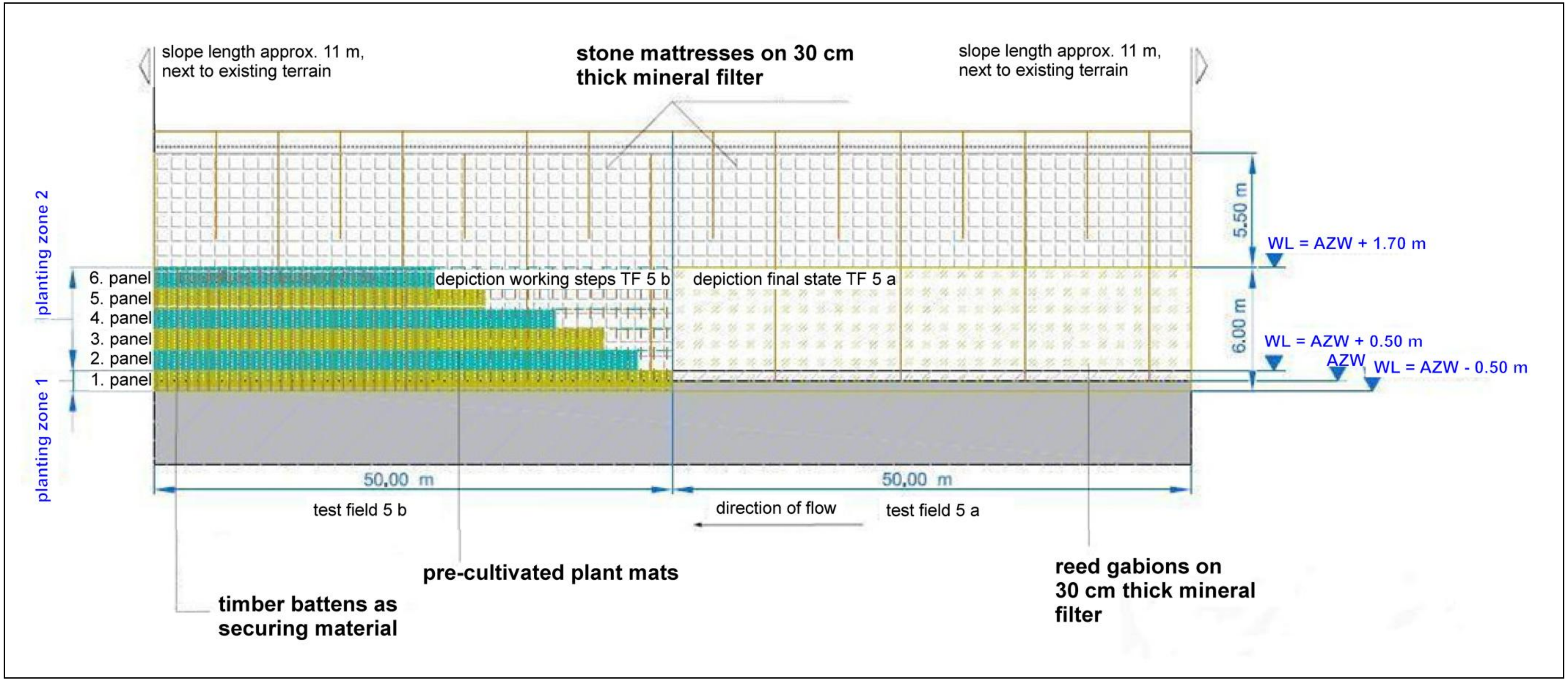

Figure 21: System diagram of test fields 5a and 5b (modified according to [2])

Tab. 6: Details test field 5

element	material/plant species	dimensions	installation area
mineral filter layer	frost-resistant, inert material granite chippings	thickness: approx. 30 cm grain size (1/25) [6]	TF 5a and 5b
reed gabions	multiply machine twisted hexagonal wire mesh (galvanic alloy), filling: reeds and armourstones made of natural stone ($CP_{45/125}$ /TLW, 2003/)	mesh size wire mesh: 6 x 8 cm, wire diameter: 2.2 mm gabion in total: 2.0 m x 1.0 m x 0.3 m (L x W x H)	TF 5a
planting zone 1	<u>main species</u>: slim sedge (60-75%) + mixture of species from reed zone (25-40%)		AZW - 0.5 m to AZW + 0.5 m
planting zone 2	<u>main species</u>: reed fescue and reed canary grass (60-75%) + mixture of species from reed zone, grasses (25-40%) → completely covered and rooted		AZW + 0.5 m to AZW + 1.70 m
stone mattresses	high-strength net of synthetic fiber filled with frost-resistant quarried natural stones (quartz-porphyry)	2 m x 1 m (300 m^2) 2 m x 2 m (550 m^2) height: 0.25 m mesh size: 45 mm stone size class: $CP_{45/125}$ /TLW, 2003/	TF 5a: AZW + 1.70 m to top of slope TF 5b: AZW - 0.5 m to top of slope
plant mats	carrier material: coir filter mat with coir lining, planted with 20 Qty./m^2 plants of the bank and reed zone	length: 5 m width: 1 m thickness: approx. 4 cm	TF 5b

planting zone 1 **planting zone 2**	main species: slim sedge (60-75%) + mixture of species from reed zone (25-40% → covered and rooted main species: reed fescue and reed canary grass (60-75%) + mixture of species from reed zone, grasses (25-40%) → covered and rooted, little vegetation in certain sections due to lack of dominant species		AZW -0.5 m to AZW + 0.5 m AZW + 0.5 m to AZW + 1.70 m
hedge layers	bare rooted young woody plants; seedling and light shrubs of native species: field maple, spindle tree, hawthorn, dogwood, hazel	length: 60 to 100 cm	top of slope

3.2.5.2 Objective

In general:

- test pre-cultivated plant elements of various construction methods (reed gabions, plant mats) on their technical effectiveness with regard to ensuring bank stability and their ecological effectiveness (establish close-to-nature bank vegetation through pre-cultivated plant elements)
- test stone mattresses on promotion of natural succession in comparison to the traditional riprap

Bank protection_

- stability and erosion control guaranteed through pre-cultivated technical-biological securing elements placed area wide
- filter stability guaranteed through mineral granular filter
- weight of reed gabions increases slope stability already in initial state

- anchoring of individual elements on the slope with increasing root growth, increase of shear strength and slope stability

Ecological enhancement:
- initiate habitat-adapted bank vegetation (reeds, grasses in the alluvial softwood and alluvial hardwood forest zones, woody plants in the alluvial hardwood forest zone)
- enhance local conditions to promote natural succession (lower thickness of stone mattresses, cover measure with soil)
- create habitats for riparian fauna especially for species preferring reeds and woody plants (e.g. birds, insect and spiders)
- create habitats for aquatic fauna at higher water levels

3.2.5.3 Construction Period

From week 39 to 48 (installation from 27.9. to 29.11.2011) with interruptions

3.2.5.4 Photo Documentary

Figure 22: Installation of a reed gabion with cross beam (11.10.11)

Figure 23: Construction of a stone mattress (11.10.11)

Figure 24: TF 5a: Reed gabions (below) and adjoining thereto stone mattresses on an approx. 30 cm thick mineral filter layer (20.10.11)

Figure 25: TF 5b (left part of the picture) plant mats in winter condition fixed with battens and single armourstones on the stone mattresses. TF 5a (right part of the picture). The stone mattresses were covered with soil in the upper slope area of the entire test field 5 (14.12.11).

Figure 26: Stone mattress covered with soil in TF 5a with adjoining single-row hedge layer of native woody plants (14.12.11)

3.2.5.5 First Installation Experiences

A lot of individual construction elements come together in this test field. The transitions and interfaces of the single construction elements must, thus, be planned and carried out in a way that all elements among one another and together form an uninterrupted, firm and stable bond. Thus possible points of impact for ship-induced loads are avoided. In order to sufficiently secure e.g. plant mats on the stone mattresses, the wire knotters had to be threaded through the plastic network structure of the stone mattresses and then again through the plant mats when they were placed. After the placement of the timber battens the wire knotters were twisted above. Therefore, a lot of manual work is necessary. In addition, the plant mats were then weighed down and stabilized with single armourstones to prevent an upward deflection of the mats between the fixing points during wave impact. High planning, high material and labor-intensive efforts must be taken into account for these work steps.

Unexpected problems occurred with regard to the plant mats (shortage of material, material deficiencies and in parts too little plant vitality). Overall these factors called for an increased planning, material and labor effort. The increased working effort concerned both the construction works and the construction supervision. It is to be expected that the state of the delivered plant mats which partially did not meet quality requirements will have a negative impact on the service state.

Field 5b is not in an optimum state after the completion of construction works due to the abovementioned deficiencies of the plant elements. As a result the construction method is more vulnerable to the described loads from current and navigation. Replacement planting at fail places in the mats of planting zone 2 was not possible due to the season and cannot be carried out until spring 2012. Before then, especially the fail places of the mats offer more possible points of impact for loads.

3.2.6 Test field 6: Riprap with topsoil alginate blend, hydroseeding and individual plants (Rhine-Km 441.125 to 441.200 – 75 m TF-length)

3.2.6.1 Description

The existing riprap in test field 6 remains as bank protection. It is made of loose armourstones of the stone size class $LMB_{5/40}$ /TLW, 2003/ and has a layer thickness of approx. 60 to 80 cm without an additional filter layer. The test field was ecologically improved by

- filling the cavities of riprap with a topsoil alginate blend
- hydroseeding of the topsoil alginate blend
- locally installing single plants (reed bales) into the riprap between AZW - 0.5 m and AZW

Existing debris on the revetment was removed, but the vegetation of thorny berry bushes was maintained. Two preliminary tests were carried out to test the preparation and installation of the topsoil alginate blend as well as to determine the optimal mixing ratio. The mixture must be prepared high-speed in order to improve the erosion stability compared to simple topsoil. In comparison to mixtures with cement additives no hardening takes place in this case, but a colloidal mixture with high adhesion forces develops. The consistency has to be adjusted in a way so that the material is fluid and fills the cavities. It may, however, not be too liquid as it will otherwise flow down the slope. Separation of the colloidal mixture may not occur during the filling process. A truck mixer with an attached concrete pump was used. After the installation from 4 to 7 October 2011 (water level at about ELWL, 84.9 m a.s.l.) the entire cavity down to the soil in place was filled with the topsoil alginate blend. Hydroseeding was carried out afterwards.

At AZW single reed bales were placed into the riprap with the topsoil alginate blend. The individual bales were wedged between the armourstones as best as possible. The single bales withstood 4 days of submergence directly after the installation.

