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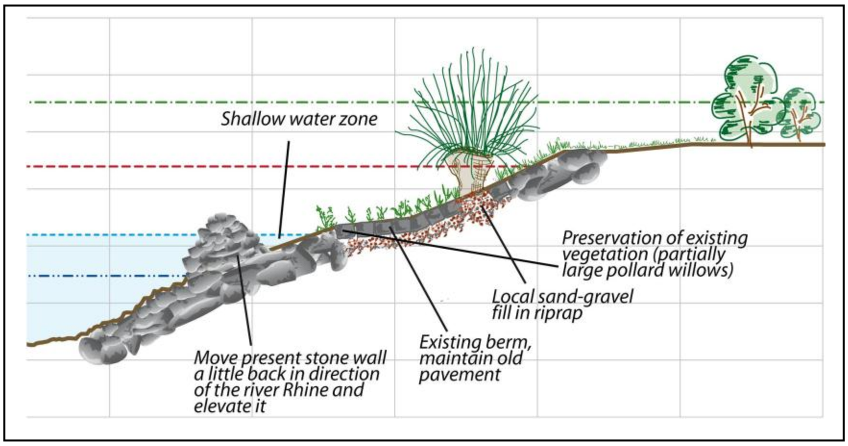

Installation of a Test Stretch with Technical-Biological Bank Protection Measures River Rhine km 440.6 to km 441.6, right bank

Recommendations for the Construction of Bank Protection Measures

07 May 2010

Summary

Within the frame of studies carried out jointly by the Federal Waterways Engineering and Research Institute (BAW) and the German Federal Institute of Hydrology (BfG) on the hydraulic load-bearing capacity and the ecological effectiveness of alternative technical-biological bank protection measures applied on inland waterways, a test stretch is currently being prepared along the river Rhine near Worms. The Federal Waterways and Shipping Administration (WSV), represented by the Waterways and Shipping Directorate Southwest (WSD) and the Local Waterways and Shipping Office Mannheim (WSA), is the responsible authority of this measure. The aim is to test different alternative bank protection measures under known boundary conditions. As a result of this field test, it is expected to gain important insights on the implementation of alternative technical-biological bank protection measures on the river Rhine and on other waterway sections, as well.

In the search for an appropriate test stretch in coordination with the WSA Mannheim, the section km 440.6 to km 441.6 (right bank) of the river Rhine has proven to be well suited for intended purposes. There are plans to apply different alternative bank protection measures on nine individual bank sections. Depending on the measure, the existing riprap will generally be maintained below a Rhine-specific mean water level (AZW or AZW - 0.5 m; AZW is about 20 cm below mean water level). The redesign will only take place in the slope area located above. Here, the riprap will be removed in five sections and a new technical-biological bank protection measure will be implemented. The riprap will be maintained in four sections, measures to improve the loose riprap ecologically will be tested in this area. The slope geometry, as a rule, will not be modified. The bank is to be improved ecologically through the intended measures while maintaining the same level of stability and erosion control. Considerable changes with regard to navigation, water body and navigational issues of water management are not to be expected. The individual measures are described in detail in the present report.

As a first step, crucial geometric, geotechnical and hydraulic boundary conditions were determined at the test stretch and vegetative as well as faunistic studies were carried out, in 2009. The slopes at the right bank of the test stretch, on average inclined between 1:2 or 1:3, are currently secured with loose armour stones of the class $LMB_{5/40}$, the old pavement partially still exists in some places. Overall, the bank is only sparsely covered with vegetation of medium significance. No existence of highly or strictly protected plants was to be found. Mostly gravelly sands of low to medium strength are located in the slope area. The water levels of the river Rhine fluctuate about 6 meters between the equivalent low water level (ELWL) and the highest navigable water level (HNWL II). The banks are exposed to hydrau-

lic loads, on the one hand, through impacts from shipping and on the other hand, through floods. All boundary conditions determined are documented in detail in the present report.

The detailed planning for the redesign of the banks on the test stretch will be carried out by an engineering company commissioned by the WSA Mannheim. Construction is expected to take place in spring 2011. The measures will be monitored comprehensively on a long-term basis.

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0 German Abbreviations

German Abbreviation	Complete German Term	English Explanation
2er SV	1-schiffiger, 2-gliedriger Schubverband	1x2 convoy
AZW	Ausbauzentralwasserstand	Rhine-specific water level for hydraulic constructions, which is about 20 cm below mean water level
B	Boden-Klasse	soil class
BASF	Badische Anilin- und Soda-Fabrik	Baden Aniline and Soda Factory (BASF)
BAW	Bundesanstalt für Wasserbau	German Federal Waterways Engineering and Research Institute
BfG	Bundesanstalt für Gewässerkunde	German Federal Institute of Hydrology
BK	Kernbohrung	core drilling
ES	Europaschiff	European-type ship
ETP	Ersatztrapezprofile	equivalent trapezoidal profiles
FFH	Fauna-Flora-Habitat-Gebiet	flora-fauna-habitat (FFH)
FR	Fahrrinne	navigation channel
GlW	Gleichwertiger Wasserstand	equivalent low water level (ELWL)
GMS	Großmotorgüterschiff	large motor cargo vessel
GOK	Geländeoberkante	ground surface
HN-Modell	hydraulisch-numerisches Modell	hydraulic-numerical model
HSW I	höchster schiffbarer Wasserstand I	highest navigable water level (HNW) I
HSW II	höchster schiffbarer Wasserstand II	highest navigable water level (HNW) II
KV	Koppelverband	special push-tow unit consisting of GMS plus barge
MS	Motorschiff	motor vessel
NN	Normalnull	mean sea level (m.s.l.)
NN+	über Normalnull	above mean sea level

		(a.s.l.)
NNW	niedrigster Niedrigwasserstand	lowest low water level (LLW)
OK	Oberkante	top of slope
PS	Passagierschiff	passenger ship
RhSchPV	Rheinschifffahrtspolizeiverordnung	Rhine Navigation Police Regulations
SPA	Special Protection Area	Special Protection Area
SV	Schubverband	push-tow unit
üGMS	überlanges Großmotorgüterschiff	oversized large motor cargo vessel
WaStrG	Bundeswasserstraßengesetz	Federal Waterway Act
WRRL	Wasserrahmenrichtlinie	Water Framework Directive (WFD)
WSA	Wasser- und Schifffahrtsamt	Waterways and Shipping Office
WSD	Wasser- und Schifffahrtsdirektion Südwest	Waterways and Shipping Directorate Southwest
WSP	Wasserspiegel	water level
WSV	Wasser- und Schifffahrtsverwaltung des Bundes	Federal Waterways and Shipping Administration

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(Note: The appendices are available in German language only)

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1 Motivation/ Objective

In order to protect banks of inland waterways permanently from erosion and other negative impacts due to ship-induced hydraulic loads, they are usually secured with technical revetments such as riprap or sheet pile walls. The basis for the application of these bank protection measures is a corresponding set of rules from the Federal Waterways and Shipping Administration (WSV). The stability of the banks exposed to hydraulic loads of the waterways can be guaranteed based on the guidelines and recommendations included therein. Since the new Water Framework Directive (WFD) and the §§ 8 par. 1, 12 par. 7 of the Federal Waterway Act (WaStrG) came into effect, ecological aspects have become increasingly important for new constructions and development as well as maintenance measures along federal waterways. Apart from technical aspects, ecological aspects are to be considered, as well. This means that the application of close-to-nature technical-biological bank protection measures has to be considered increasingly when it comes to new constructions and development as well as maintenance measures along federal waterways. The aim of applying close-to-nature technical-biological bank protection measures is to protect, improve and develop sensitive habitats in and at waters, as well as to secure ecological functions and to improve the quality of the bank structure while ensuring the bank stability under hydraulic loads as well as the safety of shipping traffic.

However, only little experience has been gathered on the implementation of technical-biological bank protection measures along waterways so far and standards do not exist at all. Therefore, the German Federal Waterways Engineering and Research Institute (BAW) and the German Federal Institute of Hydrology (BfG) have been carrying out studies in a joint research project on the hydraulic load-bearing capacity and the ecological effectiveness of technical-biological bank protection measures with regard to shipping since 2004. The objective is to develop application recommendations and dimensioning standards for their use along inland waterways. First results are available at http://www.baw.de/ufersicherung/index.php. A focal point of the studies includes the performance of field tests in which new bank protection measures are tested on a large-scale under set boundary conditions and on the basis of preliminary findings. Such a test stretch is currently being prepared along the river Rhine near Worms /BMVBS, 2009/. As a result of the field test important insights are expected on how to apply alternative close-to-nature bank protection measures on the river Rhine and on other waterway sections respectively. The Federal Waterways and Shipping Administration (WSV) is the responsible authority of this measure, represented by the Waterways and Shipping Directorate Southwest (WSD) and the Local Waterways and Shipping Office Mannheim (WSA).

In the search for an adequate waterway section in coordination with the WSA Mannheim, the section km 440.6 to km 441.6 (right bank) of the river Rhine near Worms turned out to be well suited due to its boundary conditions. Important criteria for the selection were relatively high ship-induced hydraulic loads, on the one hand, and the usual slope inclinations at waterways of about 1:2 and 1:3, on the other hand. Both criteria generally call for bank protection measures which are to date technical constructions.

First, crucial boundary conditions of the test stretch were determined and on this basis recommendations for the redesign of the bank with technical-biological protection measures were developed, in 2009. The intended measures are to improve the banks ecologically while achieving equal stability and erosion control at the same time. Considerable changes with regard to navigation, water body and water management are not to be expected.

The present report documents the geometric, geotechnical and hydraulic boundary conditions as well as the results of vegetative and faunistic studies in the area of the test stretch, in detail. The new bank protection measures to be carried out are described and depicted in charts. First indications on building construction, subsequent monitoring and maintenance are provided.

The detailed planning will be carried out by an engineering firm commissioned by the WSA Mannheim. The building construction is expected to take place in spring 2011.

2 General Description

The 1-km-long section near Worms chosen from several possible test stretches along the river Rhine extends from km 440.6 to km 441.6 on the right bank. It starts about 200 metres downstream the junction of the Lampertheimer cut-off meander and is, therefore, located outside of the nature, FFH and bird conservation area “Lampertheimer Altrhein” (cut-off meander of the river Rhine near Lampertheim) at the southern edge of the Hessian Upper Rhine plain.

The FFH-area “Maulbeeraue“ (floodplain with mulberry trees) begins about 2.2-km downstream of the test stretch. It extends up to Nordheim and will also not be affected by this measure. The FFH-area “Rhine flood plain Ludwigshafen - Worms” on the left bank of the river Rhine located opposite of the test stretch will not be subject to the redesign of the bank, either.

