Bundesanstalt für Wasserbau
Federal Waterways Engineering and Research Institute

BAWLetter No. 02/2014

Structural Stability and Design of Technical-Biological Bank Protection Measures Applied on Inland Waterways: Where do we stand 2014?

1 Motivation

In order to protect the inland waterways against erosion and other negative impacts from ship-induced hydraulic loads and at times floods, they are mainly secured with technical constructions such as revetments consisting of riprap or sheet pile walls. The design basis is a comprehensive set of rules from the Federal Waterways and Shipping Administration (WSV), including the "Principles for the Design of Bank and Bottom Protection for Inland Waterways" (GBB) (BAW, 2010).

Since the EC-Water Framework Directive (WFD) came into effect in 2000 and the revision of the corresponding national regulations was carried out, that is Federal Water Act (2009), Federal Waterways Act (2007) and Federal law on the protection of nature (2009), modified framework conditions exist for new constructions and development as well as maintenance measures along federal waterways. If so far technical aspects predominantly determined the designs that guaranteed an adequate state of the waterways ensuring permanently safe and smooth shipping traffic, ecological aspects increasingly have to be taken into account today, too.

The application of close-to-nature technical-biological bank protections as an alternative to the traditional riprap revetment might contribute to achieving the required goals of the Water Framework Directive at waterways, such as the preservation and development of habitats for plants and animals.

As there are many experiences with bioengineering measures from smaller watercourses without navigation, however, not from waterways with today's ship-induced bank loads, a joint research project between the Federal Waterways Engineering and Research Institute (BAW) and the Federal Institute of Hydrology (BfG) about "Technical-Biological Bank Protection Measures – Quantification of the Load Rating and Feasibility of Application" was launched in 2004. The aim is to analyze possible applications and limits of alternative bank protection measures at inland waterways as well as their ecological effectiveness and to develop design principles analogously to the technical framework for the long term.

The following text presents where we stand today, ten years later, from a technical perspective, which measures were and will be carried out with regard to stability and the design of technical-biological bank protections, what kind of results and experiences are available and what is planned for the future. In this context the currently published draft standard DWA-M519 (DWA, 2014) is also referred to and a relation to the joint research project of BAW and BfG is established.

2 Definition "Technical-Biological Bank Protections"

"Technical-biological bank protections" applied on waterways are bank protections which either completely consist of plant elements (e.g. willow brush mattresses, plant mats) or of a combination of vegetative and technical elements (e.g. reed gabions, vegetated stone mattresses). The latter also include measures to ecologically enhance existing technical revetments (e.g. subsequently vegetated riprap). Protection and stabilization of the bank slope through plants may be achieved through plant parts above-ground and roots in the ground.

Bank protections made of plants can generally be applied above a mean water level only. The bank must, if necessary, be further technically secured below mean water level. Ecological efficiency of the bank protection increases with an increasing number of plant elements, the hydraulic load-bearing capacity, however, decreases and vice versa (see overview in figure 1).

3 Joint Research Project BAW/BfG

3.1 Involved Parties, Content and Objectives

The tests on the applicability of technical-biological bank protections at waterways have to consider phytosociological, faunistic and ecological aspects in addition to geotechnical and hydraulic aspects. In order to take a holistic approach, experts of the different fields are involved, such as from the sections Earthworks and Bank Protection (responsible), Ship/Waterway and Field Studies of BAW as well as from the departments Landscape Management/Vegetation Studies and Fauna of BfG. The aim of the project is to develop, test and recommend bank protection measures using plants that are sufficiently stable and at the same time ecologically efficient. From a technical perspective the following mechanisms have to be examined for this purpose: how can plants permanently guarantee bank protection at waterways with their roots and aerial parts. The corresponding verifications of structural stability which have to be carried out must be calculated. The necessary installation conditions and the load-carrying capacity of

