Living Brush Mattresses

Specification (status: February 2018)

Living Brush Mattresses

1) Overview	
Description	shoot-forming and elastic willow branch layer that covers the bank the layer is firmly secured to the soil by stakes, crossbars (*shoot-forming/non-shoot-forming) and wire-bracing*) **desired vegetation:** indigenous and site-adapted woody plants (*trees and/or shrubs – according to willow species and maintenance objectives*)
Bank protection	immediately effective and complete protection of the bank in case of tight area-wide coverage against surface erosion induced by currents and waves area-wide and flush to the soil installation of the willow branches or the assembly of an additional filter between willow branches and soil provide filter stability applicable on slopes with an inclination of 1:3 or less when affected by ship-induced water level drawdown, only applicable if there are no excess pore water pressures in the soil threatening bank stability (*low drawdown values, highly permeable soil in the slope area, flat slope inclinations – examination according to GBB*[1)]*)*
Ecological potential *in comparison with riprap*	**promotion/development of indigenous and site-adapted woody plants** - increase in structural diversity as well as biodiversity at the waterbody - decrease in/ prevention from settlement of invasive plants - creation of habitats for animals preferring woody plants (e.g. birds and insects) - particularly during intermitted maintenance, possible development of structures, similar to riparian forests, providing valuable living space and hiding places for various habitat-typical animal groups - creation of habitats and shelters for aquatic fauna (invertebrates, fishes) at an advanced stage of the measure in case of intermitted maintenance and thus growth into the aquatic area
Advantages/ Disadvantages	**advantages** - living materials which can sometimes be cut in-situ - comparatively low costs - manual installation; no special machines required - quick vegetation owing to the fast-growing and shoot-forming willows **disadvantages** - limited installation period *(willow branches can only be cut and installed during winter dormancy)* - at an initial stage, soil-cover has to be renewed in case of high-flooding if necessary - appropriate indigenous willow plants may not be available - high and dense vegetation may influence discharge - increased maintenance (*in particular for high-grown willow tree species*)

2) Components and installation

Components **Living brush mattresses**	**shoot-forming willow branches** indigenous and site-adapted willow trees and/or shrubs *(if possible, the branches should be straight for better soil contact; combination of male and female specimen)* ∅: 2 - 5 cm *(blend of thin and thick branches: thick branches form more shoots; thin branches provide better soil contact)* L: 200 - 500 cm Willow trees: white willow (*Salix alba*), hybrid crack willow (*Salix x rubens*) Shrubby willows: purple willow (*Salix purpurea*), almond willow (*Salix triandra*), common osier (*Salix viminalis*)
Filter	In case of imminent soil discharge in the initial state, application of a geotextile filter between willow branches and the soil below (*dimensioning according to MAG*[12)]*)* ideal solution: entirely biologically degradable geotextile that is easily pierceable for roots; only necessary for the initial state – approx. three years –, afterwards roots will carry out filter function in case of a lack of an entirely degradable geotextile, a stable synthetic non-woven fabric (≥ 300g/m²) may be used as well
Securing material	**stakes and crossbars** shoot-forming (*indigenous and site-adapted willows, additional root formation and denser vegetation)* non-shoot-forming *(any kind of wood*) $\varnothing_{stake}$: 8 - 10 cm L_{stake}: at least 80 - 100 cm $\varnothing_{crossbar}$: approx. 10 - 12 cm *(if possible, crossbars should be straight for better soil contact)* **bracing wire** (*in order to tie stakes and crossbars*) diameter: 0.3 cm, annealed
Cover	**soil** cover on top of the measure made of slightly plastic clayey to sandy-gravelly soil *(for better soil contact and protection against dehydration of branches)* upper edge of cover: approx. 3cm above willow brush mattress
Cutting and installation period	**cutting of willow branches** dormancy period (= *period between shedding of leaves and budding; respect nature conservation regulations of BNatSchG [Federal Nature Conservation Act] when cutting branches of wild willows)* **installation of willow branches** (*during dormancy period, on frost-free days*) ideally: March/April (*roots form immediately after installation*) limited suitability: October/November (*roots form not until next spring*)