The test stretch itself is located in the area of the nature reserve "Rhine Hessian Rhine basin" (see figure 1c). The following protective purposes are set out in the respective regulation from 17 March 1977 in §3:

- preserving the character and beauty of the flood plains, which accompany the river Rhine, with its vegetation structuring the landscape and its bordering fluvial terraces, which are either partially gently rising or partially steep and dominate the landscape;
- safeguarding the recreational value of the landscape;
- maintaining a balanced landscape ecosystem through the preservation of natural living conditions such as soil, water, air, climate, fauna and flora.

With regard to the criteria mentioned above, no negative consequences due to the redesign in the test stretch are to be expected.

Worms is located about 2-km downstream on the left bank of the river Rhine (see figure 1a, b and c). The course of the river Rhine is characterized by a transition from a slight bend to the left to a slight bend to the right in the area of the test stretch. Thus, a change from an undercut slope (km 440.6) to a slip-off slope (km 441.6) occurs (see figure 1b).

The geographical location of the test stretch is SE - NW. Therefore, there is plenty of sunlight from noon until late in the evening. Figure 2 shows pictures of the test stretch.

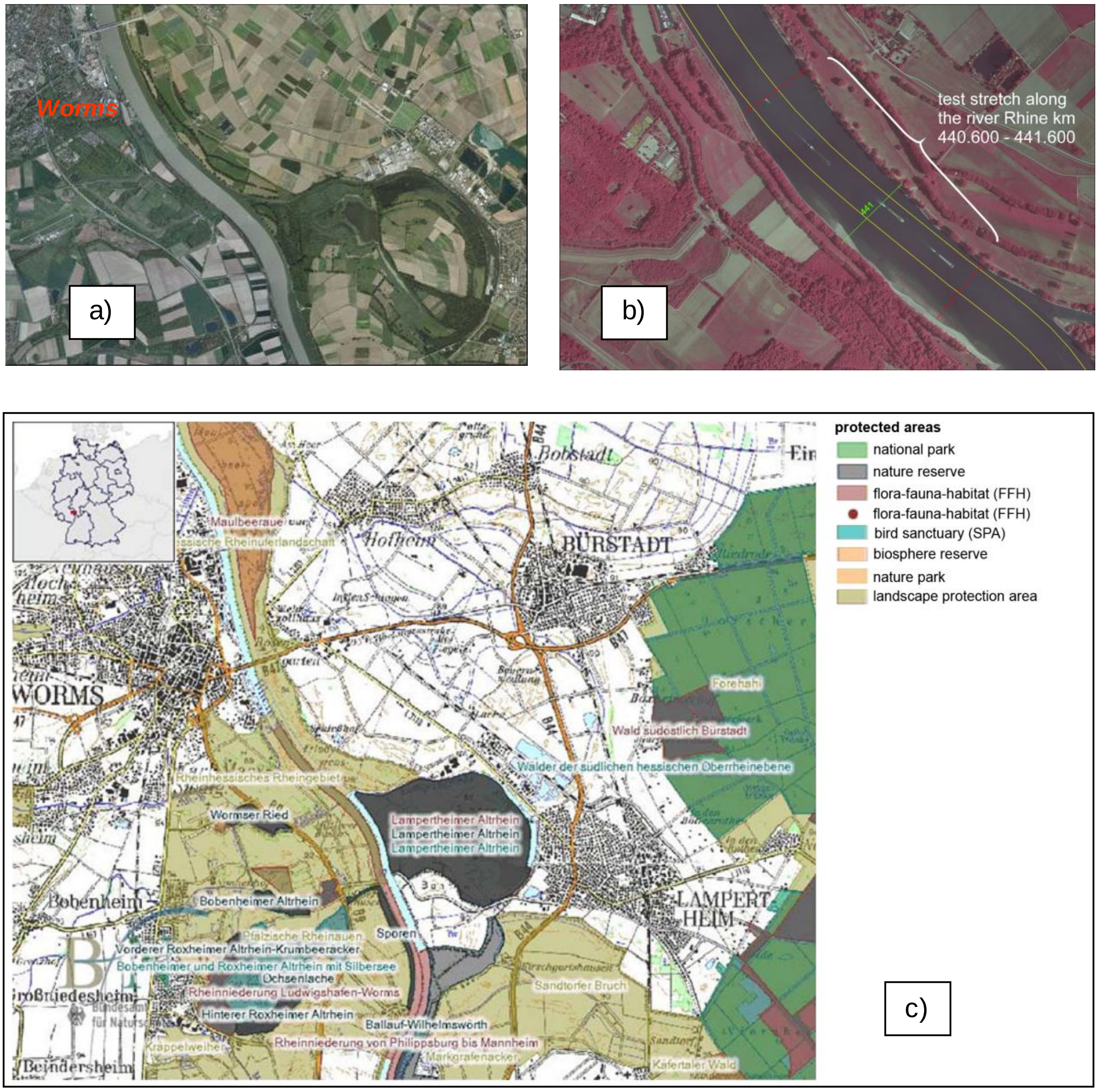


Figure 1: Aerial images of the test stretch; a) geographic location (source: digital orthophotos of the WSV); b) detail from infrared aerial images with channel (yellow lines) (source: NW flights of the WSV 2003); c) overview of the affected conservation areas (source: www.bfn.de)

Figure 2: The test stretch today; (left) riprap with brushwood; (right) poplars at the top of the slope and maintenance path

In order to characterize the water levels in the area of the test stretch, the nearby Worms gauge (km 443.3 on the left bank) may be used with the following characteristic values (see Appendix 16):

ELWL:	m.s.l. + 84.81 m
HNWL I:	m.s.l. + 88.56 m
HNWL II:	m.s.l. + 90.66 m

At HNWL I navigation is allowed to a limited extent only. Downstream navigation must take place in the center of the channel, upstream navigation must take place in the middle third of the channel to minimize the load on the bank (§10.01 RhSchPV, English: Rhine Navigation Police Regulations). Once HNWL II is reached, navigation will completely be stopped. Since the test stretch is located about 2 to 3-km upstream, SL-heights of the water levels are respectively about 20 to 30-cm higher here than at the Worms gauge. A mean water-level shall be decisive for the installation of alternative technical-biological bank protection measures; the selected reference value is the AZW (German: “Ausbauzentralwasserstand”, which is a set water level for hydraulic constructions):

AZW:	km 440.6 …..	m.s.l. + 86.50 m
	km 441.6 …..	m.s.l. + 86.36 m

The water levels “AZW” in the test stretch correspond to the mean water levels from 1991 to 2000 (km 440.6: m.s.l. + 86.65 m; km 441.6: m.s.l. + 86.53 m).

The traffic volume at the level of the test stretch is characterized by

- shipping traffic to or from the southern regulated Upper Rhine to Basel (e.g. ports Strasbourg and Basel),
- downstream shipping traffic (gravel transports) from the Upper Rhine area,
- shipping traffic to or from different inland ports along the Upper Rhine (e.g. Mannheim, Ludwigshafen) and private loading and unloading wharfs (e.g. BASF)
- shipping traffic to or from the river Neckar, whose mouth into the river Rhine is located at about km 430.

According to statistics (Planco-report 2008), about 46.3 Mio t were transported up- and downstream in the area of the test stretch in 2004, which is equivalent to about 47.000 cargo vessels. Therefore, on average about 125 vessels pass the test stretch each day. The average amount of freight of a loaded vessel amounts to about 1300 t. The possible draught of vessels at the free-flowing river Rhine depends largely on the water levels so that the average amount of freight varies a lot.

The fleet is above all comprised of cargo vessels such as European-type ships ES, large motor cargo vessels GMS, oversized GMS (üGMS) and push-tow units (SV) (mostly as 1x2 convoy = *German* 2er SV). The largest vessels are push-tow units, for example the SV Dynamica (214 m x 11.45 m) – a special permit is necessary for this vessel – and the SV Ursa Montana (193.0 m x 17.30 m) with about 10.400 t deadweight tonnage and above 5.000 hp engine power. Furthermore, ship types such as pusher crafts and tug vessels, recreational crafts, passenger ships, cabin passenger ships as well as workboats of the WSV are present. Leisure craft vessels appear more during the summer.

3 Crucial Boundary Conditions/ Initial Condition

3.1 General

In order to choose and dimension the alternative technical-biological bank protection measures, it was necessary to determine and document the crucial boundary conditions in the test stretch as accurately as possible, first. In 2009, studies were carried out, which included the following key aspects:

- current bank protection
- river and bank geometry
- subsoil
- existing vegetation

- fauna
- bank loads due to shipping and natural flow

All results of these studies are presented in a table in Appendix 1 and are briefly described in the following chapters.

3.2 Current Bank Protection

The banks with an average slope inclination of 1:2 or 1:3 are mainly secured with a revetment of loose armour stones from the top of the slope to the river bed. The revetment was examined on site by the BAW in July 2009. The current bank protection measure is in a good condition visually and fully functioning above water level. According to the WSA there is no need for maintenance measures to a far greater extent than normal.

The size and weight of the present armour stones were determined for 50 individual stones at 5 different locations that are easy to access. Thereupon, the top layer is made up of loose armour stones of the stone size class $LMB_{5/40}$ /TLW, 2003/ - see figure 3. The armour stones mainly consist of granite and basalt, partially also of sandstone. Currently no statement can be made on the present layer thickness of armour stones. In spring 2010, it is intended to remove the rock fill locally at several places together with the WSA in order to determine the layer thickness. On this occasion it can also be examined if a filter layer exists below the stones of the revetment.

From about km 441.375 old, well preserved pavement still exists locally about above mean water level. In order to secure the toe of the pavement from scouring it is covered with armour stones. Thus, a small stone wall has already developed (see figure 4).

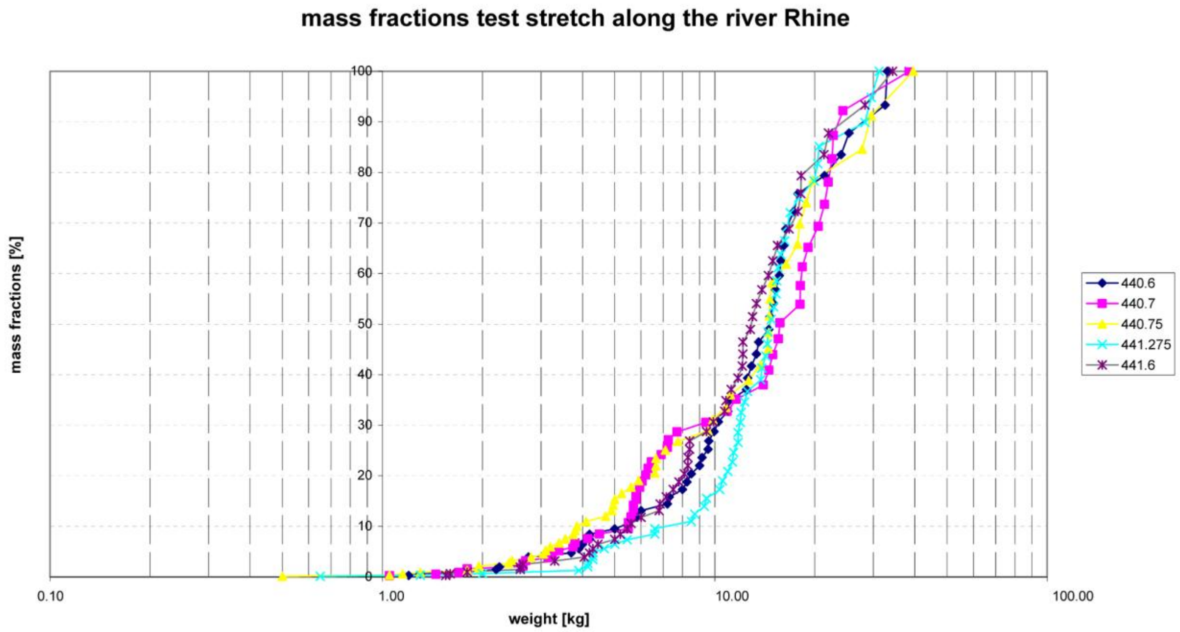


Figure 3: Stone size class of armour stones determined on site

Figure 4: Old pavement at km 441.375 (picture taken during low water)

The area around km 440.950 is currently used as a gravel pit.