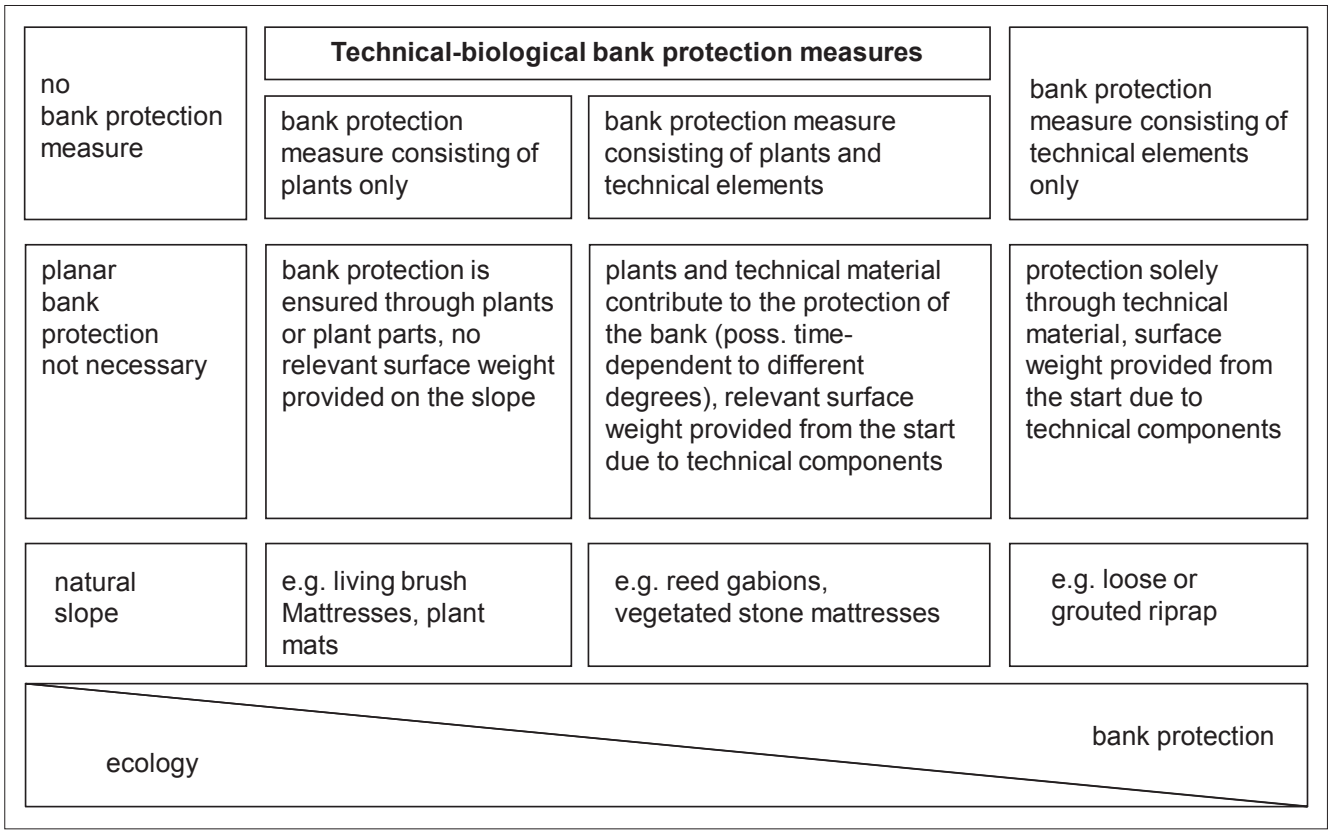

Figure 1: Overview of bank protection measures

technical-biological bank protections concerning ship-induced and natural impacts as well as their durability with regard to different maintenance measures must be investigated. Expenses and costs for the installation and maintenance must be analyzed. From an ecological perspective the verification of efficiency of the different technical-biological protection measures must be provided in order to fulfill the requirements of the new laws and guidelines. All findings are supposed to result in well-founded installation, design and evaluation recommendations for technical-biological bank protections at waterways and to serve as a working basis for the planning engineer from WSV.

3.2 Difficulty – Plants as Living Construction Material

In urban regions where a natural bank development cannot be allowed the same requirements have to be imposed on technical-biological bank protections as on conventional technical revetments applied so far. This means that besides the verification of the overall slope stability the following verifications according to GBB (BAW, 2010) have to be provided:

- resistance against sliding in a sliding surface close to the surface and with regard to hydrodynamic soil displacement (caused by excess pore water pressures in the soil resulting from drawdown due to passing ships),
- resistance against surface erosion (caused by natural and ship-induced currents and waves),
- safety against internal erosion (caused by flowing water inside the slope) to guarantee filter stability in the bank zone.

Technical revetments made of loose riprap ensure bank protection through the surface weight (dimensioned with regard to occurring excess pore water pressures in the soil caused by drawdown) and a sufficient size of the single stones (dimensioned with regard to flow velocities and stern wave heights close to the bank) – GBB (BAW, 2010). Bank protections that only consist of plants do not have a significant surface weight. Resistance against sliding in a sliding surface close to the surface can therefore, only be ensured through roots in the soil which increase the shear strength of the soil as a network of roots or lead to a soil nailing through single roots. These mechanisms are examined by the BAW within the frame of the abovementioned research project. With regard to the resistance against surface erosion experiences from smaller water courses without navigation can be used. This is where limit values for tolerable flow velocities already exist for different protection measures with plants. First experiences at navigable waterways are currently gained concerning the permissible wave load. Further investigations are carried out in order to guarantee filter stability in the initial state and permanently for different construction methods.

In contrast to sole technical riprap revetments, bank protections using plants are construction methods with living materials. Therefore, besides technical factors, a series of non-technical influencing factors have to be taken into account which influence the installation and stability of bank protection measures and are difficult or impossible to be defined in a formula (see figure 2).