Boundary conditions for installation	**distance to water level** lower edge of willow brush mattress (= basal ends): approx. mean water level/normal water level (*on waterways with marginal or without water level fluctuations, ~0.5 m below normal water level is possible, see 3), there "Flooding tolerance", there "experiences gained at the Rhine test-stretch…*") **slope inclination** ≤ 1:3 **lighting** sun or partial shade
Installation instructions	**tight area-wide installation** approx. 40 to 50 branches per running meter *(depending on branch diameter)* installation in the direction of the slope or diagonally (see Appendix 1); thick, basal ends pointing downwards **water supply** lowest layer (closest to the water): basal ends of branches reaching into the water upper layers: 1 m long basal ends of branches buried at least 0.5 m deep into the ground (*if multiple layers on the slope*; see Appendix 1*)* **overlapping** overlapping of multiple layers between water and upper edge of slope: - toe embedment in underwater riprap or trenches - thin ends of lower installed willow brush mattresses cover basal ends of the next higher row **securing** distance between stakes ≤ 100 cm; if necessary, install stakes inclined to the flow direction (*increased stability*) distance between crossbars ≤ 100 cm; crosswise wire-bracing *(parallel to the bank line or diagonal installation of the crossbars in order to minimise downward soil displacement in the initial state)* secured willow branches require areal soil contact on the entire slope surface for the development of roots (*if necessary, the distance between crossbars and stakes has to be diminished*) **procedure** (see Appendix 2) 1) prepare subgrade; if necessary, dig trenches for toe embedment 2) drive in stakes (at first only down to 2/3 of their length) 3) install willow brush mattresses and embed at least 100 cm of the lowest layer into the riprap *(usually existing beneath mean water level)* 4) install crossbars on top of brush mattresses 5) install wire-bracing on top of stakes and crossbars 6) drive stakes deeper into ground *(press crossbars and willow branches tightly onto soil)* 7) saw off ends of stakes approx. 4 inches above wire *(minimising exposed length)* 8) cover with soil *(if necessary, renewal after flood during initial state)* **ensuring filter stability** - press willow branches on soil, tight area-wide - install additional filter in case of potential loss of soil *(in case of very fine soil or insufficient density of brush layer)*

3) Mode of action and load-carrying capacity

Mode of action

protection against surface erosion induced by currents and waves

right after installation	by a tight area-wide, filter-stable cover of the slope made from willow branches, securing measures, installation of an additional filter (if necessary)
in the long term	additional protection by a network of roots close to the surface and shoots of the growing willows above the surface (*filters and securing measures become increasingly dispensable*)

protection against slope-sliding due to drawdown/excessive pore water pressure

right after installation	by sufficiently dimensioned stakes (*embedment depth and adequate distance)*
in the long term	by a dense network of roots/single roots reaching deep into the ground (*increasing shear strength of soil (cohesion due to roots), soil nailing)* *(securing measures become increasingly dispensable over time*)

protection against hydrodynamic soil displacement due to drawdown/excessive pore water pressure

right after installation	no protection, limitation of downward soil displacement by cross bars which are orientated parallel or diagonally to the bank line (*pressed firmly on the soil)*
in the long term	by a dense network of roots reaching deep into the ground (cohesion due to roots)

general

shoots above ground and leaves of willow branches can reduce wave and current impact and favour local sedimentation and aggradations

Tolerance to hydraulic loading

basis: present experiences gained at navigable waterways[3) to 8)] **and watercourses without navigation**[13)]

- drawdown:	no data	(*at the moment not applicable if drawdown leads to excess pore water pressures in the ground which are relevant to stability (for verification see GBB*[1)]*)*
- wave height:	0.4m[*)]	*(derived from experiences gained at watercourses without navigation for waterbodies with navigation)*[13)]
	0.4m	*(measured load until present at relevant water level heights at the river Weser test stretch near Stolzenau)*[2)]
	0.3m	*(measured load until now at relevant water level heights at the Rhine test stretch – test sections 2 and 3)*[6)]
- flow velocity close to the bank:	2.0m/s	*(derived from experiences gained at watercourses without navigation for waterbodies with navigation)*[13)]
	1.0m/s	*(measured load until present at relevant water level heights at the river Weser test stretch near Stolzenau)*[2)]
	0.5m/s	*(measured load until now at relevant water level heights at the Rhine test stretch – test sections 2 and 3)*[6)]