3.3 River and Bank Geometry

In the area of the test stretch the river Rhine has a water level width (at ELWL) of 230 metres (km 440.6) to 300 metres (km 441.69). At km 440.6 the right bank has developed an undercut slope and the river cross section is almost triangular with the thalweg close to the right bank. Due to the river course, the undercut slope gradually turns into a slip-off slope in downstream direction. At km 441.6 the thalweg already passes close by the opposing left bank (see figure 5).

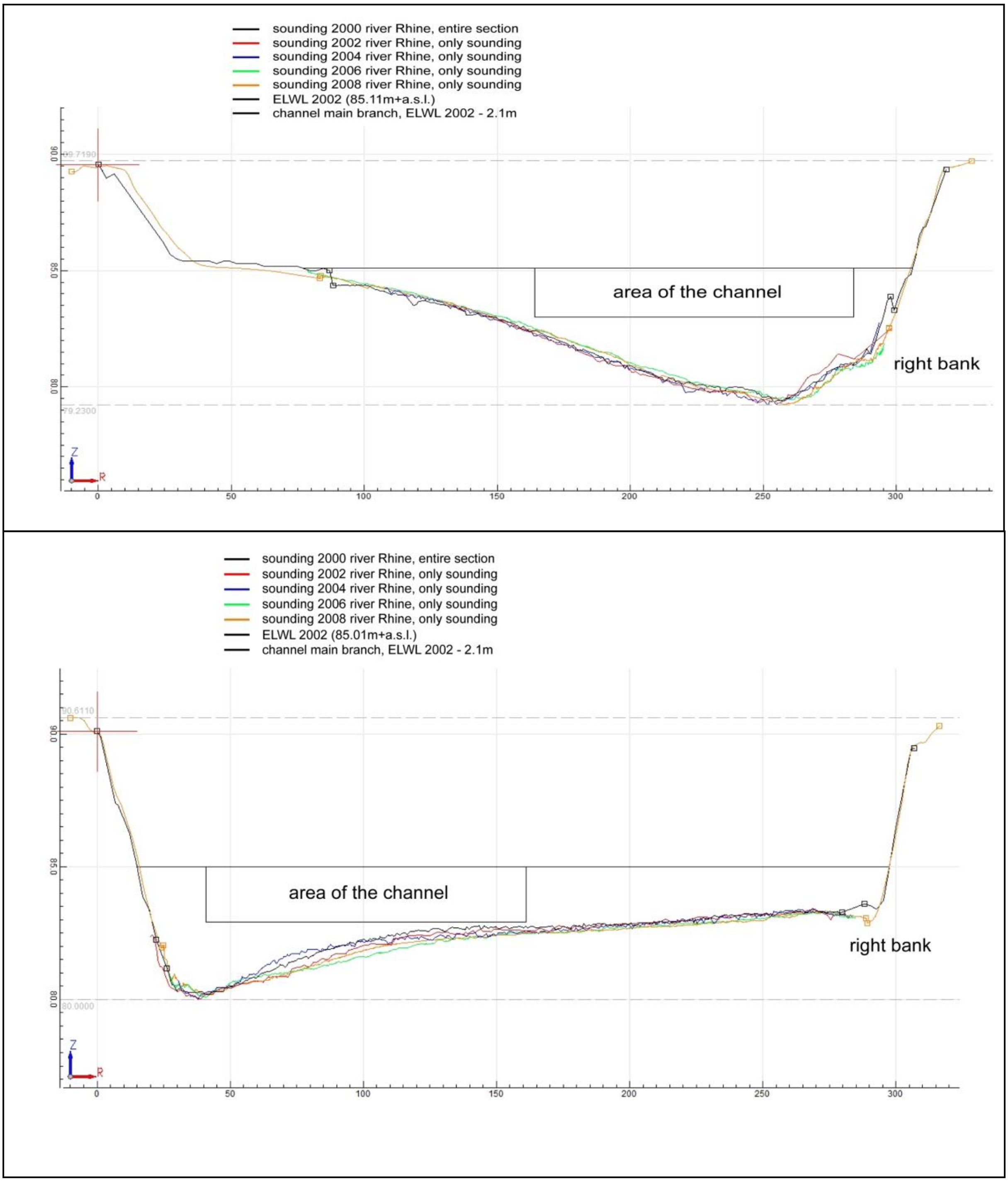


Figure 5: River cross sections (sounding results from 2000 to 2008) at km 440.6 and km 441.6

Figure 5 also shows that the channel passes very close to the bank at km 440.6 (distance about 23 m) which means that ship passages close to the bank and higher ship-induced loads are to be expected here accordingly. In downstream direction the channel deviates increasingly from the bank, at km 441.6 the right edge of the channel is already at a distance of 140 metres from the right bank. This course of the channel meandering between the banks is typical for the entire Upper Rhine. It is a result of the low water regulation at the beginning of the 20th century, which was accompanied by a fixation of the alternating deposits on the right and the left bank through groynes.

In order to determine the present geometry of the right bank, cross section measurements were carried out at a distance of 25 metres, commissioned by and with the support of the WSA Mannheim. In the course of this, the slope of the bank and additionally 5 to 10 metres of the adjacent terrain as well as about 5 metres of the river bed area were recorded. All cross sections are presented in charts in Appendix 2; to assess the existing slope inclinations, inclinations of 1:2 and 1:3 were additionally marked as dashed lines.

The measurements show that slopes usually have an inclination of 1:2 to 1:3. Locally, however, far steeper or flatter inclinations exist also. The slope height from the river bed to the adjacent terrain amounts to almost 10 metres at km 440.4, at the end of the test stretch at km 441.6 it is about 7 metres. The ground surface of the adjacent terrain lies on average at a.s.l. + 90 m.

The slope area above water level, which is relevant to the new bank protection measures, extends from a.s.l. + 86.00 m (AZW - 0.5 m at km 440.6) to a.s.l. + 90 m (GOK). For example, at a height of 4 metres a slope width of 12 metres with an inclination of 1:3 and 8 metres with an inclination of 1:2 is free for design.

3.4 Subsoil

The area of the test stretch is geologically located in the Upper Rhine Graben region. The subsoil in the relevant area consists of soil of the Quaternary (fluviatile sediments), which are crucially influenced by the sedimentation and erosion processes of the river Rhine. Due to accumulation, thick gravel and sand parts with embedded clayey and in parts also peaty layers have developed.

In September 2009, in order to investigate the subsoil in the bank area in detail, the WSA Mannheim commissioned the enterprise Striehl Baugrundbohrungen und Brunnenbau GmbH (specialised in subsoil drillings and well sinking) to carry out the following soundings: 4 core drillings in the area of the maintenance path up to 15 metres below ground level and

4 soundings of the type dynamic probing heavy (DPH) each at a distance of about 3 metres next to the single drillings. In the course of this, disturbed soil samples were removed and examined in the laboratory of the groundworks section at the BAW. Appendix 3 shows the single explorations on the site plan.

Appendix 4 depicts the results of the single drillings each with the corresponding sounding results. The in-situ soil types and the detailed ground layering can be determined from the drilling results. The soundings provide information on strength or density of non-cohesive soil.

First, there is low-cohesive alluvial clay (layer thickness: 1.5 to 2.5 metres) in place in the relevant slope area below a thin topsoil layer. Underneath there are gravelly sands with low to medium strength with local silt lenses (layer thickness: 8 to 9 metres). In the area of BK 1 and BK 2 drillings they are supported by very gravelly sands with high strength and in the area of BK 3 and BK 4 drillings by fine and medium sands. Grading curves, which have been determined from representative, disturbed soil samples are depicted in Appendix 5. Figure 6 offers a geotechnical overview.

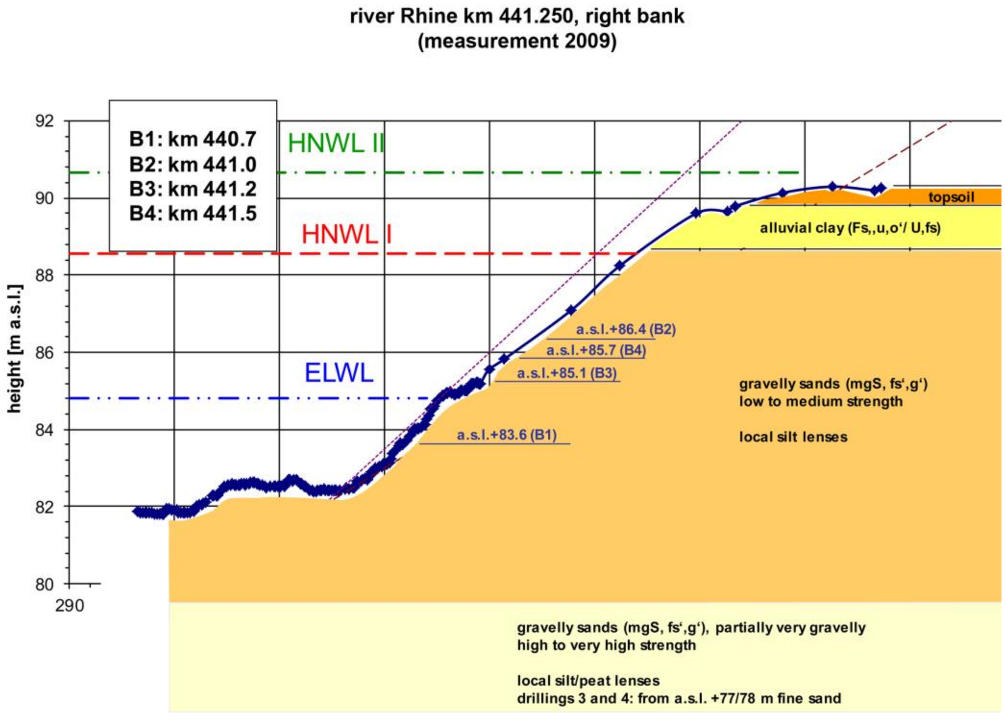


Figure 6: Simplified ground section, set out exemplary in the cross section km 441. 250

For the individual layers, soil parameters indicated in table 1 can be used to calculate the slope stability and revetment dimensions. In order to calculate the revetment according to /GBB, 2005/ with the software GBBSoft (see chapter 3.9) gravelly sands can, for simplification purposes, be assigned to the soil B1 according to /MAR, 2008/.