As opposed to sole technical bank protections, bank protections with plants can only be installed at specific times (usually during dormancy periods). Impacts from navigation, fluctuating water levels and at times floods influence the installation and further development as well as the long-term load-bearing capacity of the measures. Bank protections with plants permanently change during their operating time as there are always different development statuses due to plant growth. The bank protection must, however, always be ensured. The initial state is usually the most critical state as roots and shoots must develop first. In order to guarantee stability in the initial state mostly mountings and, if necessary, temporary filters are thus required which have to be dimensioned. Excessive plant growth can also have a negative impact on the bank protection (shading of adjacent bank zones) and on flood control for the long-term (narrowing of the discharge profile). Long-lasting submergence, dry periods and parasites can negatively affect the vitality and growth of plants and hence endanger the bank stability.

Performing model and field tests with plants as living construction material within the frame of research activities is also a considerably more complex and lengthy process than with technical material. Plants, bank protection measures with plants respectively, must be pregrown a certain period of time for laboratory and model tests, first. Since different development states must be

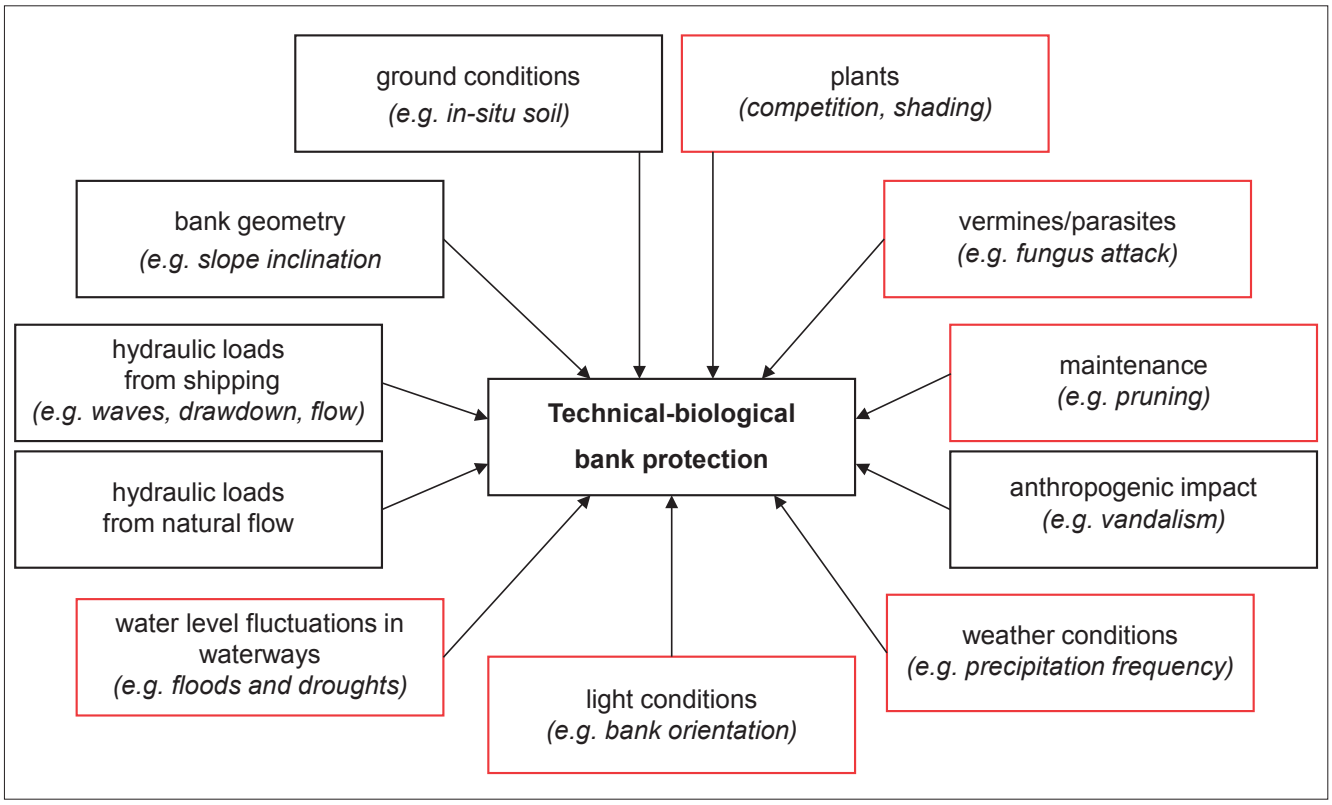

Figure 2: Most important influencing values on bank protection measures at waterways (framed in red: additional impacts on bank protections with plants)

examined the plants continually need enough time to grow before new tests can be carried out. For field tests at waterways regarding development and load-carrying capacity of the tested bank protection measures with plants well-founded conclusions can only be drawn after several vegetation periods.