After installation and hydroseeding (Figure 30) the water level rose about 1 m to 86.75 m a.s.l. (see peak in hydrograph at the Worms gauge in Figure 2) on the 12./13.10.2011 for a short time. As a result the topsoil alginate blend in the temporarily submerged area was washed out due to the hydraulic loads. Figure 31 shows the bank section after the drop of water levels 9 days later. The topsoil alginate blend was not sufficiently resistant to erosion. In order to favor vegetation of riprap at this point too and at the same time protect the topsoil alginate blend from further washing out, gravel was filled into the cavities of the riprap in a section (length of section 30 m) and subsequently silted up. Close to the surface the finer grain fractions of the gravel were washed out at higher water levels (see Figure 28).

Figure 27 depicts the ground plan of the measure (excerpts from the detailed design [2]). Table 7 lists details of the individual securing elements.

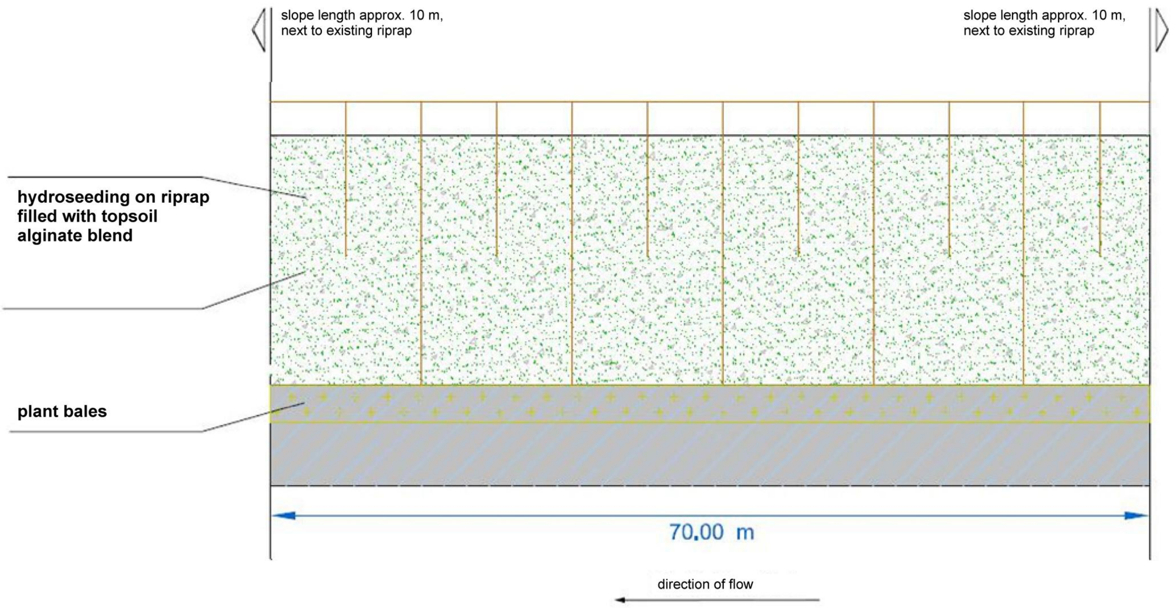

Figure 27: Plan view of test field 6 (modified according to [2])

Tab. 7: Details test field 6

element	plant species/ material	dimensions
topsoil alginate blend	Per m^3 of mixture: 1.5 t topsoil, water, 15 kg sodium-alginate (mixed with bentonite), 2 kg straw	250 l per m^2 of the revetment surface
hydroseeding	bent grass, reed fescue, couch grass, meadow foxtail, ryegrass, reed canary grass, tufted hairgrass, meadow soft grass	seeds: 30 g/m^2
single plants	reed bales (yellow iris, bulrush, bugle-weed, water-mint)	4 plants per m^2 from AZW - 0.5 m to AZW bale size: 10 x 15 cm
gravel		grain size 0/63

3.2.6.2 Objective

In general:

- test possibilities to ecologically enhance an existing loose riprap for waterway sections in which a technical bank protection is indispensable due to high hydraulic loads
- test vegetation with topsoil alginate blend as carrier substance for subsequent hydroseeding
- test planting of riprap with individual reed bales

Bank protection:

- the existing riprap continues to ensure the bank protection.
- all other measures are to ecologically enhance the bank area. Vegetation and planting can also permanently contribute to increasing the bank stability after root growth in the subsoil

Ecological enhancement:

- initiate habitat-adapted bank vegetation (reeds in zone of water level fluctuation, grasses in the alluvial softwood and alluvial hardwood forest zones)
- improve local conditions to promote natural succession (topsoil alginate blend as initial substrate for plant growth)
- promote species preferring reeds and soil fauna
- create habitats for aquatic fauna at higher water levels

3.2.6.3 Construction Period

From week 38 to 43 (19.09. to 28.10.2011) with interruptions

3.2.6.4 Photo Documentary

Figure 28 shows the completed test field 6 on 14.12.2011 at AZW (Worms gauge: 86.19 m a.s.l.). Hydroseeding was carried out on 11.10.2011 and already started to sprout after about 2 months. First grasses are clearly visible. Figure 29 shows the view from the water.

Figure 28: Completed test field 6 (picture taken on 14.12.2011 at about AZW)

Figure 29: View from the water on the test field 6 (picture taken on 14.12.2011 at about AZW)

Figure 30: View on 11.10.2011 (85.80 m a.s.l.)

Figure 31: 20.10.2011 (86.00 m a.s.l., approx. AZW)

3.2.6.5 First Installation Experiences

The first test to prepare and install the material with a concrete hand mixer and an excavator shovel showed that the desired preparation cannot be achieved in this way. The topsoil alginate blend must be produced in a compulsory type mixer with high speed in order to ensure a preparation with a high number of revolutions. Washing out in areas of flowing water can, however, not be completely prevented then, either. This is also clear from present applications at canals above the water level where the topsoil alginate blend was partially washed out in the influence area of ship-induced waves. Outside this area the growth of vegetation on the riprap was generally achieved.

3.2.7 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 – 175 m TF-length)

3.2.7.1 Description

The test field is divided into three sections TF 7a (7a1, 40 m; 7a2, 35 m), 7b (40 m) and 7c (40 m) with the respective transitions (20 m in total). This division developed over the course of the detailed design. Initially, it was planned to test a sheep wool fleece as a filter fleece on most of the surface of the test field. This fleece was to prevent the washout of fine material from underneath the planned vegetative securing elements (plant mats). Prior to this, research and tests on the material properties (root penetration, filter stability, shear strength, biodegradability) of the sheep wool fleece were carried out. It was the first time that a sheep wool fleece was to be used at a waterway. The fleece fulfilled the requirements to the greatest extent during the tests.

Different thicknesses (460 g/m^2 and 1000 g/m^2) of the sheep wool fleece (needle punched single-layered, not thermally bonded) were to be tested in combination with the intended plant elements. The firm Ökon Vegetationstechnik GmbH was in charge of pre-cultivating the plant mats. The plant mats based on coir tissue were fixed on the sheep wool mats which were placed in the firm’s pre-cultivation basins over one growing season in 2011. This way the plants were to be given the possibility to root directly from the coir tissue through the sheep wool mat so that a first dense network of roots could already develop underneath the filter mats at the time of delivery of the combined mats.

In May the plants developed naturally, whereas in July root growth was limited and the sheep wool fleeces started to rot and decompose themselves. This development was caused by the cultivation in still water at the prevailing high temperatures in summer. The water in the pre-cultivation basins was changed on a regular basis from then on. For this purpose, the mats were removed from the basins temporarily. The mat combination of sheep wool and plant mats was not successful for this pre-cultivation method. In order to deliver the plant mats, the rest of the rotten sheep wool was removed from the plant mats. The vitality of individual plant species suffered from these conditions. Especially the slender-tufted sedge and reed canary grass which were planted most turned out to be hardly vital or failed completely whereas the species reed fescue developed well in comparison to the mats in TF 5. Since the plant mats in test field 5 (planting zone 2), which were pre-cultivated without sheep wool fleeces, partially had little vegetation, the combination with sheep wool fleece is, however, not the only cause for the bad state of the plant mats.

The failure of single species within the mats is particularly serious as the mats were not planted as initially planned without zonation, but according to a specific planting scheme (Figure 35). Due to the failure of single species entire sections of the individual mats are without vegetation.

Since the conditions in the pre-cultivation basins (permanent water accumulation at high summer temperatures in June, July, August) can, however, not be compared to the on-site conditions at the test stretch, it was decided that the sheep wool mats were to be integrated into the test despite the swift degradation observed. For this purpose, new sheep wool fleece of the uniform thickness of 460 g/m^2 was ordered. At the same time an approved synthetic geotextile and a coir mat of the thickness 1000 g/m^2 were installed underneath the plant mats for comparative purposes. In order to do this the test field was divided into different areas. All filter mats were placed in layers in the dip direction of the slope with an overlap of 30 cm. The synthetic geotextile is not biodegradable. Even though the coir mat is easily penetrable, it is not sufficiently filter stable. Thus, the coir mat was installed in the upper slope areas, only, as they are flooded less often. A filter fleece that similarly fulfills all requirements (filter stability, strength, root penetration and biodegradability) was not available.

Finally, a further increase of differentiation within the test field arose from the use of different types of plant mats. The plant mats that showed especially high losses in species or had mostly plants of little vitality and root formation, were already replaced on-site by plant mats from the standard scheme of the firm Ökon with comparable species combination.

The ordered plant mats and the mats of the standard scheme were marked with different colors by the firm (ordered mats: orange and blue, mats from the standard scheme of the firm Ökon: red) (Figure 32). With regard to the subsequent evaluation of results and their comparability, it was already made sure during the construction works that the different types of plant mats had the same proportion of the different filter mats placed below: sheep wool, geotextile and coir.

The individual construction methods, types of plant mats and their position in the test field are described in detail in the following section:

The riprap was removed on the entire slope surface above AZW - 0.5 m. After that the slope was flattened to 1:3 and the subgrade was constructed.

Two different filter fleeces are already used in TF 7a (Figure 32) so that the field 7a can again be divided into sections 7a1 and 7a2. In the area 7a1 beginning upstream a sheep wool fleece was placed planar on the slope. It extends from AZW - 0.5 m to AZW + 1.70 m

and the upper end was placed into a fascine pit where both, the dead wood fascine and the sheep wool fleece, were fixed to the ground.
Reed mats (Figure 32: mats in blue) were placed on the sheep wool mat transversally to the direction of flow. They were propagated and pre-cultivated with different species of the reed zone by the firm Ökon Vegetationstechnik GmbH (see previous description). Since several of the delivered plant mats could not be installed due to bad quality, shortages of material occurred so that the intended scheme for the placement of reed mats in the detailed design could not completely be complied with. In the upper area (close to AZW + 1.70 m) mats from the standard scheme of the firm (Figure 32: mats in red) and mats which were ordered and designated for TF 7b and 7c due to their species combination had, thus, to be used (Figure 32: mats in orange).