Table 1: soil parameters

soil layer	bottom edge of the layer a.s.l. + m	Φ' / c' [°] / [kPa]	γ / γ' [kN/m3]
alluvial clay/ topsoil	87.5	27.5/ 2	19/ 10
gravelly sands low to medium strength	78.0	32.5 to 35.0/ 0	18/ 10
gravelly sands/fine sands high strength	75.0	37.5/ 0	19/ 11

3.5 Vegetation

Scope of the Preliminary Examinations and Objective

In July 2009, the current status of the vegetation along the embankment from km 440.6 to km 441.6 was recorded; in the course of this all zones in the slope cross section were phytosociologically mapped from the zone of water level fluctuation to the top of the slope including the adjacent area up to the maintenance path of the WSV. In addition, two reference sections of 100 metres length were included in the mapping, both at the downstream and the upstream end of the test stretch (see map on habitat types in Appendix 15).

In the mapping process the following steps were carried out:

- mapping of the different habitat types concerning the area
- record of species composition of the habitat types separated by zones, which could be defined on the basis of the dependency of species from duration of flooding (moisture gradient), ship-induced loads and the substratum (riprap revetment, old pavement)
- marking these zones with dots at distinctive sites, which can clearly be recognised (e.g. settlement boundary of dewberry brush)
- assessment of plant settlement according to aspects on the legal protection status of species
- evaluation of the current condition in terms of nature conservation

Registering the current condition of vegetation is necessary in order to derive application criteria for the use of alternative technical-biological bank protection measures. Furthermore, recording the current vegetation serves to make statements about the settlement potential of specific bank protection measures in the following years after the redesign of the stretch and it helps to analyse the degree of ecological improvement of the littoral zones.

<u>Existing Vegetation</u>

The current vegetation settlement of the individually determined slope areas can be described as follows:

Lower slope area (around AZW → water level fluctuation zone): This area, which is massively secured with riprap, is mainly free from vegetation of higher plants. In downstream direction from km 441.350 a bank section with slip-off slope subsists, which consists of little floodplain meadow vegetation with pressed rush and single reed types (e.g. reed canary grass, purple loosestrife, reed); this is due to an already existing stone wall parallel to the bankline and a shallow water zone, which developed consequently above old paving stones.

Mean slope area (AZW to AZW + 1m): Mainly dewberry brush of different cover-abundance ratings grows on the riprap (types of cover-abundance: <5%, 5-30%, 30-60%, 60-100% and 100%). In parts, single ashes, hybrid poplars and box elders are interspersed, whereas hybrid poplar and ash-leaved maple are neophytes. In the area of the old pavement from about km 441.375 high cover-abundance ratings of the dewberry brush are achieved. In addition, the highest number of species was determined in this area, whereas these are mainly species of medium biological value (different types of grass, herbs and single reeds). Especially striking are several large pollard willows in the section of km 441.380 to km 441.500.

Upper slope area (AZW + 1m until the top of the slope): In addition to the typical dewberry brush, bush elements of the alluvial hardwood forest grow here (e.g. hawthorn, elder, European spindle, blackthorn, common dogwood, field elm i.a.).

Adjacent terrain until the maintenance path of the WSV: Riverside of the path about 50 cm of the meadow strip is cut free as well as the areas in which kilometer markings are located. These are cut free and mowed until the top of the slope. Apart from that, this area is made up of dewberry brush rich in species (mixed with different types of meadows and herbs). Individual species dominate single sections such as common reed beds at km 441.380. Bush elements of the alluvial hardwood forest, which exist in some areas, extend mainly from the top of the slope until the mowed meadow strip. Occasionally oak trees were planted. Additionally, there are large hybrid poplars along the path, which span the bank area extensively with their tree crowns. The terrain in the area around km 440.950 is currently used as a gravel deposit. Next to it brushwood of grey poplar has developed, which is worthy of preservation. The adjacent floodplain grassland landward to the maintenance path is intensively mown.

Evaluation in terms of Nature Conservation

Overall, the tested bank section is mainly populated with species of medium biological value. The section downstream from km 441.350 is of higher quality ecologically, as reeds have partially developed there. In most areas the settlement potential is low due to massive rock filling. In addition, especially the water level fluctuation zone is mostly unpopulated as the result of high ship-induced loads. There are also almost no natural bank zones (in particular pondweed zone, reed zone, softwood alluvial forest, hardwood alluvial forest) owing to the massive top layer, a lack of space and high loads, which is why there is only little structural diversity.

Currently existing brushwood elements of the alluvial hardwood forest (i.a. the field elm as a species on the Red List) were able to establish themselves naturally in specific zones (upper slope area and adjacent terrain), which is why they should be preserved as native woody plants. Neophyte species such as the ash-leaved maple and the young hybrid poplar stands, which sporadically established themselves within the rock filling, as well, should be removed in favor of the indigenous vegetation.

No occurrence of specially or strictly protected plant species could be found. The field elm as an endangered species occurs in a few places. The young shrubberies are partially weakened by Dutch elm disease. Populations are integrated into the alternative bank protection measures, if they have sufficiently good vitality.

3.6 Fauna

Scope of Preliminary Examinations and Objectives

Initially, a record of the current condition as well as a premonitoring is planned in order to subsequently evaluate the fauna of the new bank protection measures. The prerequisites for an adequate and resilient data collection are as little changes as possible at the test stretch until October 2010. Indicators are birds (aves), ground beetles (carabidae), spiders (araneae), reptiles (reptilian), macrobenthos and fish (pisces). Birds, ground beetles and spiders have established themselves as indicators for amphibian habitats. Whether reeds are populated by birds or not depends largely on they are spatial expansion, the form of their vertical structure and the plant species of which their made up. Spiders and ground beetles react within small areas, but are also very sensitive to anthropogenic influence. Spiders are very sensitive to material and mechanical impairment and respond quickly to changes due to their high potential of dispersal. As predators they are less dependent on the occurrence of single plant species than on specific structures. A lot of ground beetle species are adapted to specific soil parameters (grain size, moisture) and microclimatic conditions. Apart from reeds, especially banks with sparse vegetation develop habitats for a series of highly specialized species, as well. The occurrence of reptile species in the test stretch is to be determined prior to the redesign of the banks. For aquatic fauna a redesign down to the low water level would primarily be of importance. Material such as deadwood represents a natural substrate for macrobenthos and develops shelters especially for juvenile fish. Shallow water zones can also have a positive impact on the juvenile stages of some fish species. The specific potential of certain measures to promote individual species can be determined after the redesign. Overall, the potential of technical-biological bank protection measures to enhance biodiversity is to be examined and evaluated for all animal groups.

The following investigations will be carried out during the recording of the current situation:

- ground beetles and spiders: record data with pitfall traps 3 x 2 weeks in spring-summer (depending on the weather from April until June) and 2 x 2 weeks in fall (September-October)
- birds: a combination of recording transect lines and territorial mapping during 5 inspections depending on the weather from April until the end of June
- reptiles: visual observations during 3 inspections, depending on the weather in spring (from April) and in summer (August)
- macrobenthos: as part of the long-term monitoring at the river Rhine in May/June
- fish: in June and September through electrofishing

3.7 Hydraulic Loads on the Bank from Natural Flow

The natural flow of the river Rhine represents a basic load on the bank and therefore, on the bank protection respectively. The usual factors with which this is depicted are flow velocity v_{Str} and shear stress τ. As the load-carrying capacity of alternative bank protection measures can be analysed, among other things, on the basis of limit values of the permissible flow velocity and the shear stress, these factors were then determined in the frame of preliminary examinations with the aid of a hydraulic-numerical (HN-) model (available at the BAW) for the area of the test stretch.

The section W1 "River Systems" at the BAW, provides an HN-model OPDYMO of the free-flowing river Rhine between Iffezheim and the German-Dutch border, for many years now. It is a one dimensional, transient model and its calibration is continually updated according to the most recent soundings. Flow velocities and shear stresses for the four characteristic water levels LLW, ELWL, HNWL I and HNWL II were determined with this model. The results are available in segments and at a mean depth for every cross section.

For the water levels ELWL, HNWL I and HNWL II flow velocities and shear stresses close to the bank were determined every 100 metres, initially. Additionally, an analysis across the water depth was carried out at the right bank starting at a fictional toe of the slope. The resulting values for v_{Str} and τ are listed in Appendix 6 on page 1 with the respective minimum and maximum values for the given slope areas.

Since the alternative bank protections depending on each measure are located above AZW or AZW - 0.5 m, only flow velocities and shear stresses are decisive, which occur at water levels in the range of AZW - 0.5 m and above and even then only those that are predominant in the area of the new bank protection measure. The loads below AZW - 0.5 m are not relevant to the new bank protections. The corresponding crucial loads are additionally set out in a chart in Appendix 6 on pages 2 to 5. The new bank protections are not subject to loads at ELWL (no values for AZW are available). Therefore, only the values "above ELWL at HNWL I and II" are decisive for HNWL I and HNWL II accordingly. These values are, as expected, lower than those determined below ELWL.

It should be noted that the values at HNWL I and HNWL II tend to decrease slightly from km 440.6 to km 441.6 as the slight undercut slope turns into a slip-off slope here. The following overview of the values in the vicinity of the bank in the area of the planned alternative bank protection measures can be given (see Appendix 6):

HNWL 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)*
HNWL II: v_{Str} = 1.5 *(km 440.6)* … 1.3 m/s *(km 441.6)*
τ = 7.0 *(km 440.6)* … 5.7 N/m^2 *(km 441.6)*

In addition, the development of flow velocities and shear stresses is demonstrated exemplary across the depths for the water levels ELWL, HNWL I and HNWL II for the cross section km 440.6 in Appendix 7. The load intensities increase at a specific water level with increasing water depth. The following values in the vicinity of the bank are decisive for the alternative bank protections here:

HNWL I: v_{Str} = 0.1 m/s *(at the height of HNWL I)* … 0.99 m/s *(at the height of ELWL)*
τ = 0.15 N/m^2 *(at the height of HNWL I)* … 3.6 N/m^2 *(at the height of ELWL)*
HNWL II: v_{Str} = 0.65 m/s *(at the height of thetop of the slope)* … 0.7 m/s *(at the height of HNWL I)* … 1.5 m/s *(at the height of ELWL)*
τ = 1.9 N/m^2 *(at the height of the top of the slope)* 2.3 N/m^2 *(at the height of HNWL I)* … 7 N/m^2 *(at the height of ELWL)*

The determined flow velocities are also used for the calculation of ship-induced hydraulic loads on the bank (see chapter 3.9).