3.3 Previous Activities and Most Important Results

The work within the frame of the research project currently focuses on four work packages (figure 3):

- working on existing data in order to record present practical experiences both within and outside the WSV (bibliographic research and detailed examinations in-situ at selected waterway sections at which bank protections using plants have locally been installed in the past, but experiences therewith have not been evaluated, yet)
- laboratory and model tests, theoretical considerations in order to understand the mechanisms guaranteeing bank protection with plants (growth and shearing tests, filter tests, tests in the wave basin)
- new applications and consultations within the frame of WSV-orders, installation of test stretches (field tests) on the basis of current knowledge on validating model tests and collecting thorough practical experiences
- exchanging experiences and gaining knowledge by participating in national (DWA WW1.5/2.5) and international (PIANC InCom WG 128) committees.

A close connection exists between the single work packages, the corresponding experiences and conclusions continuously contribute to the recent work of the other packages, e.g. the gained knowledge from laboratory and model tests contributes to the planning and implementation of field tests. Conversely, practical experiences from applications form the basis for the development of new laboratory and model tests. In addition, a professional cooperation with different universities exists, such as in the form of internships and master's theses as well as doctorate studies.

The most important activities and tests that have been carried out within the frame of the joint research project of BAW and BfG are listed in table 1 (see on page 6). The details and corresponding results have

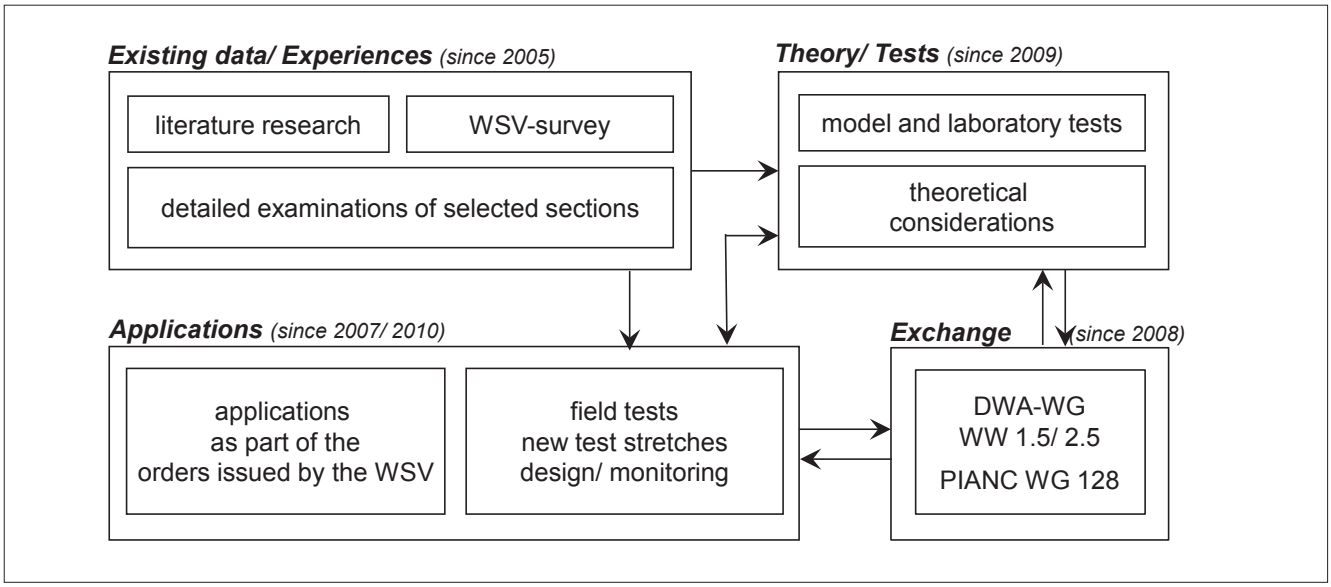

Figure 3: Working packages of the research project

already been published in numerous reports, papers and presentations in a timely manner and are available on the subject-oriented website (http://ufersicherung.baw.de/de/index.html). Two colloquia were held on this topic in order to publish first results and particularly to exchange experiences within WSV (2010 and 2013). Its contents and presentations are also available online (http://ufersicherung.baw.de/de/veranstaltungen/index.html).

The field test at the river Rhine near Worms is especially worth mentioning. It has been carried out in cooperation with the Waterways and Shipping Office (WSA) Mannheim since 2011. This is where nine different bank protection measures with plants are tested under realistic waterway conditions along a 1 km-long stretch at the right bank from km 440.6 to 441.6. The single measures were selected based on current findings from the research project. At this point they are exposed to high ship-induced load and large water level fluctuations (above 6 m). Within the frame of the monitoring, which will be jointly carried out by BAW and BfG together with WSA Mannheim until 2016, important insights on the load-bearing capacity, durability, maintenance and ecological efficiency of the installed bank protections are expected.