[*)] *values for the critical initial state*

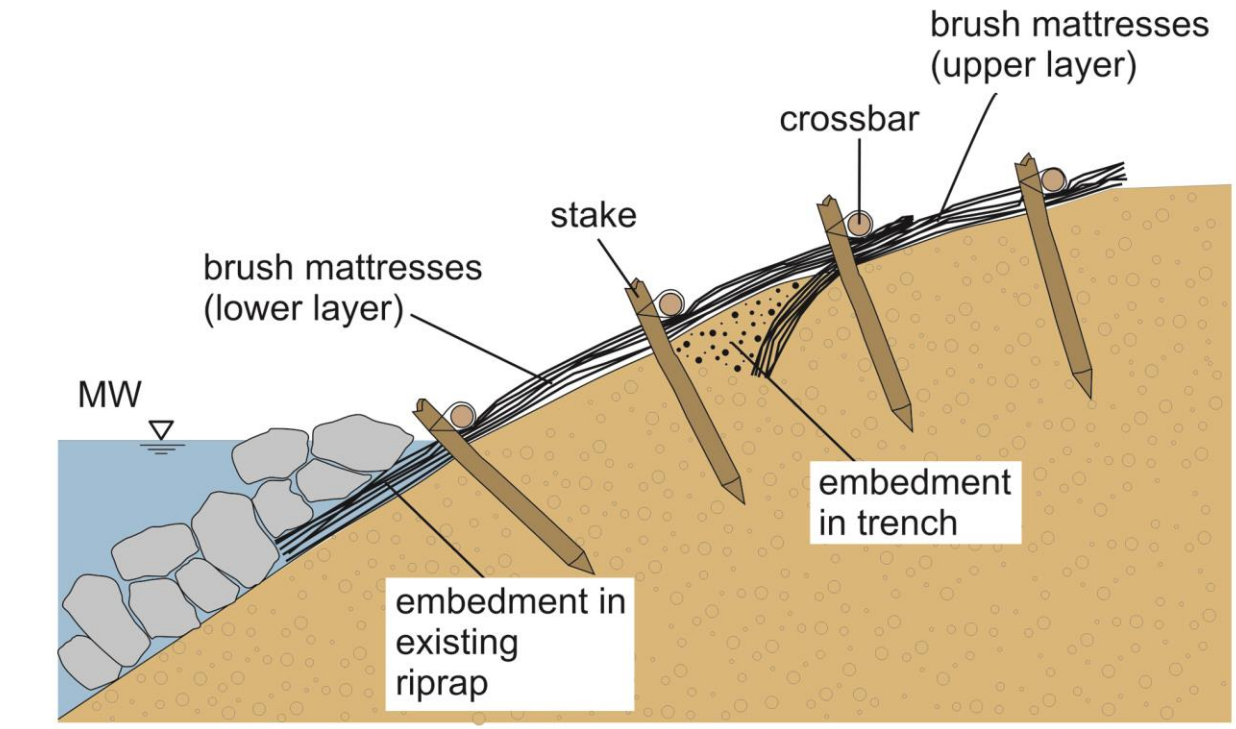
Flooding tolerance	willows have a high flooding tolerance from 80 days (basket willow)[11)] up to 130 days (French willow, purple willow) and/or 170 days (white willow)[9) to 11)] per year (*benchmark!*) further influence on the flooding tolerance by: flooding height, flow, age and growth height of the trees/bushes, flooding period (during growing season or dormancy), plant vitality experiences gained at the river Rhine test-stretch [4) to 7)]: limited shoot growth in the zone of fluctuating water levels (MW ~ 0,5m to MW + 1m) in case of frequent, long lasting surcharge due to floods (up to 10 consecutive weeks) and simultaneous ship-induced charges at longer low water periods
4) Miscellaneous	
Maintenance	**procedure for the development of a stratified willow stand with high ecological value** maintenance-pruning should be performed non-uniformly and in longer periods according to growth rates (willow trees and shrubby willows) and maintenance objectives to ensure both traffic safety at the waterway and site-adapted willow populations diverging in age in a long-term perspective (*large-scale pruning must be avoided*) to be carried out only between 1st October and end of February to minimise disturbance for breeding birds and other wildlife (*according to BNatSchG*) **pruning** *considering the desired vegetation (willow trees and shrubby willows* in order to - guarantee sufficient flood discharge - prevent shading of undergrowth *(threat of erosion)* - preserve and rejuvenate willow population (*maintain elasticity*) - promote root growth (*slope stability*)
Examples at German waterways	- test stretch at the river **Weser** near Stolzenau, km 241.550 - 242.300, right bank, (test sections 7a and 10), installation finished in 1989[2)] - test stretch at the river **Rhine** near Lampertheim, km 440.600 - 441.600, right bank, (test sections 2 and 3), installation finished end of 2011[4)3)5)6)] - bank relocation at the river **Main**, left bank, km 310.000 - 311.000, installation finished 2012
Literature	[1)] BAW (2011): Bundesanstalt für Wasserbau (Hrsg.), Grundlagen zur Bemessung von Böschungs- und Sohlensicherungen an Binnenwasserstraßen (GBB 2010), Eigenverlag, Karlsruhe 2011. [2)] BAW, BfG (2008): Bundesanstalt für Wasserbau, Bundesanstalt für Gewässerkunde, Untersuchungen zu alternativen technisch-biologischen Ufersicherungen an Binnenwasserstraßen - Teil 2: Versuchsstrecke Stolzenau/Weser, Eigenverlag, Karlsruhe, Koblenz 2008. [3)] BAW, BfG (2012): Einrichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein, km 440,600 bis km 441,600 (rechtes Ufer), Erster Zwischenbericht – Randbedingungen, Einbaudokumentation, Monitoring, 25.01.2012, abrufbar unter http://ufersicherung.baw.de/de/index.html [4)] BAW, BfG, WSA MA (2013): Einrichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein, km 440,600 bis km 441,600 (rechtes Ufer), Zweiter Zwischenbericht – Erste Monitoringergebnisse 2012, 20.06.2013, abrufbar unter http://ufersicherung.baw.de/de/index.html