All values indicated above are load intensities in the vicinity of the bank. It has to be taken into account that the limit values, which can be found in literature with regard to soil resistance to erosion or different bank protection measures (critical velocities and critical shear stresses), refer partially to mean values in the main channel and partially to values determined close to the bank. The differentiation is of vital importance here.

3.8 Hydraulic Loads on the Bank from Shipping – Measurement Results

In order to choose appropriate alternative technical-biological bank protection measures, the most accurate knowledge of ship-induced hydraulic loads on the bank possible is essential. Ship-induced loads result from water level drawdown, waves and velocities due to interaction between ship and waterway. They occur only locally and temporarily. The engineering company Schmid IBS from Kapsweyer, Germany was commissioned to carry out a measuring campaign (traffic monitoring) of the “actual state” in the test stretch at the river Rhine near Worms within the frame of preliminary examinations. The aim was to record all ship passages (except for recreational crafts) and determine the crucial parameters for hydraulic bank loads over a period of 7 days. In particular dimensions and draught of ships as well as the ship’s distance to the bank were determined and the wave heights and flow velocities generated at the bank by passing ships were measured.

The traffic monitoring was carried out from 19 August 2009 to 26 August 2009 from about 6:00 to 20:00 each day at the following three cross sections in the area of the test stretch:
- km 440.6 (determination of ship parameters, wave heights and flow velocities)
- km 441.1 (determination of wave heights)
- km 441.6 (determination of ship parameters and wave heights)

Figure 7 exemplary shows the position of the measuring probes as well as the shape of the bed and the water level positions for the cross section at km 440.6.

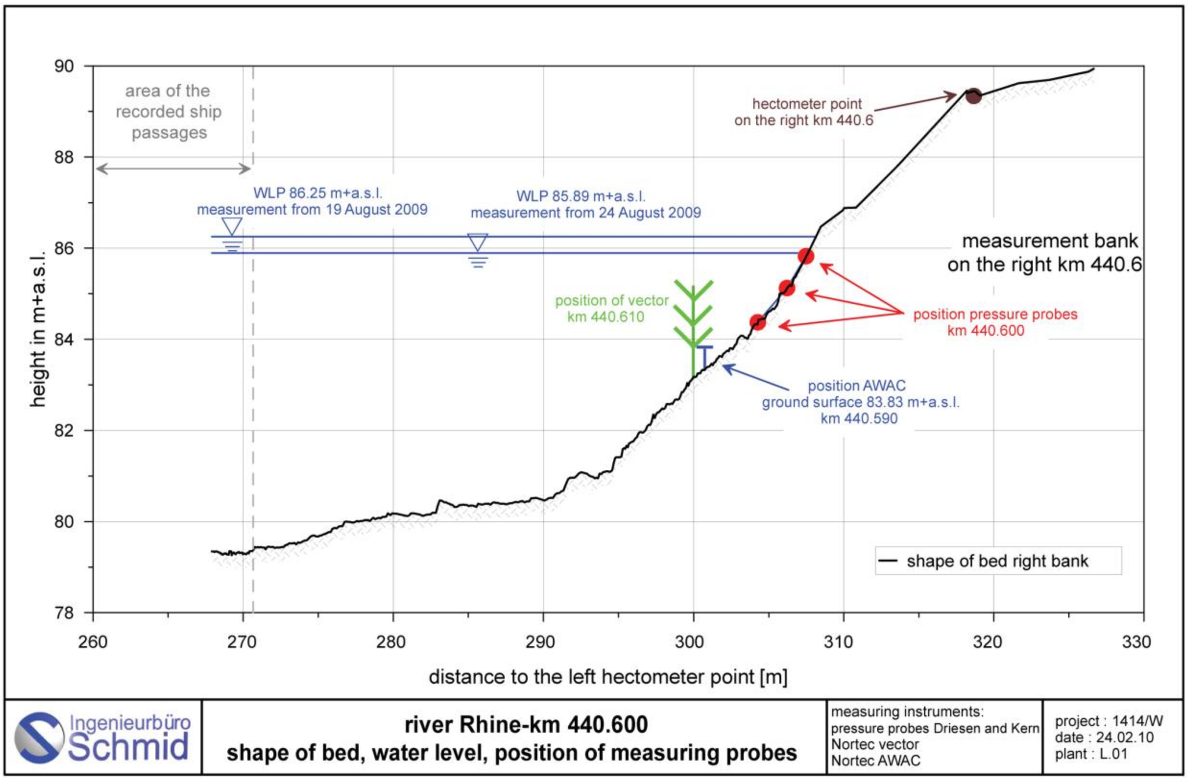


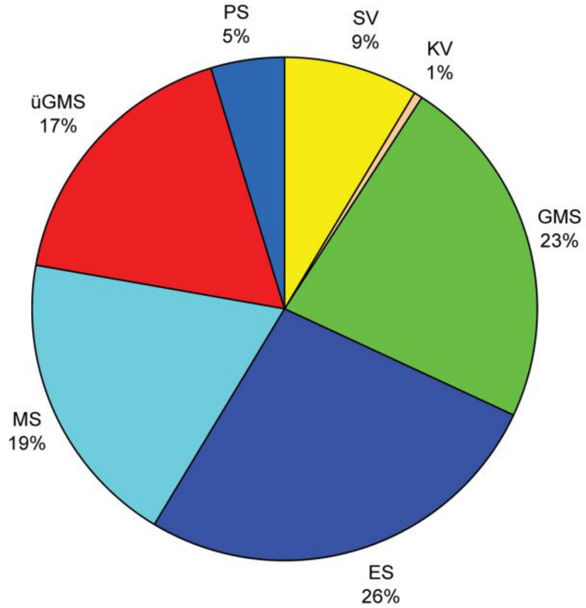
Figure 7: km 440.6 – bed shape, water level, position of measuring probes (“vector“≙ ADV-measuring probe, “AWAC“≙ ultrasound wave probe)

At the beginning of the measurements the Worms gauge (ELWL = 65 cm, corresponds to a.s.l. + 84.81m) was at about AZW (187 cm, which corresponds to a.s.l. + 86.03m at the Worms gauge) and fell continuously over the course of the measuring campaign to 137 cm (a.s.l. + 85.83 m), i.e. to about AZW - 0.5 m.

The approach of the measuring campaign, the execution and the results of the evaluations are presented in detail in the reports of the engineering office Schmid IBS /IB Schmid, 2010/. The results are summarized below.

Fleet Structure

552 cargo vessels were recorded during the measuring campaign from 19 August 2009 to 26 August 2009 (7 days each from about 6:00 to 20:00). Small crafts and ships travelling at night were not taken into account. The number of ships per day (79) provided here, must therefore be below the total daily average of about 125 ships as stated in chapter 2. Figure 8 shows the percentage distribution of ship types observed during the measurement period.



Abbreviations

MS	motor vessel
ES	Europe ship
GMS	motor cargo vessel
üGMS	oversized motor cargo vessel
SV	push-tow unit
KV	special push-tow unit consisting of GMS plus barge
PS	passenger ship

Figure 8: Fleet structure of ships as recorded during the measurement period at the river Rhine near Worms (August 2009)

Bank Distances

The measured distances between the ship's axis and the hectometer point at the right bank were evaluated for all three cross sections. The course of the channel already shows that the cross section is subject to significantly larger loads at km 440.6, as the bank distances are considerably smaller than those in the other two cross sections. The results from traffic monitoring confirm this.

Figure 9 shows the site plan of the section at the river Rhine with the navigation channel (dark blue band) and the observed ship distances. The ship symbol distinguishes between downstream vessels (blue) and upstream vessels (red) and it indicates the distance from the bank most vessels travelled. The bars transversal to the ship represent the area between the minimum and maximum observed distance. In principle, it was determined that downstream vessels travel closer to the right bank and they vary less in distances than upstream vessels. Table 2 lists medium, maximum and minimum bank distances for the three cross sections. The smallest distance to the right hectometer stone observed occurs in the upper cross section for a downstream vessel with 48 metres. This corresponds to a distance to the bank line of about 38 metres.

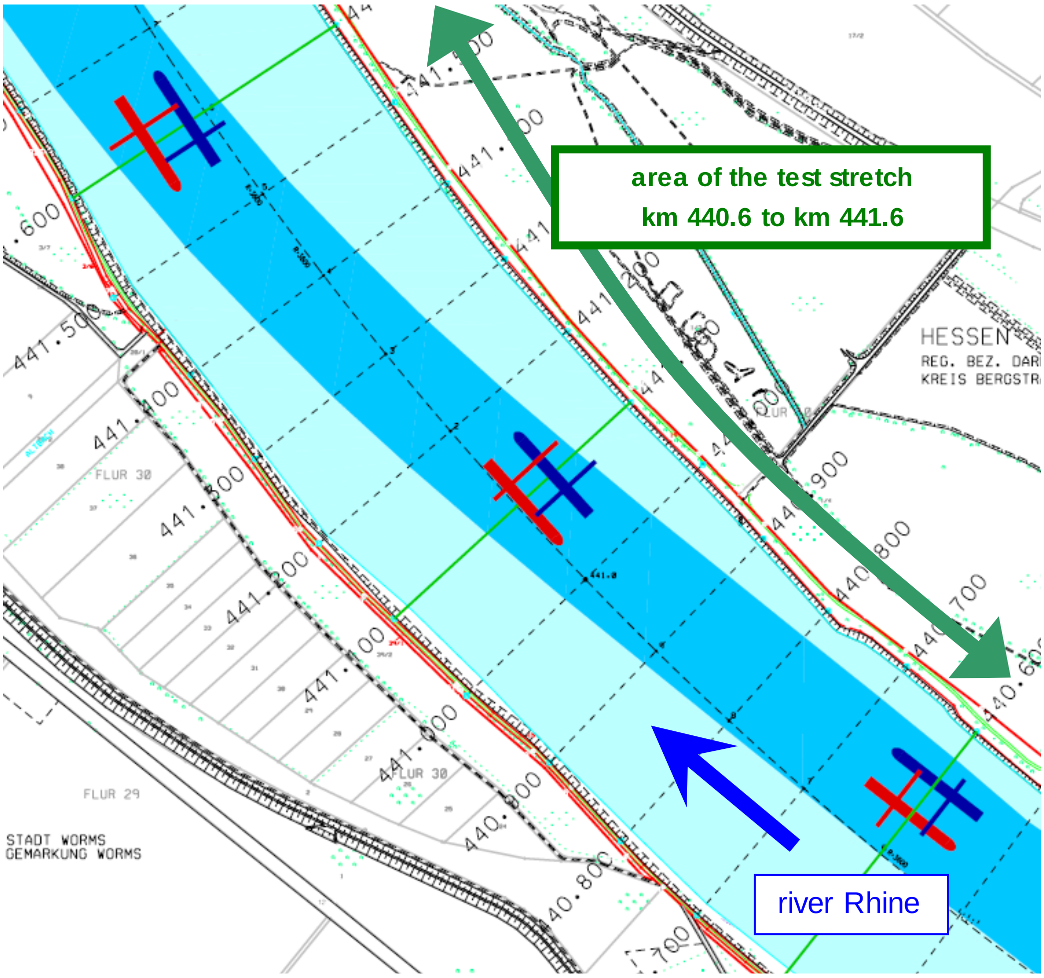


Figure 9: Site plan of the test stretch at the river Rhine near Worms with navigation channel and ship symbols in order to indicate the observed bank distances

Table 2: Minimum, maximum and medium bank distances observed (right bank of the river Rhine)

	Direction of Travel	No. of vessels	Distance ship's axis – right hectometer [m] medium	maximum	minimum
km 440.6	Downstream	272	77	131	48
	Upstream	280	102	179	57
km 441.1	Downstream	269	108	146	70
	Upstream	278	140	197	88
km 441.6	Downstream	269	178	231	118
	Upstream	277	218	267	112

Ship Speed

All recorded speeds are ship speeds above ground. The evaluation of the measured data resulted in a typical speed distribution of the observed vessels. The downstream vessels generally travel with a higher speed above ground than upstream vessels. Medium, maximum and minimum ship speeds above ground are listed in table 3. Downstream vessels travel with on average between 18 km/h and 19 km/h and upstream vessels with around 11 km/h, whereas the variability of speed is considerably higher for downstream vessels.