Plant mats in section 7a2 were placed identical to those in section 7a1. Instead of sheep wool fleece a thin synthetic geotextile is located underneath the plant mats in this area. The plant mats as well as the geotextile end in the fascine pit. In the upper slope area (above the fascine pit to the top of the slope) hydroseeding with seeds of native grasses and herbs was carried out on the raw soil surface which was completely covered with coir fabric afterwards. All filter mats end in the fascine pit and are stabilized and held together by installing dead wood fascines and their stakes. Additionally, in order to secure the plant mats, they were staked in a tight grid and secured with cross beams. The coir mats above the seeds were secured with single stakes only.

The area TF 7b starts with vegetation rolls at the slope toe (around AZW) which were installed into a previously excavated pit. The roll in TF 7b was made of coir fabric. The inside of the roll consists of a gravel mixture and reed bales. After the roll was built, the armourstones were placed at the sides of the roll again. Following the rolls, a synthetic geotextile was placed on the subgrade to the top of the slope functioning as a filter on which again panels of plant mats were installed transversally to the direction of flow. The mats were staked and additionally secured with cross beams. The originally ordered mats have a similar combination of species as the mats in TF 7a. Reed, however, is not included as a dominant species.

In test field 7b, the originally planned installation scheme for the plant mats could also not completely be complied with due to the same reasons as in TF 7a. Thus, in one section on the slope surface mats ordered by the BfG (Figure 33: mats orange) were installed and in another section mats from the standard scheme of the firm Ökon with a similar species combination (Figure 33: mats red).

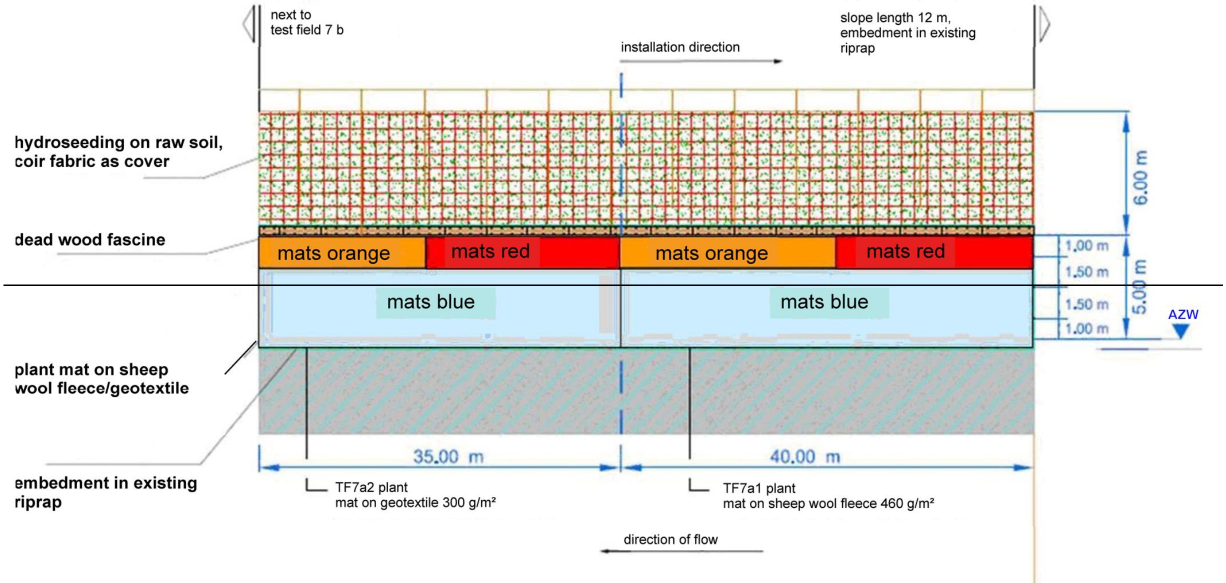

Figure 32: System sketch of the test field 7a (the individual mat types are explained in the text)

Test field 7c is structured as TF 7b regarding its single elements. The casing of the vegetation roll was, however, fabricated with a sheep wool fleece inside the roll and a coir fabric outside. A sheep wool fleece functions as a filter on the slope on which the plant mats were placed identical to TF 7b. In this upper panel of plant mats half of the mats in TF 7c and all mats in TF 7b are from the standard scheme of the firm Ökon. All plant mats in TF 7 were installed edge to edge without any overlap.

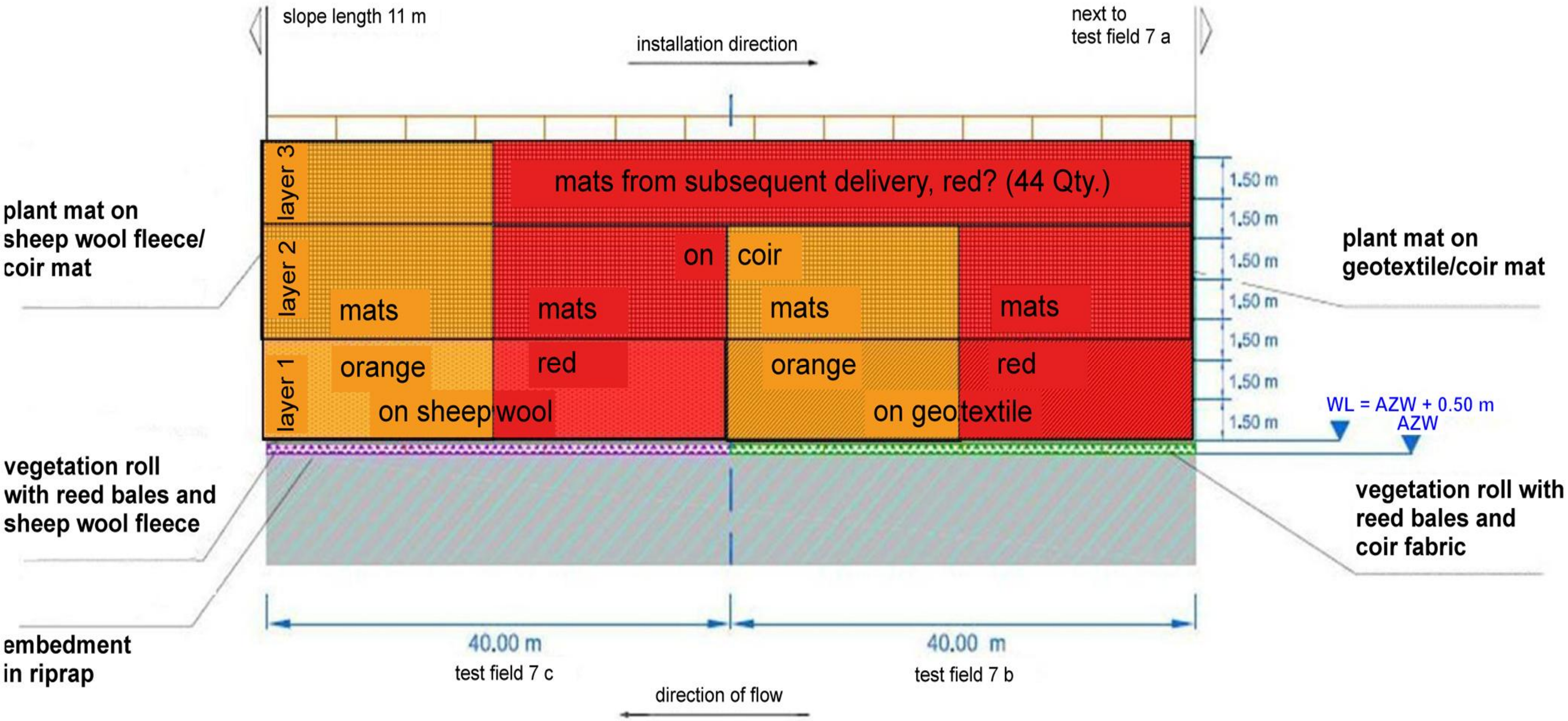

Figure 33: System sketch of the test field sections 7b and 7c (the individual mat types are explained in the text)

Since a lot of plant mats placed in test field 7 (a, b and c) showed losses with regard to individual plant species, hydroseeding of the entire test field with swiftly sprouting species was carried out subsequently. Thus, seeds of swiftly sprouting winter cereals were used which ideally support the bank protection in winter due to the additional root meshwork. These species are permanently replaced by the native species of plant mats.

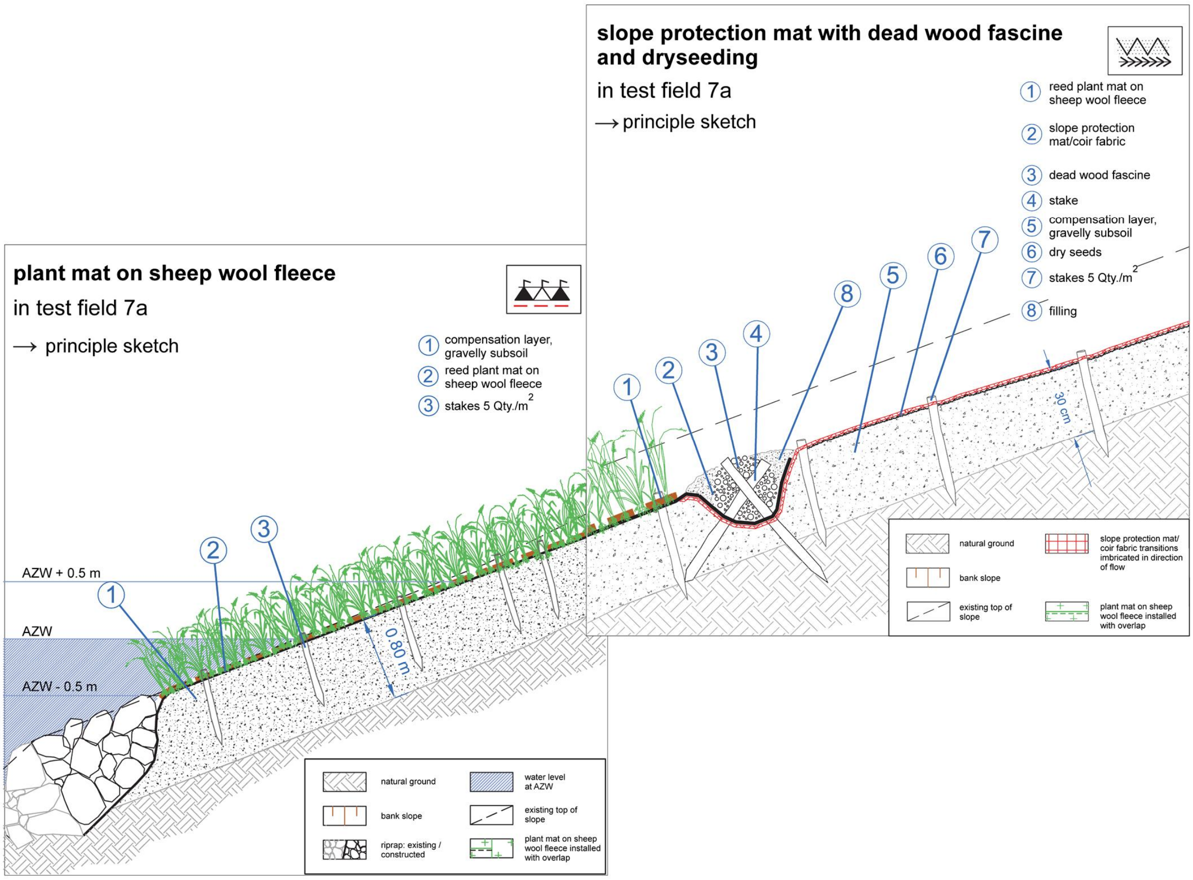

Figure 34: Principle sketch of the test field section 7a1; left half of the picture: (reed) plant mats on sheep wool fleece; right half of the picture: dead wood fascine, adjacent thereto subgrade with hydroseeding and coir mat above) [2]