The scientific examinations (laboratory, model and field tests) are not yet completed. On the basis of present findings the following can be said on practical applications of technical-biological bank protections at inland waterways from the stability point of view at this moment in time:

- In principle, bank protections with plants can be considered for the application at inland waterways. Their use depends first and foremost on the prevailing ship-induced and natural hydraulic loads on the bank. Minimal loads and flat slopes increase the possibility of application. It is, therefore, reasonable to verify case by case if the hydraulic bank loads can be reduced through constructive measures (e.g. parallel structures) or administrative measures (e.g. limitation of the ship speed) and if a flattening of the slope is feasible.
- The initial state is usually the most critical state. Directly after their installation, the bank protections with plants, which have to develop roots and shoots, first are exposed to loads caused by shipping. Corresponding mountings (e.g. stakes, cross beams) and temporary filter mats, if necessary, are required and must be dimensioned. An early submergence due to flooding and simultaneous ship-induced load leads to impacts on the newly installed bank protections due to uplift, current and waves, especially at waterways with highly fluctuating water levels. Present experiences show that light bank protection constructions without significant dead weight are not suitable in this case, such as plant mats with punctual or linear mountings only and few plant species that are resistant to submergence, as permanent soil contact necessary for root growth in the subsoil cannot be achieved.

working package	most important activities (selection)	year	reports (selection)
data collection/ experiences	international bibliographic research on the application of technical-biological bank protections at waterways	2005	report by the university of Stuttgart
	WSV-survey on old projects at waterways with technical-biological bank protections	2005/06	report (BAW/ BfG, 2006) BAWLetter 2/2006 (BAW, 2006)
	detailed examinations at a bank section of the Weser river with technical-biological bank protections, km 241.55 to km 242.30 (Stolzenau)	2006/08	report (BAW/ BfG, 2008) BAWLetter 1/2011 (BAW, 2011)
	detailed examinations at the Midland Canal, km 189.6 to km 190.1 (Haimar)	2013/14	report in progress
	new WSV-survey on current projects with technical-biological bank protections within the WSV	2014	evaluation in progress
theory/ tests	test on the load-bearing capacity of willow brush mattresses in the wave basin of BAW	2008 until 2014	test results are currently evaluated and documented within the frame of a doctoral study, publications on the tests in the Newsletter no. 95, July 2012 (Fleischer, Eisenmann, 2012)
	growth tests with different willow species to quantify root formation		
	tests on the permeability to roots of different geotextiles (biodegradable and non-degradable)		
	large shear tests with willows (quantification of shear strength of the rooted soil)		
applications	different consultations of WSV during projects	continously	
	test stretch at the river Rhine near Worms, km 440.6 to km 441.6, right bank (field test with 9 different bank protection measures in cooperation with the WSA Mannheim) (preliminary planning, construction supervision, documentation, monitoring)	since 2009	report (BAW, BfG, 2010) report (BAW, BfG, WSA MA, 2012) BAWLetter 5/2012 (BAW, 2012) report (BAW, BfG, WSA MA, 2013) report (BAW, BfG, WSA MA, 2014)
	drafting of specifications for different alternative bank protections on the basis of present experiences, especially from the field test at the river Rhine	2014	(BAW, BfG, 2012) specifications - willow brush mattresses - reed gabions - vegetated riprap
exchange	participation in DWA committee WW1.5/2.5, drafting of the Code of Prac-tice M519	2008 until 2014	first draft of the code of practice 31.10.2013 draft standard (DWA, 2014)
	participation in PIANC committee WG 128	since 2009	