Table 3: Minimum, maximum and medium ship speeds above ground
(right bank of the river Rhine)

	Direction of Travel	No. of vessels	Ship speed above ground [km/h] medium	maximum	minimum
km 440.6	Downstream	265	19.0	24.4	12.3
	Upstream	258	11.2	15.2	5.7
km 441.1	Downstream	269	18.9	23.9	9.8
	Upstream	278	11.2	14.6	7.3
km 441.6	Downstream	252	18.2	23.8	11.6
	Upstream	261	11.1	14.7	6.8

Wave Heights

Bow, stern and secondary wave heights were evaluated from the measurement results /GBB, 2005/. Primary waves in comparison to secondary waves lose a lot of height with increasing bank distance. Therefore, the secondary wave heights are, as expected, of the same magnitude as the primary waves due to the large bank distances here and especially at km 441.6, hence they can indeed be relevant for the design. Medium and maximum values of wave heights are listed in table 4. The largest wave events were recorded at km 440.6 as bank distances are the smallest here. Altogether, they can, however, be classified as comparatively low on average.

Table 4: Maximum and medium wave heights (right bank of the river Rhine)

		km 440.6	km 441.1	km 441.6
	No. of vessels	494	429	429
bow wave height	medium	0.11	0.09	0.09
	maximum	0.51	0.43	0.40
stern wave height	medium	0.11	0.09	0.09
	maximum	0.81	0.37	0.43
secondary wave height	medium	0.12	0.07	0.07
	maximum	0.57	0.29	0.43

Flow Velocities

The evaluation of ship-induced flow velocities (only at km 440.6) turned out to be very difficult. The return flow velocity $v_{Rück}$ was determined for 302 vessels, the wake v_{Nach} for 70 vessels. Both flows, but especially the wake, were strongly affected by the turbulent natural current close to the bank. The return flow velocity was on average 0.45 m/s, the maximum value amounted to 0.93 m/s. The measured values of the flow velocities can, however, not be considered to be too reliable due to the strong weedage of the probes. As a result of low data quality, a statistical evaluation of the wake was not possible.

3.9 Hydraulic Loads on the Bank from Shipping – Calculation Results

Hydraulic loads on the bank due to shipping can either be measured on site (see chap. 3.8) or the loads can be calculated theoretically. The current state of knowledge on the determination of hydraulic loads from shipping on navigable waterways and the revetment design based on this was published in the BAW newsletter No. 88 (GBB, 2005) "Principles for the Design of Bank and Bottom Protection for Inland Waterways", in 2005. Since December 2008, the software GBBSoft is additionally available, which simplifies extensive calculations according to GBB.

In order to determine the magnitude of ship-induced loads for the test stretch theoretically, in addition to the time-restricted measurements on site, the respective calculations were carried out with GBBSoft, version V 1.0.3616 from November 2009. Furthermore, due to the calculated load intensities, a theoretically required revetment was calculated for comparison purposes with the current revetment and the planned alternative bank protections. Essential points were determined in advance.

- The calculation is carried out for the initial and the end profile of the test stretch in order to determine the range of load intensities.
- Typical standard vessels of the modern Rhine fleet are examined.
- The three water levels EWL, HNWL I and HNWL II are considered.
- Two ship positions are indicated, one in the center of the navigation channel and the other at its right edge as close to the bank as possible.
- The basic flow velocity of the river Rhine is taken into account (see chap. 3.7).
- The propulsion power of ships represents an upper limit for their possible ship speed through water (in accordance with (BAW, 2008)).

The following assumptions form the basis of the calculations:

<u>geometry</u>

- cross sections: equivalent trapezoidal profiles ETP (see below)

<u>ships and positions</u>

- ships: ES, GMS, üGMS, 2er SV
- loading: unloaden, loaden
- positions: in the center of the navigation channel (FR) and at the right edge of FR

(*note*: FR, in its original position, is transferred to the ETP; center of the FR does not correspond to the axis in the center of gravity of the ETP; the FR remains at its position for all water levels)

- directions: upstream, downstream

<u>subsoil</u>

- soil: according to /MAR, 2008/ soil class B1 – sands, gravels (see chap. 3.4)

<u>elements of the revetment</u>

- stones: $LMB_{5/40}$, $\rho_{St} = 2650$ kg/m^3 (see chap. 3.2)
- revetment: permeable, loose armour stones

(*note:* probably without a filter)

- support: mounded toe, embedding depth 0.7 m < $t_{F,Plan}$ < 1.1 m

(*note*: assumption, since no precise information about the toe design is available)

The software for the design of revetments GBBSoft can in its present form, strictly speaking, only be used for channels or rivers with channel-like, constant geometry over its length. At the river Rhine, however, generally no constant cross sections exist. Due to the location of the test stretch in a slight river bend, cross sections are characterized by slip-off and undercut slopes (see chap. 3.3). The river bed is temporarily and locally subject to constant changes.

In order to use GBBSoft nevertheless, hydraulically equal equivalent trapezoidal profiles (ETP) were constructed for the irregular natural cross sections. Thus, a rough approximation is possible. The following requirements had to be met:

- The water depth in the ETP must be equivalent to the mean water depth in the area of the navigation channel.
- The slope inclination of the right bank of the ETP, the design bank in the software, where the test stretch is located, too, shall correspond to that of the real bank if possible, especially in the zone of fluctuating water levels.
- The slope inclination of the left bank of the ETP is to be selected medium, but not flatter than 1:10.
- The water level width of the ETP should approximately correspond to the actual width.
- The area of the flow cross sections of the real profile and those of the ETP should have approximately the same size.

This resulted in six ETP for the three water levels to be examined at both cross sections considered – km 440.6 and km 441.6. The resulting six ETP are presented in Appendix 8.

Additionally, for the application of GBBSoft, the flow velocities (natural flow) in the ship's path (in the center and at the right edge of the navigation channel) and at the bank, where the impact on a single stone is the highest, had to be determined in advance. This was possible on the basis of the HN-model available at the BAW (see chap. 3.7). The values are listed in a table in Appendix 9.

The most important results are presented in a table in Appendix 10, which consist of the calculated hydraulic load intensities due to shipping and the necessary dimensions of a revetment consisting of loose armour stones. The highest load values occur, as expected, at the upstream beginning of the test stretch at km 440.6 (navigation channel very close) for the lowest water level ELWL (a.s.l. + 84.81 m at the Worms gauge).

The hydraulic loads at ELWL are only relevant to the new alternative bank protections, which are located in the area of the wave run-up, with regard to erosion stability (see chap. 4.1). The geotechnical stability is determined by the water level drawdown due to shipping and thus, especially by the processes below the lowered water level (see chap. 4.1). This means that higher water levels than ELWL are decisive for this. These water levels must be at least that high so that parts of the new bank protections are below the lowered water level during ship's passage. If the bottom edge of the new bank protection lies at AZW - 0.5 metres, only water levels above AZW are decisive with regard to slope stability.

The calculated hydraulic loads from shipping at HNWL I and HNWL II differ only slightly. The following load intensities for HNWL I and HNWL II (in brackets) were obtained for km 440.6 at the right bank:

bow wave height ……………………………………….0.65 (0.63) m
stern wave height ……………………………………… 0.85 (0.84) m
return flow velocity ....……………………………………0.33 (0.25) m/s
velocity of the slope supply flow ……………………..….1.38 (1.38) m/s
secondary wave height …………………….. ………… 0.22 (0.20) m
rapid water level drawdown at the bow …..…….……... 0.65 (0.63) m
rapid water level drawdown at the stern ………..……… 0.80 (0.80) m

All load intensities are significantly smaller at km 441.6 (end of the test stretch) than at the beginning, as the navigation channel is considerably farther away from the bank with about 140 metres (km 440.6 only about 23 metres).

A direct comparison of the calculated and the hydraulic load intensities measured in-situ is not possible as the measurements were carried out at water levels between AZW and AZW - 0.5 metres. No calculation results are available for these water levels, yet. The values can, however, be compared in terms of size. The calculations were based on the most unfavourable, but practically still possible boundary conditions, e.g. ships sailing with 97% of the critical ship speed and sailing at the outermost right edge of the navigation channel. A majority of the ships will, however, not actually sail in this extreme way.

In a second step, the revetment of loose armour stones was dimensioned with GBBSoft on the basis of the calculated hydraulic impacts. As a result, the stone size class $LMB_{5/40}$ is necessary, which in fact is currently present on site. In order to ensure the stability of the stone structure, a minimum thickness of 60 cm is necessary for the stone size class $LMB_{5/40}$ according to /MAR, 2008/. It can be expected that at least this thickness exists on site. The geotechnically necessary revetment thickness is primarily determined by the size of the drawdown and the drawdown velocity as well as by the permeability and the shear strength of the soil in place. Gravelly sands in place in the test stretch are relatively permeable so that excess pore water pressures in the soil arise to a limited degree for the occurring loads only. Therefore, a revetment thickness of a maximum of only 16 cm would theoretically be necessary. The existing revetment of loose armour stones is thus, first and foremost, needed as erosion control.

4 Recommendations for the Implementation of New Bank Protection Measures

4.1 General Remarks

The most important tasks of both technical as well as vegetative bank protections at inland waterways are to ensure sufficient safety against surface erosion and sufficient geotechnical structural stability of a sloped bank.