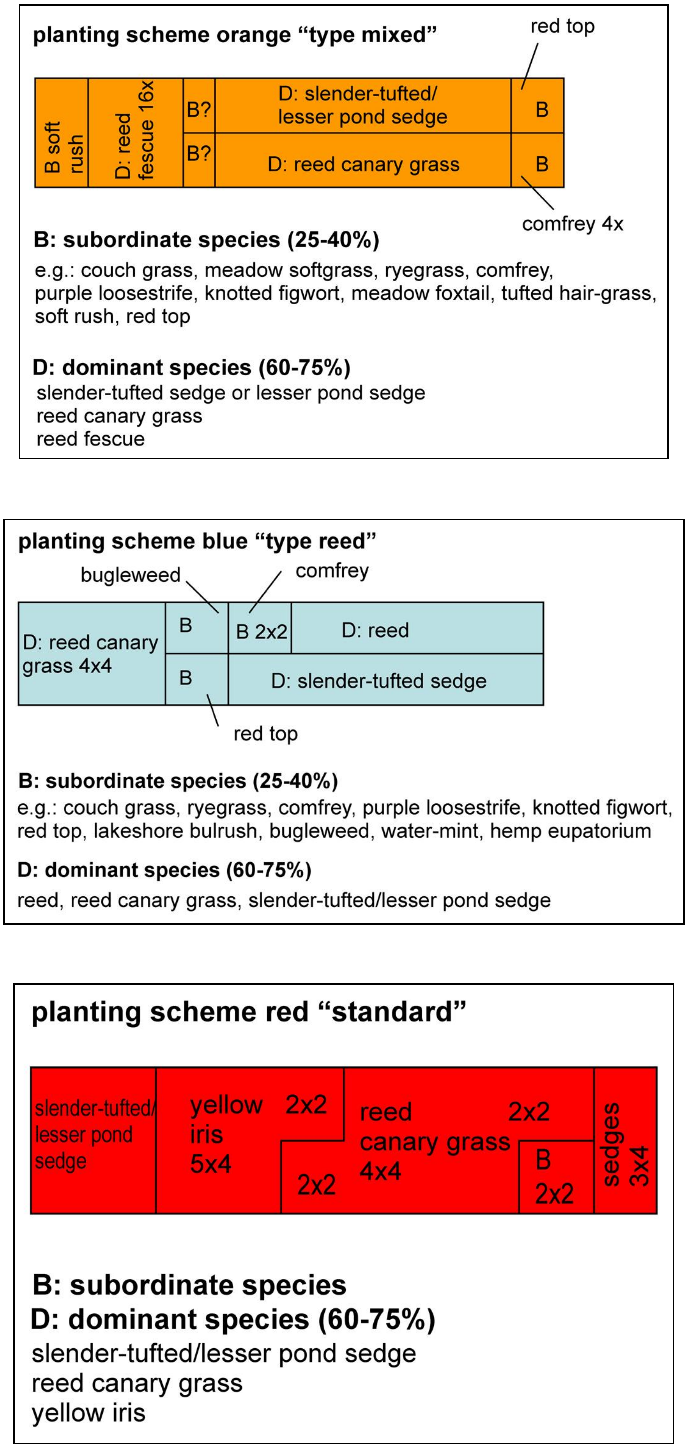

Figure 35: System sketch of the different mat types installed in test field 7 (L x W = 5 m x 1 m) with the corresponding planting schemes (tuffs)

Tab. 8: Details test field 7

element	material/ plant species	dimensions	installation area
sheep wool fleece (7a1) (firm Baur)	filter stable, biodegradable, rootable	460 g/m^2	AZW - 0.5 m to AZW + 1.70 m (TF 7a1)
geotextile (7a2) HaTe, type M 300 (firm Huesker)	filter stable to a limited extent, rootable, not biodegradable	300 g/m^2	AZW - 0.5 m to AZW + 1.70 m (TF 7a2)
reed (reed mats) (mats blue) → pre-cultivated without zonation	carrier material: coir filter mat with coir fabric casing, planted with 20 Qty./m^2 of plants belonging to the bank and reed zone main species: reed, reed canary grass, slender-tufted sedge (60-75%) + mixture of species from reed zone (25-40%) → vegetated and rooted, section wise without vegetation due to loss of individual species!	length: 5 m width: 1 m thickness: approx. 4 cm	AZW - 0.5 m to approx. AZW + 0.6 m (TF 7a1/7a2)
reed mats (mats red) → standard scheme of the firm	main species: yellow iris, slender-tufted sedge, if necessary other species (60-75%) + mixture of species from reed zone, grasses (25-40%) → completely vegetated and rooted		AZW + 0.6 m to AZW + 1.7 m embedment into fascine pit (TF 7a1/7a2)
reed mats (mats orange) → originally intended for TF 7b and TF 7c	main species: slender-tufted sedge, reed canary grass, reed fescue (60-75%) + mixture of other species from reed zone (25-40%) → vegetated and rooted, section wise without vegetation due to loss of individual species!		AZW + 0.6 m to AZW + 1.7 m embedment into fascine pit (TF 7a1/7a2)

dead wood fascine	dead, non shoot-forming branch material (branches of deciduous wood with lateral twigs), tied with annealed wire	length (individual branches): 200 to 400 cm Ø (individual branches): 2 to 5 cm Ø fascine: 45 to 55 cm	roughly center of the slope (TF 7a1/7a2)
hydroseeding	native grasses and herbs: red top, reed fescue, couch grass, meadow foxtail, tufted hairgrass, meadow softgrass, ryegrass, reed canary grass	approx. 20 g/m^2	upper half of slope (TF 7a1/7a2)
coir fabric	not filter stable, very good rootable, biodegradable	1000 g/m^2	
vegetation roll	casing: double-layered coir fabric stitched with jute filling material: gravel 5/32 reed bales (multiple shoots, densely rooted: yellow iris, reed, lakeshore bulrush, purple loosestrife, bugleweed)	coir min. 1000 g/m^2 jute 300 g/m^2 approx. 0.8 m^3/m^2 dimension plugs: 10x15 cm (Ø x height), plug volume approx. 1.2 l	AZW to AZW + 0.5 m (TF 7b)
geotextile HaTe, type M 300 (firm Huesker)	see TF 7a2	see TF 7a2	AZW + 0.5 m to top of slope (TF 7b)
reed mats (mats red) **→ standard scheme of the firm**	see TF 7 a	see TF 7a	AZW + 0.5 m to top of slope (TF 7b)
reed mats (mats orange) **→ originally intended for TF 7b and TF 7c**	see TF 7a	see TF 7a	AZW + 0.5 m to top of slope (TF 7b)

vegetation roll	casing: sheep wool fleece and coir otherwise like TF 7b		AZW to AZW + 0.5 m (TF 7c)
sheep wool fleece (firm Baur)	filter stable, biodegradable, rootable	460g/m^2	AZW + 0.5 m to top of slope (TF 7c)
reed mats (mats red) → standard scheme of the firm	see TF 7 a	see TF 7a	AZW + 0.5 m to top of slope (TF 7c)
reed mats (mats orange) → originally in-tended for TF 7b and TF 7c	see TF 7a	see TF 7a	AZW + 0.5 m to top of slope (TF 7c)
subsequent hydroseeding	winter vegetation with rye brome, rye, spelt and winter wheat	20 g/m^2	TF 7 completely

3.2.7.2 Objective

In general

- test pre-cultivated plant elements of different species combinations (plant mats, vegetation rolls) and different seeding procedures (hydroseeding) on their technical effectiveness with regard to guaranteeing bank stability and its ecological effectiveness
- test different filter mats, compare biodegradable, environmentally sound materials (sheep wool, coir) with technical fleeces (geotextile)
- test different construction methods of various species combinations (vegetation rolls, plant mats) on their technical and ecological mode of action

Bank protection

- in the initial state bank protection is guaranteed through planar coverage of the slope with plant and coir mats firmly pressed to the ground, sufficient securing through stakes and cross beams are a prerequisite for bank protection in the initial state
- filter stability guaranteed through different filter mats
- plant mats are anchored with the ground in-place due to increasing root formation, increase of shear strength of the ground, increase of slope stability

Ecological enhancement

- initiate a habitat-adapted bank vegetation (reeds, grasses from the alluvial softwood and alluvial hardwood forest zones)
- enhance local conditions to promote natural succession
- create habitats for riparian fauna, especially for animals preferring reeds (e.g. birds, insects, spiders), at higher water levels for aquatic fauna, too

3.2.7.3 Construction Period

From week 42 to 48 (installation in the period from 20.10.to 30.11.11)

3.2.7.4 Photo Documentary

Figure 36: Construction of vegetation rolls (left) with coir casing and completely installed vegetation rolls (right) weighed down with armourstones in the area of AZW - 0.5 m (picture taken on 20.10.11 left, 2.11.11 right).

Figure 37: Test field 7a1: plant mats secured with stakes and cross beams on a filter mat made of sheep wool fleece (8.11.11)

Figure 38: Test field 7a: hydroseeding covered by a coir fabric above the fascine pit (22.11.11)

Figure 39: Finished TF 7a (29.11.11, opposite perspective compared to Figure 38)

Figure 40: Plant mats placed planar in TF 7b (2.11.11)

Figure 41: View on TF 7b. Both sections are clearly visible, mat type orange (left) and mat type red (right) (2.11.11).