Literature *(continued)*	[5)] BfG, BAW (2014): Einrichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein, km 440,600-441,600 (rechtes Ufer), Teilbericht Vegetation, Monitoringergebnisse 11/2012 bis 10/2013, letztmalig aktualisiert am 19.3.15, abrufbar unter http://ufersicherung.baw.de/de/index.html [6)] BAW, BfG (2015): Einrichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein, km 440,600 bis km 441,600 (rechtes Ufer), Teilbericht Standsicherheit und Unterhaltung, Monitoringergebnisse 11/2012 bis 10/2013, 30.03.2015, abrufbar unter http://ufersicherung.baw.de/de/index.html [7)] BAW, BfG, WSA MA (2016): Einrichtung einer Versuchsstrecke mit technisch-biologischen Ufersicherungen, Rhein, km 440,600 bis km 441,600 (rechtes Ufer), Fünfter Zwischenbericht – Monitoringergebnisse 11/2014 bis 10/2015, 08/2016, abrufbar unter http://ufersicherung.baw.de/de/index.html [8)] BAW, BfG: Internetportal zur Thematik „Alternative technisch-biologische Ufersicherungen an Binnenwasserstraßen“, http://ufersicherung.baw.de/de/index.html [9)] Dister, E. (1988): Ökologie der mitteleuropäischen Auenwälder. Wilhelm-Münker-Stiftung. Heft 19. S. 6-30. Siegen [10)] Späth, V. (1988): Zur Hochwassertoleranz von Auenwaldbäumen, Natur und Landschaft 63, 1988, S. 312 bis 315 [11)] Westhus, W. (1986): Beobachtungen zur Überflutungstoleranz von Gehölzen und daraus abgeleitete Pflanzvorschläge. Hercynia N. F., Leipzig 23 (1986) 3, S. 346-353. [12)] MAG (1993): Merkblatt Anwendung von geotextilen Filtern an Wasserstraßen (Ausgabe 1993) [13)] DWA (2016): Technisch-biologische Ufersicherungen an großen und schiffbaren Binnengewässern, Merkblatt DWA-M519, März 2016