Erosion control: Wave loads (stern and secondary waves) and current loads (return flow and slope supply flow) caused by shipping and current loads caused by natural flow, especially due to flood discharge, can lead to surface erosion at the bank. Protection is always required whenever the soil in place is not resistant to erosion itself. If technical revetments consisting of loose armour stones are used, the necessary stone size or the necessary stone weight will be dimensioned in such a way that the single stones are stable during all occurring loads /GBB, 2005/. Bank protections consisting of living or dead plant parts or plants can under specific circumstances present good erosion control for slopes. If direct hydraulic impacts are to be expected after the completion of the bank protection, such as at waterways, an area wide protection must be guaranteed right away. When using vegetative bank protections the initial state is generally the most unfavourable state, as the load-bearing capacity, as a rule, increases with plant development time. This has to be taken into account in the planning measures.

Slope stability: The stability of slopes is influenced by excess pore water pressures in the in-situ soil during ship's passage, which can be caused by the water level drawdown. The size of the exess pore water pressure depends largely on the in-situ soil, in addition to the size of the water level drawdown and the drawdown velocity, but especially on its permeability and shear strength. If the stability of the existing unprotected slope is not guaranteed, the mass per unit area when using a technical revetment consisting of armour stones as bank protection must be dimensioned correspondingly, so that sliding parallel to the slope in a soil layer close to the surface is prevented and the stability of the slope is ensured in this way despite the excess pore water pressures /GBB, 2005/. These failure mechanisms, however, only affect the slope area below the lowered water level due to shipping, in which vegetative bank protections, as a rule, do not exist. The mechanisms described above do, nevertheless, play a role at rivers such as the river Rhine, where the alternative bank protections can be submerged for a longer period of time due to floods and shipping still takes place. Here, the bank stability must be ensured with vegetative bank protections against excess pore water pressures, if necessary. A weight corresponding to those of revetments cannot be achieved with biological bank protections. Sliding in a sliding surface close to the surface in the soil can be prevented through corresponding roots, either through single roots in terms of a soil nailing or through a dense, branched, fine root system in terms of soil cohesion. What applies in this regard too, as was the case for the erosion stability, is that the plant development time has a decisive impact on the slope stabilizing effect of the vegetative bank protections.

9 bank sections in the test stretch are to be secured with different alternative bank protection measures. All alternatives are listed in a table in Appendix 11. The existing riprap, depending on each measure, is in general maintained below AZW or AZW - 0.5 metres. The redesign is solely carried out in the slope area above. The individual sections were defined on site taking the local conditions into account. In five sections the riprap is removed above about AZW or AZW - 0.5 metres and new technical-biological bank protections are constructed, in one section of these, the slope is not secured. In four sections the riprap is maintained, measures to ecologically improve the loose riprap are to be tested here. The slope geometry is generally maintained, solely in two sections it is aimed at a slight flattening within the range of possibilities. This means that the changes of the bank in comparison with the total cross section of the river Rhine (water level width at ELWL: 230 metres (km 440.6) to 300 metres (km 441.6)) are of secondary importance. The cross section of the waterway is thus not considerably changed. Therefore, impacts on the hydraulic conditions of the river Rhine due to the measures are not to be expected.

4.2 Planned Bank Protection Measures 1 to 9

The bank protection measures presented below were developed on the basis of the results of the preliminary investigations. Measures were chosen, which are to fulfill the requirements of traffic safety as well as the ecological improvement of the bank section with regard to the existing load situation, the current population settlement of vegetation and faunistic considerations.

Bank sections, which are not included in the kilometrage of the following presentation of the different alternatives, are not affected by measures. Reasons for this are local structures (e.g. outlet structures, listed stairs) or the already existing structural diversity in partial sections. All in all only 85 metres of the pilot section are not affected by measures. Cross sections of the single measures 1 to 9 are available in Appendix 12 (12.1 to 12.9). In the beginning of this appendix an overview of all measures in the ground plan (Appendix 12.0) can be found which bases on the biotope type map (Appendix 15).

**Measure 1 - Planned for the section of the River Rhine km 440.630 to km 440.800
Planting of the existing riprap with long willow branch cuttings**

The riprap is maintained in the entire section. Only some stones are removed locally in areas above AZW, in which long willow branch cuttings are then planted. In order to do so, i.a. areas shall be used, which are currently populated by smaller hybrid poplars, but also other areas without poplar growth shall be removed from stones in order to plant branch cuttings. The hybrid poplar growth is completely removed (with root stock) by the WSA so that the resulting pits are suitable for planting with branch cuttings. The single branch cuttings are planted in groups in the area of the alluvial forest with softwood (at AZW to AZW + 1 m); however, it needs to be considered that the groups are arranged offset to the currently existing shrub elements of the alluvial forest with hardwood in order to prevent mutual shading. The stonefree planting areas are then filled up with a gravel mix around the branch cuttings. Other native shrub elements can be planted in the upper slope area (alluvial forest with hardwood from AZW + 1 m), where appropriate. The currently existing shrub elements are to be preserved and integrated.

Within a part of the section of 140 metres length (km 440.630 to about km 440.770) the local waterline lies backwards of the main waterline. That is why a shallow water zone is to be constructed additionally towards the slope through the structure of a stone wall. The stone wall is to be built within a short distance of about 3-4 metres to the bank in the direction of the river Rhine and it is to be deepened and elevated until about AZW-height in undulated form. Thus, an exchange between the water of the free-flowing stretch and the calm shallow water zone is to take place. In addition, an unhindered passage of fish is to be enabled. At the same time, the elevated areas are to be constructed longer than the deepened areas. The shallow water zone located behind it is filled with a sand gravel mixture in order to increase the settlement potential.

**Measure 2 – Planned for the section of the River Rhine km 440.820 to km 440.860
Willow brush mattress (longitudinal) after removal of riprap**

In this 40 metres long section, the riprap is to be completely removed from the slope surface until about 0.5 m below AZW on the entire slope. It is planned to ensure the bank protection with a dense placement of willow brush mattresses instead of a revetment. The rods are installed longitudinal to the direction of the flow, in this process the branches are bound together tightly and are pressed onto the soil surface with wire and wooden stakes. The lower rods are installed just below AZW and are buried under the existing riprap. The lateral boundary layers are also tied into the existing riprap. Existing vegetation of the alluvial forest with hardwood (shrub elements) could be cleared and thus, preserved and if applicable integrated (e.g. ashes). Neophytical population (hybrid-poplar young population and box elder) should if possible be completely removed (with roots) from the slope. The willow brush mattress will be slighltly covered with topsoil after the construction.

Measure 3 – Planned for the section of the River Rhine km 440.880 to km 440.950
Willow brush mattress (transversal) after removal of riprap

Similar to measure 2, the technical protection in the 70 metres-long section is to be replaced by the planar placement of willow brush mattresses. In order to do so the riprap is completely removed from the ground surface to AZW - 0.5 metres (see measure 2). The placement of willow rods differs from measure 2 in its direction of installation, as the rods are to be installed transversal to the direction of flow. The basal ends of the willow rods (feet of the willows) are installed below the mean water level (until about 0.5 metres) and are buried under the existing riprap, there. Apart from that the method is carried out as described in measure 2.

Measure 4 – Planned for the section of the River Rhine km 440.950 to km 441.00
Covering the existing riprap with gravel

The planned measure is carried out over a length of 50 metres. It is planned to slightly flatten the embankment in this process, where applicable. The existing revetment shall be covered with a sand and gravel mixture afterwards, which can possibly be taken from the gravel storing area currently present there. Hybrid-poplars, which have established themselves at the slope, will be removed. The gravel fill does not function as additional bank stabilisation. The settlement potential for plants and animals will rather increase because of the substrate that will be washed into the gaps of the stones over the course of time, and thus, an ecological improvement of the technical riprap is expected.

Measure 5 – Planned for the section of the River Rhine km 441.00 to km 441.110
Chamber revetments and reed gabions after removal of riprap

Reed gabions and chamber revetments with a pre-vegetation zonation are to be tested on their suitability as technical-biological bank protections over a length of 110 metres. For this purpose the riprap above AZW - 0.5 metres and existing vegetation (not worthy of preservation) are completely removed. The reed gabions are placed in the lower area of the slope (zone of water level fluctuation, starting at AZW - 0.5 metres). Prior to that, the gabions are pre-grown with plant material. Location requirements and ranges of tolerance of the plants need to be considered when choosing plants. Thus, the reed gabions can be divided into two zones. Rushes (round-fruited rush) are suitable for planting in the lowest zone and sedges (tufted sedges) for the zone above. Pre-grown chamber revetments are to be placed in the second section of the slope (above AZW) up to the slope surface. In this case the natural zonation needs to be met during installation of planting material, as well. Reed canary-grass is well suited for planting in the more humid lower area and reed-fescue for planting in the area above. In order to increase the structural diversity further reed species, tall forbs and grasses/herbs can be integrated into the singles zones additionally. A list of plants that are well-suited for installation into the test stretch is available in Appendix 13.

Measure 6 – Planned for the section of the River Rhine km 441.125 to km 441.200 Greening of the exisiting riprap with a gras-herb-mixture, planting (plant bales)

The riprap will remain on the 75 metres-long section and will be planted with a grass-herb-mixture (uniform mixture of seeds) up to the slope surface. In doing so the seed mixture is placed on the slope with a topsoil alginate blend or pumped into the cavities of the riprap so that the latter is almost completely covered. The species which should be used for this purpose are indicated in Appendix 13. In addition, plant bales are to be placed locally in the lower area of the slope (from AZW), which include species of the reed zone (e.g. reed canary-grass, lesser bulrush, yellow iris, lakeshore bulrush etc.). Plant bales are placed using the in situ soil and if possible alginate. Plant bales can also be planted in the middle and upper slope area initialising the settlement of further species. The existing scrub vegetation on the adjacent area will be preserved as well as the vegetation on the slope worthy of preservation. In this section it is to be analysed, whether the layer thickness of the current riprap can possibly be reduced.

Measure 7 – Planned for the section of the River Rhine km 441.200 to km 441.375 Planting of slope protection mats with vegetation zonation after removal of riprap

A planar installation of reed and slope protection mats is planned. In this process, the riprap is completely removed over a length of 175 metres (from AZW - 0.5 metres until top of the slope). Planting of the slope protection mats is carried out in different ways. One part of the section will be secured with continuous, pre-grown reed mats (starting at AZW or at AZW - 0.5 metres until top of the slope). The mat will be attached to the soil in place in an appropriate way. In another part of the section, mats will be placed, which shall be pre-grown with vegetation zonation. The combination of species is similar to the plant scheme mentioned in the descriptions above (see measure 5). Reeds are planted in the zone of water level fluctuation (around AZW). Only above, the slope protection mats will be placed. In the area of the alluvial forest with softwood (from AZW until AZW + 1 m) the vegetation mats, which consist of a geotextile, are attached to the ground with willow cuttings, additionally to the use of appropriate technical material. For this purpose a low-growing willow species (purple willow) is used in order to prevent shading of the reeds. Already existing scrubs of the alluvial forest with hardwood will, as far as possible, be preserved and integrated.