Table 1: Most important activities within the frame of the research project

- In general it must be differentiated whether bank protections are to be developed for waterways with almost constant water levels (e.g. canals) or for waterways with highly fluctuating water levels (e.g. free flowing rivers). At waterways with almost constant water levels sound possible applications and dimensioning principles are already available. There, technical-biological bank protections are applied above water level and therefore outside the reach of influence of drawdown during ship passages and thus outside of possibly harmful excess pore water pressures in the subsoil (BAW, BfG, 2008; BAW, BfG, 2014). In addition to the general verification of overall slope stability, only verifications with regard to sufficient filter stability of the bank protection with respect to the subsoil and with regard to resistance against surface erosion have to be carried out. At this point, experiences from watercourses without navigation can be used concerning permissible flow velocities.
- No sufficient dimensioning standards exist for bank protections at waterways with significant water level fluctuations yet, at which bank protections with plants are installed above a mean water level. The bank protections with plants are submerged in the case of a flood. For water levels up to the highest navigable water level (HNWL) additional loads from drawdown during ship's passage occur. At present, the BAW (Fleischer, Eisenmann 2012) still analyzes the mechanisms of plants to guarantee resistance against sliding and hydrodynamic soil displacement with their roots and without additional surface weight in laboratory and model tests.
- Until sufficient results are available on this, it must be operated according to the existing technical set of rules – GBB (BAW, 2010) – analogous to the design of riprap. It is verified, if a surface weight on the slope is mathematically necessary due to the occurring excess pore water pressures. If required, safety must be guaranteed through the calculated surface weight, the mode of operation of the roots will be neglected. This means that bank protections consisting of plants only cannot be applied in this case. Bank protections with plants and corresponding technical elements or pure technical bank protections can be applied with which erosion control can be ensured at the same time. Furthermore, the filter stability with regard to the subsoil has to be verified in this case as well, if necessary, by additional measures. When selecting the plants, impacts from submergence and drying up must be taken into account.
- Long-term experiences with technical-biological bank protections and their maintenance are not yet available, especially at waterways with fluctuating water levels. It is expected to gain important insights from the field test at the river Rhine in the next few years (BAW, BfG, WSA MA, 2012, 2013, 2014).

First recommendations on different close-to-nature bank protection measures using plants, their application conditions and load-bearing capacities at waterways have already been published within the frame of the research project in the form of specifications (BAW, BfG, 2014).

4 Code of Practice DWA-M519

In 2008, the committee WW1.5/2.5 of the German Association for Water, Wastewater and Waste (DWA) was set up with the aim to gather the current state of knowledge on the application of technical-biological bank protections at navigable waterways. Besides the representatives of BAW and BfG of the abovementioned research project, representatives of the German Association for Bioengineering (Gesellschaft für Ingenieurbiologie e. V.) and of different institutes, administrations as well as planning companies are part of the committee led by Prof. Dr. Söhngen (BAW).

Since there have been positive experiences with bioengineering constructions at watercourses without navigation for a longer time already, such as from the abovementioned research project, these were to be the basis for a specification together with present experiences from waterways, despite the fact that no definitive well-founded insights and long-term experiences with technical-biological bank protections at waterways are available, yet. A safe guideline was supposed to be developed which can be of help in the planning process of such measures. Its development appeared to be urgent, as first measures without uniform dimensioning standards have already been planned and installed by the WSV in the first few years after the legal changes on the implementation of the Water Framework Directive at waterways came into effect.

After five years of committee work with an intensive exchange of experiences a first draft of the Code of Practice DWA-M519 "Technical-Biological Bank Protection Measures Applied on Large and Navigable Inland Waterways" (DWA, 2014) was presented at a joint colloquium of BAW, BfG, German Association for Bioengineering and DWA on the 21 and 22 November 2013 in Karlsruhe, Germany. In fall 2014, the draft Code of Practice was published after representatives of WSV and the Federal Ministry of Transport and Digital Infrastructure (BMVI) had agreed on the content of the draft available at (http://ufersicherung.baw.de/de/veranstaltungen/kolloquium_2013/index.html).

The Code of Practice provides first recommendations for the planning and implementation of close-to-nature and ecologically enhancing protections of slopes at large and navigable inland waterways. It is demonstrated how technical-biological bank protections can currently be planned and installed according to the present knowledge and under specific boundary conditions depending on the requirements related to the bank stability at navigable waterways based on current technical guidelines, bioengineering experiences and considering present research results of BAW and BfG. At the same time the compiled results showed that further examinations are necessary, which are partially carried out in the abovementioned research project.

The specification recommends the approach depicted in figure 4 in terms of a conservative design for technical-biological bank protections. After that the planning of a bank protection with plants usually begins with the verification of the overall stability of the slope. If the latter is given, a fictional technical riprap revetment is dimensioned using the software GBBSoft based on GBB (BAW, 2010). The result shows, amongst other things, whether or not a surface weight on the slope is necessary to ensure local stability and if so, how high it must be. If a surface weight is mathematically not necessary (loads from drawdown not relevant), a bank protection will either not be needed at all or a bank protection consisting of plants can only be applied depending on the resistance against surface erosion. Otherwise, the necessary calculated surface weight must be guaranteed by the installation of the bank protection. This can be achieved by the application of technical-biological bank protections with technical elements (e.g. reed gabions) or at higher hydraulic loads through technical riprap with a corresponding layer thickness. The local resistance against sliding in a sliding surface close to the surface is thus conservatively ensured by a surface load, by analogy with technical revetments. In those cases, applications of bank protections with plants are still limited. Not until quantitative results on the permanent mode of action of the roots in the soil are available from the currently still ongoing tests of BAW, a different approach and thus probably more bank protections with plants can be used.

The verification of resistance against surface erosion for the technical-biological bank protection measures recommended in the specification is based on the experiences from smaller watercourses without navigation. The mechanisms are similar; the indicated limit values will be adapted with growing experiences at waterways. In addition to the stated technical requirements, bioengineering and ecological criteria have to be taken into account when selecting a bank protection measure.