5) Institutions / link

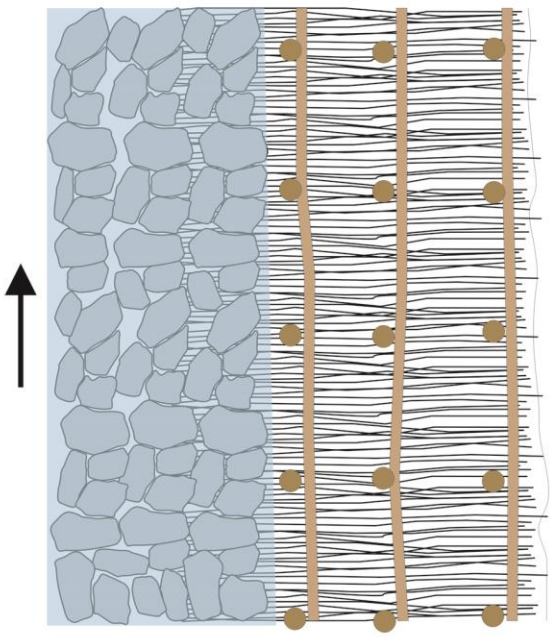
Addresses, persons of contact	**Federal Waterways Engineering and Research Institute** Earthworks and Bank Protection Section (G4) Petra Fleischer (direction): +49 (0)721 9726-3570 @: petra.fleischer@baw.de **Federal Institute of Hydrology** Vegetation Studies and Landscape Management Section (U3) Dr. Andreas Sundermeier: +49 (0)261 1306-5151 @: ag-ufersicherung@bafg.de
Link	For further information, please see: http://ufersicherung.baw.de/de

Appendix 1 **Schematic Figure**

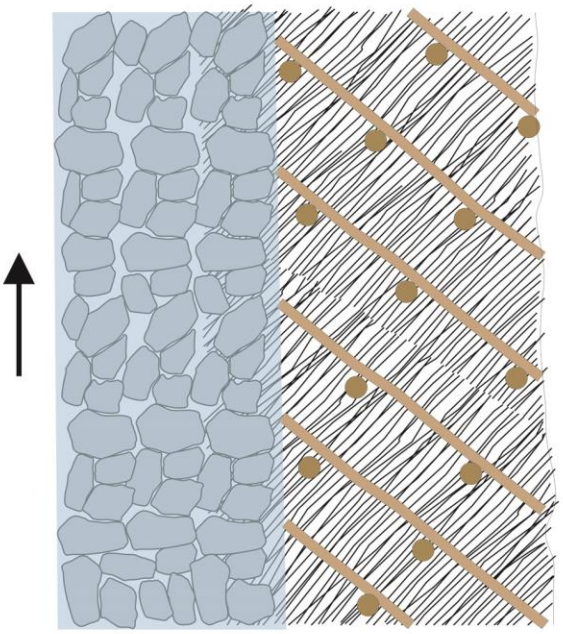


Installation alternatives (plan view)

brush mattresses orientated
in direction of slope



brush mattresses orientated
diagonally on slope



Appendix 2 — Sample Photos

Source: Test stretch Lampertheim/Rhine[3 to 8)] photos: BAW/BfG

(1) Installation material: long and straight branches of indigenous willow species; Nov. 2011

(2) Approx. 1 m deep trenches, into which the basal ends of the willow branches were later embedded; Nov. 2011

(3) Willow branches embedded in trenches (in direction of slope; multiple dense layers!); Nov. 2011

(4) Approx. embedment of lowest mattress into riprap (depth: 1m); Nov. 2011

(5) Brush mattress in direction of slope: Mattress secured by stakes, crossbars and wire-bracing; Dec. 2011

(6) Diagonally orientated brush mattress; secured by stakes, crossbars and wire bracing; Dec. 2011

(7) Sand-gravel blend covering willow brush mattresses; Dec. 2011

(8) First leaf shoots; mid-March 2012

(9) living brush mattresses with numerous shoots; mid-May 2012

(10) Detailed view on willow shoots after a growing season; end of Oct. 2012

(11) Result of an excavation of roots: root lengths of up to 60 cm in Nov. 2012

(12) Willow stands from willow brush mattresses; July 2016