3.2.7.5 First Installation Experiences

All in all, the construction of this test field turned out to be difficult and very labor-intensive. Extensive planning efforts were already necessary in advance to order and pre-cultivate the plant mats in time. The species composition determined by the BfG and the planting scheme were only partially delivered in accordance with the requirements. In addition material defects and material shortages occurred which required further re-planning. Problems occurred during the cultivation of the sheep wool fleece as no sufficient practical experience with these novel materials regarding its use as carrier material for plant cultivation, rootability, decomposition etc. exists. During the cultivation period the plant mats should already be pre-cultivated in the basins together with the sheep wool fleece. Due to a high degree of decomposition and decay processes during the hot summer months, losses of plant species and inhibition of root growth of plants occurred which in turn required re-planning.

Despite the difficulties encountered during pre-cultivation of the plant mats, the test field similar to TF 5 requires high material demand and a considerable amount of work in order to sufficiently secure the filter fleeces and plant mats with wooden stakes and cross beams. Due to the stones that were partially present in the subsoil, it was additionally difficult to drive the stakes into the ground to the required depth. Therefore, it must be expected that a part of the stakes ties less into the subsoil than planned. Sufficient securing is, however, an absolute prerequisite to guarantee bank stability in the initial state.

The test field is not in the ideal state after completion of construction due to the problems described above. As a result the construction methods are more vulnerable to the described boundary conditions of the river Rhine. Replanting the failed areas in the mat panels was also not possible due to the season and cannot be carried out until spring 2012. The possibility of replanting is basically, however, to be seen critical because of the filter fleeces installed underneath the plant mats. The aim of the hydroseeding, ordered additionally and on short notice, was to compensate for the failed areas during the winter months with swiftly sprouting winter cereal as best as possible.

3.2.8 Test field 8: Riprap and pavement with reeds, elevation of existing stone wall (Rhine-Km 441.375 to 441.475 – 100 m TF-length)

3.2.8.1 Description

In test field 8 for the most part old pavement still functions as bank protection in the slope area above approx. AZW. Below AZW the toe of the pavement is protected by the existing riprap made of loose armourstones of the stone size class $LMB_{5/40}$ /TLW, 2003/. Thus, a slightly wall-like elevation (see Figure 44) was already partially present. Under its protection riparian reeds already developed in the area of the pavement. This protection is to be improved by elevating the stone wall by about 0.5 m to AZW + 0.5 m in order to further promote natural reed succession. The armourstones of the old revetment which were removed from test field 9 were installed here. For this purpose a longfront excavator standing at the top of the slope and a compact excavator driving on the existing pavement were used. Figure 42 shows excerpts of the detailed planning [2].

Table 9: Details test field 8

element	material/plant species	dimensions
stone wall	armourstones $LMB_{5/40}$	top of riprap: AZW + 0.5 m

3.2.8.2 Objective

<u>In general</u>

- preserve already existing vegetation in the area of the old pavement
- test measures which are to reduce loads on the bank slope and subsequently promote natural succession

<u>Bank protection</u>

- guaranteed through the existing riprap and the old pavement.
- the elevation of the stone wall reduces the wave load on the bank area.

<u>Ecological enhancement</u>

- promote reed succession
- protect the riparian vegetation by reducing current and wave loads
- establish a protected bank area for aquatic fauna in the case of higher water levels
- promote the settlement of animals preferring reeds

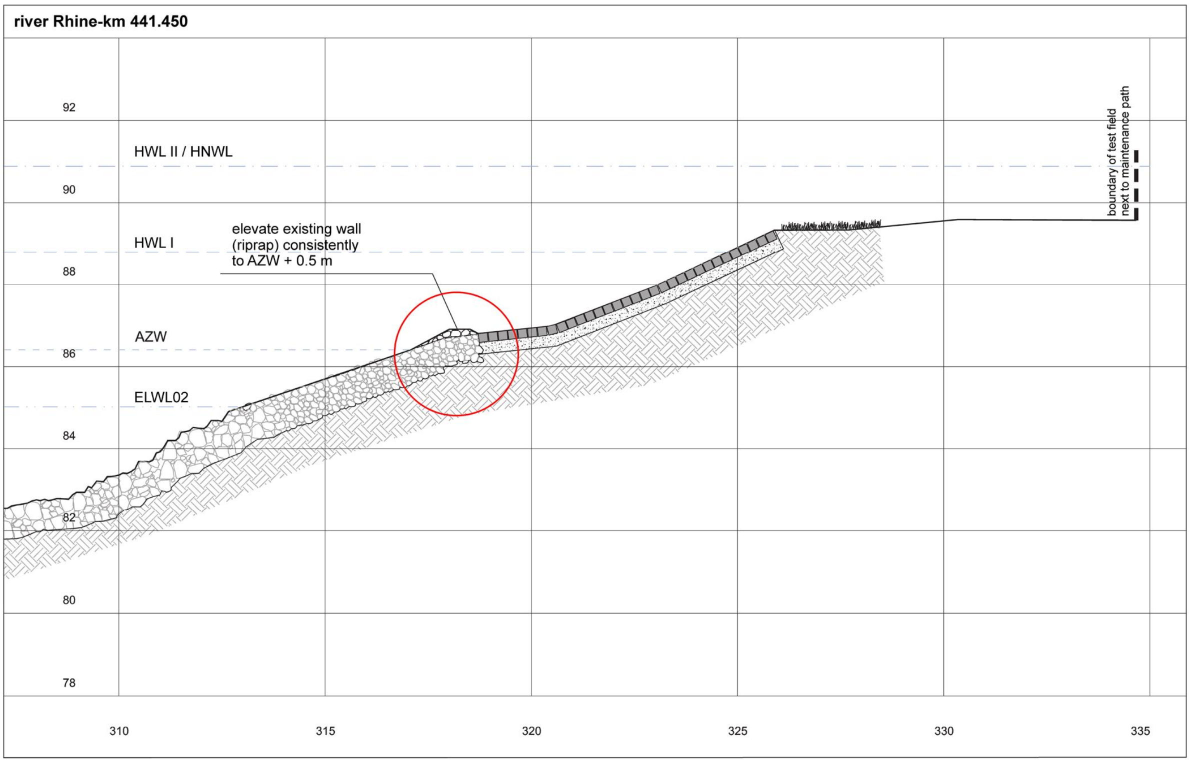

Figure 42: Slope cross section – test field 8 [2]

3.2.8.3 Construction Period

Week 37 (installation in the period from 12.09.11 to 16.09.11)

3.2.8.4 Photo Documentary

Figure 43: Finished test field 8 (14.12.2011), view from the river Rhine

Figure 44: Test field 8 prior to the construction measure (22.04.2009)

Figure 45: Finished test field 8 (14.12.2011) with stone wall

3.2.8.5 First Installation Experiences

During the installation of armourstones with the compact excavator (7 t) it was to be ensured that local settlements of the existing pavement are avoided. This risk was present as local voids exist below the pavement due to undermining. Damages that occurred were repaired. In order to be able to work with heavy machines in the slope area several woody plants had to be cut back.

3.2.9 Test field 9: Removal of riprap, acceptance of free erosion and succession, wooden groyne, log branch cuttings (Rhine-Km 441.475 to 441.600 – 125 m TF-length)

3.2.9.1 Description

This test field of 125 m length runs along the downstream end of the test stretch in the area of the slip-off slope at a larger distance to the navigation channel. In this area the ship-induced loads on the bank are significantly decreasing which is why the attempt was made to leave the slope unprotected over a length of approx. 110 m above AZW after the riprap was removed from the slope area. The bank has thus the opportunity to develop in a manner close-to-nature (Figure 48). Only at the end of the test field that is at the transition to the unchanged bank with riprap a wooden groyne (tree trunks arranged in the form of a Spanish fan) was buried in the slope, armourstones were placed onto it and it was covered with brush layers installed in rows transversally to the direction of flow (Figure 47, 49). The wooden groyne shall protect the adjacent slope area with navigation sign and the stairs on the river bank against erosion. In order to limit its autonomous development willow log branch cuttings were installed above the top of the slope at a distance of approx. 2 m along the maintenance path. All details are listed in table 10.

Table 10: Details test field 9

element	material/plant species	dimensions
wooden groyne (tree trunks arranged in the form of a Spanish fan)	4 trunks of native deciduous woody plants (beech) + 4-5 trunks of native deciduous woody plants (beech)	length: 8 to 10 m Ø: 70 to 90 cm length: 5 to 8 m Ø: 30 to 40 cm
brush layers	living willow branches grown as straight and consistently as possible species: purple willow, basket willow, white willow, broadleaf osier	length: 70 to 90 cm Ø: 2 to 4 cm
willow log branch cuttings	living willow branches grown as straight and consistently as possible species: white willow, basket willow	length: min. 2 to 2.50 m Ø: 10 to 15 cm

3.2.9.2 Objective

In general

- observe the development of a bank without bank protection measures after removal of riprap
- allow erosion processes to take place under observation

Bank protection

- no bank protection measures
- limitation of erosion through the installation of willow log branch cuttings and a wooden groyne (tree trunks arranged in the form of a Spanish fan), protection of top of slope and the adjoining maintenance path as well as protection of the adjacent slope area with navigation sign and stairs on the river bank

Ecological enhancement

- autonomous development allowed to a limited extent. The bank will flatten over the course of time, natural scarps might possibly develop
- promotion of free succession
- expose fine substrate through the washing-out of water
- promote soil fauna, especially the species of open sandy to gravelly habitats (e.g. river bank specialists among the ground beetles)
- create food habitats for birds
- digging bees and wasps will possibly settle on scraps
- wooden groyne as potential settlement substrate e.g. for insects that inhabit woody plants
- initiate wood vegetation on the top of the slope
- increase structural diversity of the wooden groyne

3.2.9.3 Construction Period

From week 38 to 49 (installation in the period from 20.09.11 to 08.12.11)

3.2.9.4 Photo Documentary

Figure 46: Slope after removal of riprap (11.10.11)

Figure 47: Tree trunks (beech) needed to construct the wooden groyne (11.10.11)

Figure 48: Bank erosion processes after a higher water level (20.10.11) – installation site of the wooden groyne is marked in red

Figure 48 clearly shows first bank erosion processes after a short water level elevation to about 86.8 m a.s.l. (see hydrograph in Figure 2). Especially the fines were washed out of the conglomerate of stones and soil [5] below the removed riprap. The slope visibly flattened in the flood plain.

Figure 49: wooden groyne with brush layer adjoining above (8.11.11)

3.2.9.5 First Installation Experiences

No problems occurred during the construction of the test field. The planned bank flattening was not carried out. Erosion processes (slight flattening of the lower slope area) were clearly visible after the first higher water level.