Furthermore, the specification lists different measures on the ecological enhancement of watercourses (e.g. connecting cut-off meanders) and on the reduction of bank loads (e.g. breakwater structures parallel to the slope such as palisades or stone walls) in order to increase the possibility of applications of bank protections with plants at inland waterways. A first ecological evaluation of the single bank protection measures is currently only possible on the basis of experiences at watercourses without navigation as in this respect knowledge at waterways is lacking, too. Thus, in the next few years, the specification is to be adapted to the then current state of knowledge from a technical and ecological perspective. Until then experiences with the depicted approach which could have some influence on the ongoing examinations and the future revisions of the specification should be collected.

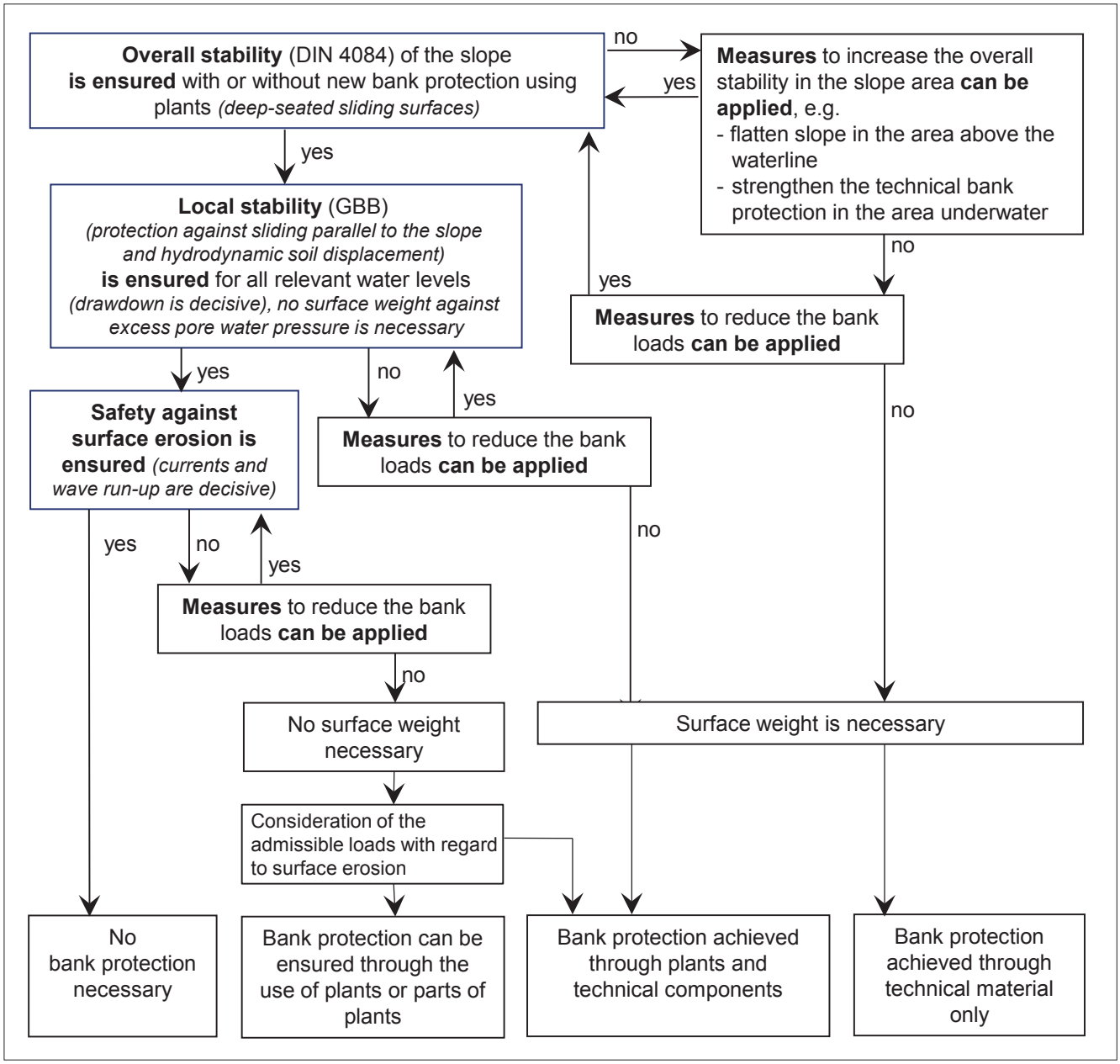

Figure 4: Approach to determine the necessary bank protection measure according to the DWA Code of Practice (DWA, 2014)

5 Outlook

So far the results gathered from laboratory and model tests, which were carried out within the frame of the research project of BAW in the last few years, are currently compiled in a doctoral study. Based on this, the tests will be continued in the next few years. Further laboratory and model tests especially focus on the filter stability of different construction methods using plants (e.g. willow brush mattresses) in the initial and in several development states, focus on the development of adequate, biodegradable geotextile filters, on the root formation and development of different plants (e.g. further willow species and herbs), on the further quantification of shear strength of the rooted soil and on different maintenance measures for bank protections with plants concerning the influence of near-ground flow velocities, the danger of erosion, but also concerning effects on the flood discharge.