Measure 8 – Planned for the section of the River Rhine km 441.375 to km 441.475
Shallow water zone through heightening of a stone wall

Since the section from km 441.375 over a length of 100 metres can already be classified as being more ecological than the other sections of the test stretch (see chapter 3.5), the existing potential of the section is exploited and increased through small measures, additionally. It is planned to extend the already existing berm area (shallow water zone) by moving an existing stone wall a maximum of 2 metres in the direction of the river Rhine and to raise it about 0.5 to 1 metre (see construction method measure 1). In addition, the old pavement shall be maintained and if necessary the riprap cover layer above shall be reduced. The current vegetation on the slope will be preserved. This includes e.g. large pollard willows, reed species and tall forbs. Sand and gravel can be filled into the riprap locally.

Measure 9 – Planned for the section of the River Rhine km 441.475 to km 441.600
Removal of the riprap, flattening of the slope, if necessary

In measure 9, the riprap of the 125 metres-long section is completely removed from the level of AZW until the slope surface, while the slope is slightly flattened (as far as possible) at the same time. In order to establish structural diversity locally, large single stones (edge length of about 60 to 80 cm) or anchored deadwood elements can be placed on the slope. In order to enable the flattening of the slope, the large hybrid poplars will be cut down on the adjacent terrain (to the maintenance path) in accordance with the WSA Mannheim.

4.3 Installation Instructions

In order to guarantee successful construction, the following important factors must be considered:

1) Materials – Which materials will be needed for the construction of the single measures? What is the origin of the living materials? How should living plants (plant parts) be stored until installation?
2) Bank zonation – Which bank zonation must be identified during the installation of living plant elements with regard to the conditions on site and to a close-to-nature zonation at watercourses, in order to increase the success of the measure?

3) Construction and installation – How will the measures, in detail, be installed on site?
4) Time of installation – When is the appropriate installation time, at which the construction can be carried out?

These questions cannot be completely answered at the current state of planning (e.g. quantity of the materials needed, diameter and length of the willow log branch cuttings and cuttings, willow rods for the brush mattresses, amount of seeds, detailed construction description of the single measures etc.), which is why only important information on parameters that need to be respected in principle is given in the following with regard to the list above.

1) Materials:

For the test stretch measures are planned, in which living plants and plant parts alone or in combination with auxiliary materials are used. Generally the following applies: only native (autochtonous), indigenuous plant material should be used, which is, at best, harvested from the direct surroundings or from the river basin (e.g. willow rods, willow cuttings, willow log branch cuttings). In order to receive information about possibilities to harvest plant material on site, the BfG is carrying out a mapping of willow species in the direct vicinity of the test stretch. Furthermore, pre-grown plants are needed, e.g. in the form of reed mats, plant bales or young wooden stands.The tender for the plant supplies should demand plants with an appropriate guarantee of the origin for example with a quality label of the producers' association. Seeds should be collected from natural stands. In order to improve germination and to protect the seeds, organic mulch material can additionally be used in the initial phase. When choosing the soil to be installed, it should be considered not to use non-native soil material. It may contain seeds and plant parts of undesirable species that affect the success of the measure and lead to additional expenses in the maintenance.

When extracting living material, attention must be paid to the restrictions resulting from the harvesting time because of provisions from nature conservation. Woods, for example, may only be extracted with special authorization in the period from the 1 March until the 30 September.

Moreover, the plant material must be stored correctly on site. Branches or plant bales may not dry out or be exposed to frost or to a lot of sunshine during the storage period. Reed blocks should, if possible, be installed directly after delivery and should only be stored temporarily on the construction site.

2) Bank Zonation:

The selection of plants and the plant scheme are determined by the requirements (habitat requirements) and characteristics (e.g. flooding tolerance, vigour of plant growth etc.) of the living building materials to be installed. In order to obtain better results of the plantings, the present vegetation zonation must preferably be met as guidance for contruction. Reeds are the appropriate species for the installation in the water level fluctuation zone (at AZW or AZW - 0.5 metres). Elastic, flooding-tolerant willow species and different tall forbs as well as grasses (see Appendix 13) are especially well-suited for planting in the zone of the alluvial forest with softwood (from AZW to AZW + 1 metre, if necessary even a little above). In the adjacent upper and drier slope area, typical brushwood of the alluvial forest with hardwood currently grows there, which is to be integrated in further plantings in this zone. An overview of potential suitable plant species and the respective suitable planting zones can be found in Appendix 13.

3) Construction and Installation:

For planar (e.g. brush mattresses, chamber revetments, vegetation mats, geotextiles) and pointwise construction methods (e.g. plant cuttings, stakes) sufficient mountings are absolutely necessary, so that the measures can withstand ship-induced impact or flooding adequately.

It must be taken into account that plants are significantly more sensitive to impacts during the growing phase than fully developed sprouts with dense root penetration. Thus, the embankment is more vulnerable during the growing period since the vegetation will only provide effective protection against erosion after some time. Depending on the location, initial protections with biotechnical constructions alone (e.g. fascines) or with auxiliary materials such as stone fills, wood, geotextiles etc. can be necessary, protecting the young plants until these are sufficiently strong.

Along with a well-founded construction planning and specification, the installation requires above all the relevant experience of the construction firm and of the engineer supervising the construction. Errors in the usage of the living material will directly affect the stability of the alternative technical-biological bank protections. In this context, the planning and construction companies need to have sound knowledge of performance, habitat requirements, mechanisms of action and life cycles of the used living materials (plants and plant parts). Especially important are the parameters light and water supply. Both must be guaranteed after the installation of the plants.

4) Time of Installation:

The appropriate time of installation is determined by the growth rhythm of the plants or plant parts. Installation of unrooted branches, which can develop shoots, and of vegetation parts (willow brush mattresses, willow stakes, willow cuttings, new planting of woods, planting of reeds and tall forbs) should be carried out during the dormancy period from October/November to March/April at frost-free days in the unfrozen ground. Since faunistic examinations are planned for autumn, it would be recommendable to start the plantings in early spring (March/April).

Living building material should not be installed during the summer months as a risk of desiccation and a risk of heavy summer rainfall exists. Planned seeding of grasses and herbes should be carried out in spring (beginning of April until mid of May), as well. It needs to be considered that germinating seeds are very sensitive to frost and heat. Hence, during the germination period of two to four weeks neither frost nor drought should occur.

4.4 Information on Costs

On the basis of the current, still very insufficient state of knowledge with regard to the costs of alternative technical-biological bank protection measures at waterways, only a very rough estimation of costs could be made based on bibliographic references (see Appendix 14). A mean slope width (measured in the slope direction) of 12 metres was assumed for the redesign. This rough estimation leads to overall costs of 947,710 € for the redesign of all nine zones.

4.5 Experts' Support during Installation

The experts' support for installation needs to focus on examining the criteria mentioned in chap. 4.3 for their correct implementation:

- Harvesting planting material (in this context, the mapping of willow species in the direct vicinity of the test stretch is carried out by the BfG to obtain information about the possibilities to harvest planting material on site).
- Correct storage of the planting material on site, if a prompt installation after harvesting cannot be carried out (branches or plant bales may not dry out or be exposed to frost or strong sunshine during storage).
- Controlling the compliance with the set planting zonation and the appropriate planting material. The single species must be planted within the zonation intended for them

(important issues to be considered: is sufficient water and soil contact guaranteed, do the plants get enough light, are the single elements protected against impact in a way that they will survive the growing period etc.)

- Correct installation of individual elements (willow stakes, if necessary young brush stands, willow brush mattresses transversally and longitudinally, chamber revetments with plant zonation, reed gabions, gras/herb mixture, pre-grown plant bales, slope protection mats with plant zonation, willow cuttings etc.)
- Special attention has to be given to the design of the transitions between the different measures. Big differences in elevation (e.g. between the zones without riprap and the zones with riprap) must be avoided. Some measures should partially merge into each other, e.g. willow brush mattresses must also be integrated into the existing riprap at the lateral boundaries of the section.

4.6 Development Prognoses

It can be assumed that the planned measures will provide adequate bank protection against the expected impacts. Since it is, however, a field test it cannot completely be excluded in advance that local bank instabilities or slope erosions won't occur. But indications will be recognized on time within the frame of the monitoring programme. Significant changes of the bank such as local cliff formations, slides and erosion will not be allowed. Local damages, for example due to a flood shortly after installation, will first be repaired in the course of maintenance (see chap. 5). If this does not promise a chance of lasting success, other alternative bank protection measures, which have proven to be stable, will be implemented. As a last option the technical bank protection in this section which is riprap will be restored.

Only for measure 9 (km 441.475 to km 441.600), for which the removal of the existing riprap above AZW over a section of 125 metres in length is intended, slightly greater changes of the bank are to be expected. These may, however, not affect the maintenance path located on the adjacent terrain. Possible flattenings of the bank slopes will accordingly be limited in their extent, if necessary through corresponding repair measures similar to those in the other sections (see above), so that no significant changes with regard to navigation, water body and navigational issues of water management are to be expected in this section, either. Furthermore, it is, thus, ensured that the measures do not infringe any rights of third parties (see Appendix 17).

First comparative calculations on the global stability of the slope according to DIN 4084 have shown that the overall stability of the slope without consideration of the imposed load after removal of the riprap is sufficiently ensured.

5 Outlook: Instructions concerning Vegetation Control, Maintenance and Monitoring

A separate concept on the maintenance of the newly installed alternative technical-biological bank protections with recommendations for the WSA Mannheim will be developed. For the realisation of the long-term monitoring, content, monitoring intervals, limit values and evaluations will be recorded in a separate document, as well. First important advice on this topic will, however, already be given at this point.

Vegetation control and maintenance

Especially during the sensitive growth period inspecting and examining the living building elements with regard to the existing habitat conditions should take place regularly. Extreme weather conditions are especially decisive such as flooding, hot summer days, heavy rainfall etc.. If necessary, specific assistance must be given for successful growth such as watering or covering of plant parts with soil. The initial maintenance of the plantations should take about two years. Regular monitoring of the condition of the installed protection measures will also provide information on whether or not control or subsequent maintenance measures are necessary. Damages that occurred must be refinished where necessary for the protection of the banks. All measures including incurred costs have to be recorded in order to make statements, in the later evaluation of results, about the maintenance requirements and finally about the erosion stability and therefore about the suitability of single measures for a successful protection measure at federal waterways.

For maintenance (e.g. pruning) restrictions concerning nature conservation must be respected.

Monitoring

In the following years after the redesign of the test stretch, a technical and ecological monitoring will be carried out. It is intended to carry out an extensive monitoring in the first five years after the completion of the test stretch and then to pursue it at larger time intervals. An ongoing evaluation will be carried out by the BAW and the BfG on the one hand with respect to the technical condition (slope stability, given erosion control, efficiency of alternative bank protection measures) and on the other hand concerning ecological and nature conservation aspects.

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