4. Monitoring plan

4.1 Basics

Basically there are three aims of the monitoring plan:

1. evaluation of the technical effectiveness of the bank protection measures with regard to guaranteeing bank stability under the prevailing hydraulic loads
2. evaluation of the ecological effectiveness of the bank protection measures among others against the background of the European Water Framework Directive (WFD)
3. evaluation of the maintenance measures (care, restoration)

In order to evaluate the technical effectiveness of the measures, the state of the vegetative and technical elements of the individual bank protection measures and the geometry of the bank slopes must regularly be recorded and assessed. Thus, first and foremost an ongoing evaluation of the state and stability of the bank slope is required. As a basis hydraulic loads due to navigation and flood at different water levels are determined in individual measurement campaigns.

In order to evaluate the ecological effectiveness of the measures, the development of vegetation and selected species of fauna are examined at defined time intervals.

Both the examination and evaluation of the technical aspects as well as the observation and assessment of the ecological aspects form the basis for the overall evaluation of the newly installed technical-biological bank protection measures. On this basis, application opportunities and possibly limits of alternative technical-biological bank protection measures at inland waterways will be drafted.

In addition, all maintenance and development measures that are carried out in the first five years irrespective of potentially occurring damages are recorded within the frame of the monitoring.

The monitoring also serves to initiate maintenance or restoration measures in a timely manner should bank instabilities occur. It is expected that the planned measures will provide sufficient bank protection regarding the estimated loads. Since it is a field test, however, possible damages cannot be excluded with certainty in advance. Indications for damages are to be detected at an early stage within the frame of this monitoring. The consequent restoration measures will be documented in detail.

In particular the monitoring includes the following key issues:

- bank stability
- hydraulic loads
- climatological data
- vegetation
- fauna
- maintenance measures
- damages/ restoration measures

All observations, measurement results and data are recorded in a log that is kept over the entire monitoring period.

The table in annex 2 provides an overview of the entire monitoring measures.

4.2 Bank Stability

The following examinations are planned to evaluate the bank stability:

Bank inspection: Visual assessment of bank protection measures

The state of maintenance of the vegetative and technical elements of the bank protection measures is recorded during different inspections carried out at various time intervals. In order to evaluate the state of bank protections, possible damages, defects, slope deformations, erosion, slides and the like are especially recorded. The results are documented in writing in the monitoring log, verified with pictures and evaluated with regard to bank stability. The bank inspections are carried out after the completion of construction and in the first five years thereafter four times a year. Additional inspections are planned after major flood events, heavy rainfall, dry periods and other extreme weather conditions.

Photo documentary: Pictures of individual test fields

Single test fields are photographed at time intervals from the water in order to systematically record the development of vegetative elements. The first pictures of test fields 5 and 7 were already taken on 18.11.2011 after completion of construction.

Photo documentary: Panoramic pictures

For comparative purposes numerous pictures of the initial state prior to the construction works were already taken in 2010 and 2011 during different seasons. All pictures were similarly taken from the same position on the opposite bank. During the construction period pictures were taken once a month. Within the frame of the post-monitoring pictures shall be taken two or three times a year during different seasons in order to record the development of the single measures and thus gain a complete overview. Additional pictures may be necessary after special events such as flood events or heavy rainfall.

Measurement: Cross section measurements/ terrestrial measurement of bank areas

The initial state prior to construction works was already measured. After the completion of construction the firm Intermetric will carry out an inspection measurement recording the initial state of the new bank protections as a basis for comparison for the following measurements. The overall slope geometry (including the area underwater) is to be measured and evaluated regarding possible changes especially deformations and erosions once a year. Additional measurements might be necessary due to the results of the bank inspection and after special events, such as flood events or heavy rainfall.

Pore water pressure measurements in the soil in test field 3:

The water level drawdown which occurs during ships' passage can lead to excess pore water pressures in the soil in place in the bank area. The size of the excess pore water pressures substantially determines the stability of the bank slope. In November 2011, a total of 17 pressure cells were installed below the willow brush mattresses at different depths in two measurement cross sections in test field 3 at km 440.900 below the slope surface. One measuring-point lies at the intersection of the top of the slope with AZW (MP1a), another at AZW + 1.50 m (MP1b). Five pressure cells each were arranged at MP1 and MP2 in a vertical borehole at depths of 0.00 m, 0.10 m, 0.20 m, 0.40 m and 0.70 m below the slope surface (Annex 3). In MP1 the measurements mostly take place redundantly at 10 pressure cells. Additionally, 2 pressure cells are arranged in the riprap revetment at the height of AZW - 0.5 m to redundantly measure the water level deviation during ships' passage (MP2). The wires were led through conduit lines to the top of the slope and there into a protection box which is attached to a Km-sign. Corresponding devices can be connected to carry out measurements. The measurements take place during individual measurement campaigns at various water levels of the Rhine (several times per year) and during all measurements on hydraulic loads (see Point 2.3). The results provide important information on how roots of the vegetative protection measures at different development states influence the excess pore water pressure in the soil and thus the slope stability. The measured pore water pressures serve also as input quantity for calculations and evaluations on the slope stability during ships' passage.

4.3 Hydraulic Loads due to Navigation

Already prior to construction, the hydraulic loads due to navigation were measured by the firm Schmid by order of the BAW over a period of 7 days at water levels between AZW and AZW - 0.5 m in August 2009. The campaign was recorded in a report [6].

As of 2012 it is planned to carry out further measurement campaigns to record hydraulic bank loads due to navigation especially at water levels HWL I and HWL II (= HNWL). Due to large water level fluctuations of up to approx. 6 m between ELWL and HNWL hydraulic bank loads due to navigation are very much dependent on the specific water level. Since the test stretch starts in an undercut slope with the channel situated close to the bank and ends downstream in a slip-off slope (channel very far away from the bank), the bank loads are different in size even in the single test fields. The exact knowledge of the hydraulic loads is an important basis for the evaluation of the load-bearing capacity of the individual bank protection measures regarding erosion and slope stability. At the same time it is planned to assess the roughness of the different technical-biological bank protections in comparison with the roughness of the riprap. The slope roughness in the newly designed test fields which changes with increasing growth of vegetation in turn influences the flow velocities and wave heights close to the bank. Thus, the measurements are repeated after approx. 2 and 4 years at about the same water levels.

The purpose of the single measurement campaigns was to measure the ship-induced loads for the prevailing water levels each. Three to four sections are selected for the measurement. The measurements are carried out in the sections where vegetative bank protections were installed that react particularly sensitive to bank loads. These are test fields 2, 3, 5 and 7.

The following sizes were measured and recorded during the single measurement campaigns:

- **recording the fleet of vessels** including the ships‘ dimensions, draughts, distances to the bank and ship speeds recorded with a digital radar detection system
- **measurement of ship-induced wave heights close to the bank** such as bow, stern and secondary wave heights employing pressure probes. Depending on the water level 2 to 4 points of measurement per cross section are installed in the area of the new technical-biological bank protection measures. The points of measurement are arranged approx. 2 m apart (transversally to the direction of flow) whereas the landward outermost point of measurement must lie approx. 0.5 m below the present water level (Annex 4, upper picture). Two pressure probes are installed at every point of measurement to guarantee redundancy of data.

- **measurement of ship-induced (and natural) flow velocities close to the bank** in three spatial directions using flow probes at the abovementioned points of measurement. Thus, at first the return current is determined using the velocity component parallel to the direction of flow in order to evaluate the bank load regarding erosion. In addition, the velocity component transversally to the main direction of flow is determined from which in turn the roughness of the bank protection can be determined. Since the ship-induced bank loads are superimposed by the natural flow, the measurement results include both influences on the bank. The measuring probes are each placed at a distance of 3 m in the dip direction of the slope in the area of the new technical-biological bank protection measures, whereas the uppermost probe is placed three meters from the point of intersection of the present water level line with the slope surface (Annex 4, lower picture). For comparative purposes a probe is placed on the existing riprap below AZW, approximately at half height between bottom and AZW. Since three points of measurement in transverse direction are required to determine the roughness, evaluating the transversal speeds is only reasonable at sufficiently high water levels (approx. from HWL I).
- **video recordings of the waves impacting the bank** were carried out, in order to record the reaction of the new bank protection measures to the natural and ship-induced hydraulic loads.

4.4 River Hydraulics

In addition to the hydraulic loads due to navigation, hydraulic loads due to natural flow impact the bank which are also measured and recorded. The water levels of the river Rhine are continuously recorded at the Worms gauge and are thus available for evaluations. Among other things maximum and minimum water levels, duration of floods of the new bank protection measures and dry periods can be determined from the hydrograph. This information is important to evaluate the development of the vegetative bank protection elements, but also for the evaluation of the natural succession and the faunistic settlement.

During a flood event on 15 January 2011 flow velocities close to the bank were measured by the firm Schmid by order of the BAW (Worms gauge on this date: 89.85 m a.s.l.). The results are depicted in a measurement report [8].

Within the frame of the planned measuring campaigns to determine the hydraulic bank loads due to navigation beginning in 2012 (see Point 4.3), flow velocities are also measured in each river cross section at the abovementioned points of measurement with an ADCP-system. Thus not only the flow velocities close to the bank are available, which are necessary to evaluate the natural and ship-induced hydraulic loads on the bank, but also the velocity distribution in the entire river cross section. The latter can be used for comparison with admissible flow velocities for vegetative bank protections from literature which usually refer to the main channel.

4.5 Climatological Data

Since living plant material is mainly used for technical-biological bank protections, climatological factors also influence its development and thus its protective function for banks. Especially temperature and precipitation are to be recorded for future evaluations. If necessary, data can be provided by the meteorological station of the University of Applied Sciences in Worms (http://wetter.fh-worms.de).

4.6 Vegetation

Due to the novelty of the measures examining, evaluating and recording the development of the plants or plant communities in the new technical-biological bank protections is necessary. Furthermore, the settlement potential of the newly designed bank sections is examined. The bank sections in which structures to promote a natural succession of native plant species were installed constitute the main focus in this process.

In spring 2009 the current state of phytosociology was already recorded. Thus, the species combination and zonation of species in the bank area were determined prior to the beginning of construction works. The results of this assessment served as an orientation for the species selection and the planting method (zonation) which were determined for the vegetative protection elements of the new technical-biological bank protection measures. Moreover, in a future comparison of the assessment of the current state with the individually re-designed bank sections conclusions can be drawn on the effectiveness of vegetative elements and the settlement potential of technical-biological bank protections.

The monitoring which was initially planned for a period of five years includes stocktaking of the vegetation directly after the construction of the measure as well as after specific time intervals which will be determined in the course of the monitoring. Several inspections per year (spring, summer, possibly fall) will take place. The examinations are carried out in the nine bank sections with different technical-biological protections and for comparative purposes in two reference stretches (100 m reference stretches each at the downstream and upstream end of the test stretch) on the entire bank slope up to the maintenance path. Thus, a planar biotope type mapping will be carried out. Furthermore, the vitality of the plants as well as dominant, characteristic, rare, endangered and protected plant species will be recorded. Additionally, transect recordings, control of undesirable neophytes and a photo documentary are carried out in selected bank sections.