A second focal point consists of the additional examinations at the test stretch at the river Rhine near Worms. Within the frame of the monitoring, which is carried out by BAW and BfG together with WSA Mannheim first for

a total of five years until 2016, important findings on the load-bearing capacity, durability, maintenance and ecological efficiency of the installed bank protections are expected. At the same time the already published specifications (BAW, BfG, 2014) are supplemented with further specifications based on the existing experiences at waterways in order to serve as an aid for the planning engineer. These include information on possible applications, on the mode of action, on the installation and maintenance of single bank protection measures with plants. The specifications will be revised gradually with increasing insights.

The results of the second survey on current projects with alternative bank protections are still being evaluated. They were carried out within WSV in 2013. The results will soon be published on the joint website of BAW and BfG in order to enable an intensive exchange of experience on this subject within WSV.

The overall results from the research project and the expected practical experiences with the DWA Code of Practice will form the basis for detailed dimensioning designs and profound ecological analyzes of technical-biological bank protections at inland waterways. With further insights close-to-nature valuable bank protections using plants will increasingly be used as an alternative to the technical riprap revetment.

6 Conclusion

With the introduction of the European Water Framework Directive and the adaptation of the corresponding national laws, the legal framework conditions for more ecological enhancement at waterways and thus for the increased use of close-to-nature bank protection measures were established. The technical foundations have been researched in a joint project of BAW and BfG for ten years now. The tests with living building materials are complex and lengthy. A lot of factors of influence have to be taken into account which cannot be defined in a formula. This must be compensated with practical experiences gained from field tests. Important issues have already been tested and preliminary results were published (http://ufersicherung.baw.de/de/index.html). The tests are still ongoing. Complete dimensioning standards can be drafted no earlier than 2016, when all monitoring results from the test stretch at the river Rhine are available and thus, first long-term experiences at waterways.

The publications on partial results from the research project of BAW and BfG (see table 1) and the DWA Code of Practice M519 “Technical-Biological Bank Protection Measures Applied on Large and Navigable Inland Waterways” (DWA, 2014) drafted at the same time provide a first uniform basis for designs of bank protections at waterways using plants.

The Code of Practice is based on bioengineering experiences from watercourses without navigation, first local experiences at waterways and present research results from BAW and BfG. Long-term experiences with technical-biological bank protections at waterways are not available, yet. The basis for verifications of the stability of bank protections using plants is therefore the existing technical regulation of the WSV in order to be on the safe side (BAW, 2010). The DWA Code of Practice M 519 is an intermediate step in the process of developing dimensioning standards for technical-biological bank protection measures at inland waterways and should contribute to an enhanced exchange of experiences and to gaining knowledge.

7 Publications/Literature

Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW) (2010): ”Code of Practice: Principles for the Design of Bank and Bottom Protection for Inland Waterways (Issue 2010) (GBB), available at http://www.baw.de/de/die_baw/publikationen/merkblaetter/index.php.html

Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW), Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde, BfG) (2006): ”Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways (R&D project) Part 1: Motivation, Survey and International Research“, May 2006

Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW), Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde, BfG)

(2008): ”Studies on Alternative Technical-Biological Bank Protection Measures Applied on Inland Waterways (R&D project) Part 2: Test Stretch Stolzenau/Weser Km 241.550 - 242.300, October 2008

Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW), Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde, BfG) (2010): „Einrichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein-km 440,6 bis km 441,6, rechtes Ufer, Empfehlungen für die Ausführung der Ufersicherungen“ [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 application of bank protections], May 2010

Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW), Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde, BfG) (2014): „3 Kennblätter: Röhrichtgabionen, Weidenspreitlagen, begrünte Steinschüttung“ [3 Specifications: reed gabions, willow brush mattresses, vegetated riprap], July 2014, available at http://www.baw.de/de/die_baw/publikationen/merkblaetter/index.php.html

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Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW), Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde, BfG), Federal Waterways and Shipping Office (Wasser- und Schifffahrtsamt, WSA) Mannheim (2014): „Einrichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein km 440,6 bis km 441,6, rechtes Ufer – Dritter Zwischenbericht: Monitoringergebnisse 2013“ [Installation of a test stretch with technical-biological bank protections, river Rhine km 440.6 to km 441.6, right bank – third progress report: monitoring results 2013], self-published, Karlsruhe/Koblenz, June 2013

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