Firstly, the monitoring results can be used to evaluate the development and settlement potential. Secondly, conclusions can be drawn on the suitability of different vegetative construction methods, plant species and planting methods regarding their protective function for the bank and hydraulic load-bearing capacity under the given boundary conditions. Furthermore, the contribution of technical-biological bank protections to the ecological enhancement of the bank can be assessed.

On the basis of a documentary on the vegetative development carried out in the year after the completion of the test stretch, first recommendations on care for the vegetative protection elements tailored to the location can be compiled, reviewed and if necessary adapted during the monitoring period.

An evaluation and a graphical representation of all data with a final assessment of the individual vegetative bank protection measures are carried out, on the one hand with regard to guaranteeing sufficient bank protection and on the other hand with regard to the ecological requirements, e.g. due to the Water Framework Directive.

4.7 Fauna

The indicators birds, ground beetles, spiders, reptiles, macrozoobenthos and fish were selected to evaluate the technical-biological bank protections. The monitoring includes recording the current state prior to the beginning of the construction measure (pre-monitoring) and success control after completion of the test stretch (post-monitoring). The adjacent bank section downstream with a length of 300 m was selected as a reference.

The current state was recorded in the period from April to October 2010. In order to determine the settlement potential of the terrestrial fauna, adjacent biotopes such as reeds and meadows were also examined in addition to the test and reference stretches.

The post-monitoring will be limited to the test and reference stretches. With the exception of fish, the success control starts in spring 2013 when the construction influences have decreased and vegetation development has started in the test stretch. The monitoring of fish already starts in early summer 2012 and will be continued in 2013. Further examinations on fauna will be carried out in 2014 and 2016 so that data from the settlement of the 2nd, 3rd and 5th year after completion of the test stretch will be available (fish 1st, 2nd, 3rd and 5th year).

A monitoring procedure is designed for every animal group which will be maintained throughout the years and thus guarantees comparability of data. If possible the methods and acquisition times of the success control will be selected according to those of the record of the current state. The mapping of breeding birds will be carried out with a combination of transect mapping and territory mapping during five inspections per year in the period from April until the end of June. Ground beetles and spiders will be recorded using ground traps in three catching periods of each two weeks in spring/early summer and two catching periods of two weeks in fall. Visual observations of reptiles will be documented during three inspections per year in spring and summer. The fish community will be determined depending on the water level per electrical fishing with the point abundance method in the specific monitoring year in June and September. The areas behind the stone walls in the test fields 1 and 8 and the dead wood structures (fascines, tree trunks) should lie significantly underwater in the course of this. The same holds true for sampling the macrozoobenthos which is generally carried out in spring or early summer of every monitoring year. Recording the current state prior to the beginning of the construction measure was carried out in the course of the long term monitoring of the macrozoobenthos at the river Rhine in May 2010 using grab sampling. The test fields are examined individually with different methods during the post-monitoring (grab sampling, kick sampling, collection by hand). Dead wood structures constitute a focal point in this process.

The technical-biological bank protection measures offer potential to promote species and groups of species and as well as to increase biodiversity. On the whole, this shall be examined and evaluated for all animal groups.

4.8 Maintenance Measures

All maintenance measures that are carried out in the first 5 years after completion of construction works are documented in detail in writing and in photographs: type and location of the measures, construction period, construction duration, objective and costs.

With completion of the construction measure in December 2011 the initial maintenance is carried out by the construction firm until the next dormancy period in October 2012. Plant growth maintenance in the following two years 2013 and 2014 is not to be expected. Control and elimination of invasive species might be necessary. First pruning is to be carried out depending on the growth progress of the willows. If necessary the growth progress and root development of the willows can be supported with pruning after 3 years. Afterwards pruning is presumably carried out every 5 years. Documenting the measures beyond 2016 is absolutely essential.

4.9 Damages/ Repair Works

All repair works that will become necessary in the area of the test stretch due to damages will be documented in detail with notes and photographs which are recorded in the log already mentioned under point 4.1. However, not only the individual damages and repair works will be specifically described (location, date and time, duration, scope and elements of repair works, etc.), but also the costs will be documented. Furthermore, the measures are to be captured in photographs after completion. Documenting the costs beyond 2016 is absolutely necessary.

4.10 Evaluation and Assessment of the Monitoring Results

All results of the monitoring will be evaluated and assessed once a year by the BAW and BfG in cooperation with the Waterways and Shipping Office Mannheim. They form among other things the basis for annual reports of the test stretch sent to the Federal Ministry of Transport and Digital Infrastructure (at the beginning of each year). In 2016 an overall evaluation will be carried out and documented in a detailed report after an operating period of 5 years. According to current knowledge, a further monitoring is necessary beyond 2016. The time intervals for the different measures will be determined on the basis of the results obtained until 2016.

5. Outlook

It is expected to gain important insights from the results of the test stretch on the application possibilities of technical-biological bank protections at large rivers such as the Rhine, but also at waterways in general. The different bank protection measures tested will be evaluated with regard to the installation conditions, installation periods, load-bearing capacity in the initial state and in the long term, flooding tolerances, maintenance measures, but also regarding construction and maintenance costs. Together with the experiences already acquired from the test stretch Stolzenau at an impounded smaller river, recommendations for further applications at waterways will be outlined.

As a first step it is planned to draft individual “specifications“ on the tested measures and to publish them on the web portal on technical-biological bank protection measures applied at federal waterways which was set up by the BAW and BfG several years ago (http://ufersicherung.baw.de/de/index.html). Hence, increasingly improving foundations on the application of close to nature technical-biological bank protection measures applied at waterways can be provided.

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Abbreviations used

a.s.l.	above sea level
AZW	Ausbauzentralwasserstand (Rhine-specific water level for hydraulic constructions which is about 20 cm below mean water level)
BAW	Bundesanstalt für Wasserbau (German Federal Waterways Engineering and Research Institute)
BfG	Bundesanstalt für Gewässerkunde (German Federal Institute of Hydrology)
CP	Coarse Particles (grain size class of armourstones)
ELWL	Equivalent Low Water Level
H	Height
HGV	Heavy Goods Vehicle (corresponding to German SLW)
HNWL	Highest Navigable Water Level
H_{uB}	Bow wave height
H_{uH}	Stern wave height
HWL I	high water level I
HWL II	high water level II
L	length
lfm	running meter
LMB	Light Mass Category B (weight class of armourstones)
MP	measuring point
OK	top of measuring device
PWD	pore water pressure
Qty.	quantity
TF	test field
v_{str}	flow velocity
W	width
z_a	water level drawdown
τ	shear stress

Annexes

Annex 1: Test Stretch River Rhine, km 440.6 to km 441.6, right bank – Overview of Existing Boundary Conditions (from BAW/BfG report)

Dimension / Situation	Rhine-km 440.6 to km 441.6, right bank (1 km-length) test stretch at the banks of the river Rhine below the junction of the Lampertheimer cut-off meander in the landscape protection area „Rheinhessisches Rheingebiet" (Rhine Hessian Rhine Basin)
Initial State of Bank Protection	technical revetment - classic riprap without an additional filter layer loose armourstones of the stone size class $LMB_{5/40}$ with a layer thickness of 60 to 90 cm old pavement exists locally
Bank Geometry	slope inclinations: 1:2 to 1:3 slope height: 10 m (km 440.6) …. 7 m (km 441.6) adjacent terrain to the top of slope: approx. 90.0 m a.s.l.
River Geometry	in direction of flow transition from undercut slope to slip-off slope km 440.6: area of undercut slope, channel close to the bank (approx. 25 m) km 441.6: area of slip-off slope, channel far away from the bank (approx. 140 m)
Subsoil	from about HWL I to approx. 3 m below the bottom of the Rhine: gravelly sands, little to medium strength, silt lenses above approx. HWL I: alluvial silt (layer thickness: 1.5 to 2.5 m)
Hydrology/ Bank Loads due to Natural Flow (Measurement Campaign 2011 at HNWL)	flow velocities close to the bank: 2 m/s (measured on 15.01.2011)
Hydrology/ Bank Loads due to Natural Flow (from HN-Models)	water level fluctuations between ELWL and HWL II / HNWL from approx. 6 m Worms gauge (km 443.3, left bank): ELWL: + 84.81 m a.s.l., AZW: 86.19 m a.s.l., HWL I: 88.56 m a.s.l., HWL II / HNWL: 90.66 m a.s.l. flow velocities and shear stresses close to the bank:

	HWL I: v_{Str} = 0.99 *(km 440.6)* … 0.95 m/s *(km 441.6)* τ = 3.6 *(km 440.6)* … 3.4 N/m^2 *(km 441.6)* HWL II / v_{Str} = 1.5 *(km 440.6)* … 1.3 m/s *(km 441.6)* HNWL: τ = 7.0 *(km 44.,6)* … 5.7 N/m^2 *(km 440.6)*
Hydraulic Loads due to Navigation (Measurement Campaign 2009 at AZW – 0.25…0.60 m)	maximum bow wave height: H_{uB} = 0.51 *(km 440.6)* … 0.40 m *(km 441.6)* maximum stern wave height: H_{uH} = 0.81 *(km 440.6)* … 0.43 m *(km 441.6)* maximum secondary wave height: H_{uS} = 0.57 *(km 440.6)* … 0.43 m *(km 441.6)* maximum flow velocities (km 440.6): 0.93 m/s
Hydraulic Loads due to Navigation (calculated according to GBB)	maximum bow wave height: H_{uB} = 0.75 *(km 440.6)* … 0.19 m *(km 441.6)* at ELWL H_{uB} = 0.65 *(km 440.6)* … 0.26 m *(km 441.6)* at HWL I H_{uB} = 0.63 *(km 440.6)* … 0.26 m *(km 441.6)* at HWL II / HNWL maximum stern wave height: H_{uH} = 1.10 *(km 440.6)* … 0.30 m *(km 441.6)* at ELWL H_{uH} = 0.85 *(km 440.6)* … 0.35 m *(km 441.6)* at HWL I H_{uH} = 0.84 *(km 440.6)* … 0.36 m *(km 441.6)* at HWL II / HNWL max. water level drawdown: z_a = 0.99 *(km 440.6)* … 0.25 m *(km 441.6)* at ELWL z_a = 0.80 *(km 440.6)* … 0.32 m *(km 441.6)* at HWL I z_a = 0.80 *(km 440.6)* … 0.32 m *(km 441.6)* at HWL II / HNWL max. flow velocities: v_{str} = 1.95 *(km 440.6)* … 1.14 m *(km 441.6)* at ELWL v_{str} = 1.38 *(km 440.6)* … 1.38 m *(km 441.6)* at HWL I v_{str} = 1.39 *(km 440.6)* … 1.39 m *(km 441.6)* at HWL II / HNWL
Initial State of Vegetation	little species diversity (no protected species, mainly thorny berry bushes, generalists, invasive woody plants such as box elder and hybrid poplars), little vegetation zonation, hardly any structural diversity, little settlement potential due to the thick riprap and the high hydraulic loads

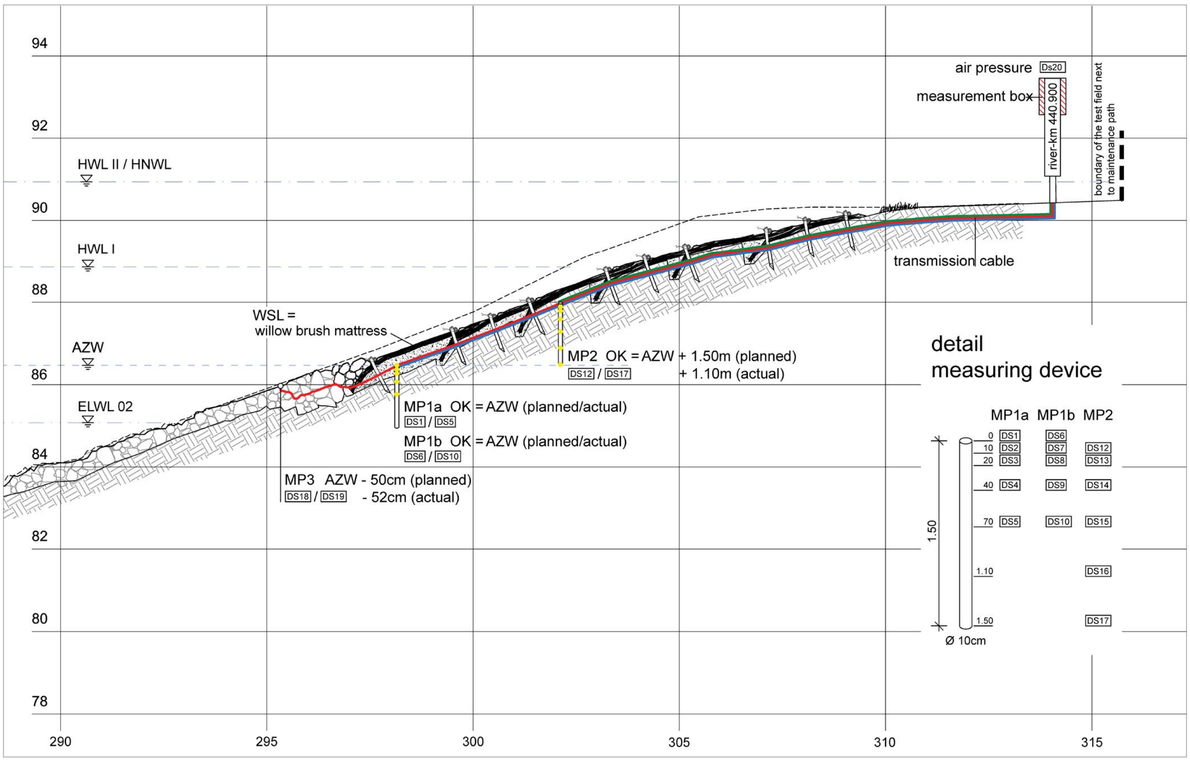
Initial State of Fauna	little species diversity; river bank specialists are not present among the terrestrial fauna groups, species without any specific habitat requirements are mainly dominant; invasive species are dominant among the aquatic fauna.

Annex 2: Test Stretch River Rhine, km 440.6 to km 441.6, right bank – Overview of Monitoring Measures 2012 to 2016

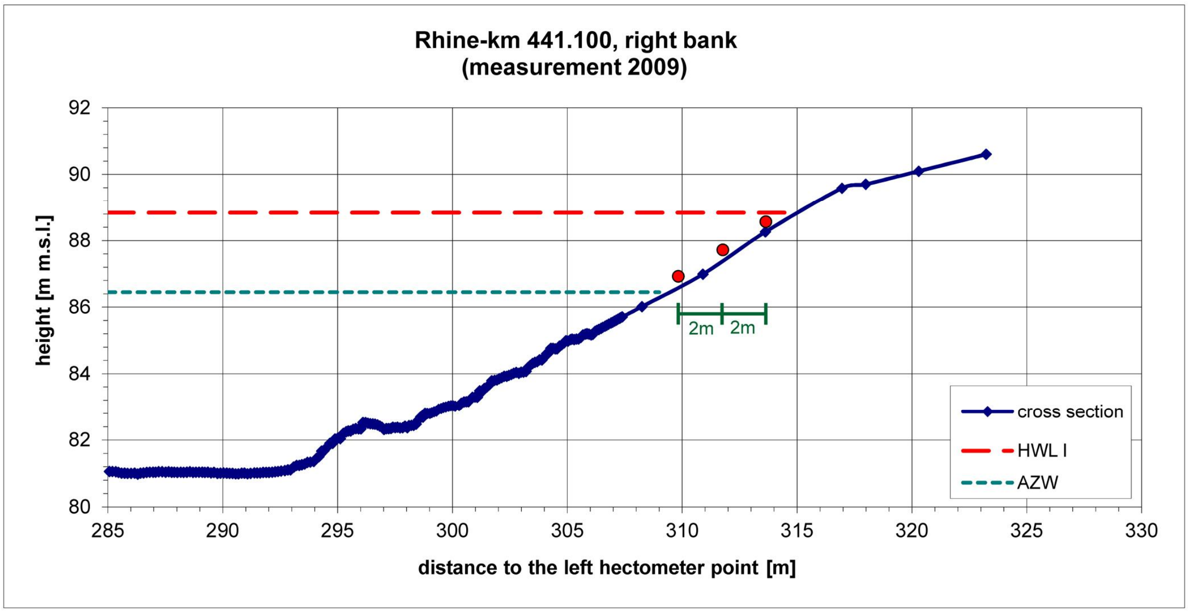
		Implementation of the individual monitoring measures					
		2012	**2013**	**2014**	**2015**	**2016**	**Comments**
Bank Stability	**Bank Inspection**	quarterly inspections, additional inspections after extreme events (e.g. flood, heavy rainfall, dry periods)					
	Photo Documentary	for all bank inspections					
	Panoramic Pictures	2 to 3 panoramic pictures per year, if necessary additional pictures after extreme events (e.g. flood, heavy rainfall, dry periods)					
	Topographic Measurement	1 measurement per year, if necessary additional measurements after extreme events (e.g. flood, heavy rainfall, dry periods)					
	PWD-measurements	1 measurement of pore water pressures per year and for all measurements of hydraulic bank loads					
Hydraulic Loads	**Ship-induced Loads**	2 measurements at water levels above AZW (HWL I, HWL II / HNWL)			2 repeated measurements at water levels above AZW (HWL I, HWL II / HNWL)		
	Natural Loads	2 measurements at water levels above AZW (HWL I, HWL II / HNWL)			2 repeated measurements at water levels above AZW (HWL I, HWL II / HNWL)		
Climatological Data		continuous recording and evaluation					
Vegetation		several inspections per year, the time intervals are determined during the monitoring phase					

Fauna	examination of fish (2 campaigns)	examination of fish (2 campaigns) breeding birds (5 inspections), ground beetle, spiders (3 catching periods), reptiles (3 inspections), macrozoobenthos	examination of fish (2 campaigns) breeding birds (5 inspections), ground beetle, spiders (3 catching periods), reptiles (3 inspections), macrozoobenthos		examination of fish (2 campaigns) breeding birds (5 inspections), ground beetle, spiders (3 catching periods), reptiles (3 inspections), macrozoobenthos	
Maintenance Measures	acquisition and documentation of all maintenance and development measures that will (must) be carried out during the test period.					
Damages	continuous documentation if necessary					
Restoration Measures	continuous documentation if necessary					

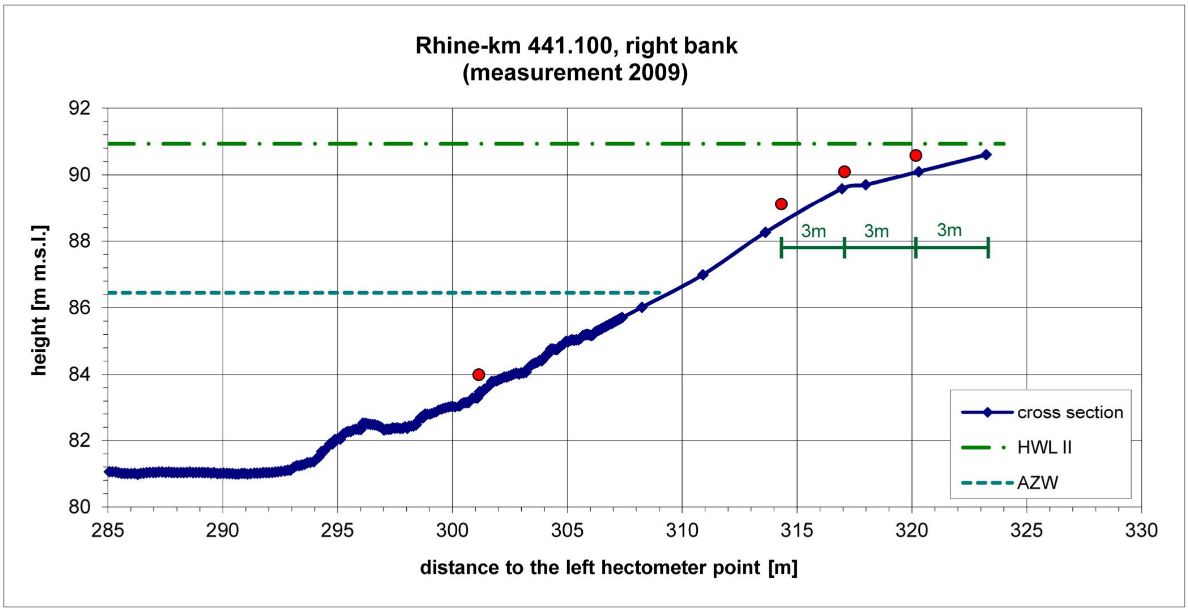
Annex 3: Position of Pore Water Pressure Sensors in Test Field 3



Annex 4: Position of Pressure Cells and Speed Probes during Measurements of Hydraulic Bank Loads due to Navigation



Position of pressure cells at HWL I



Position of speed probes at HWL II = HNWL