



| 1) Overview   |  |
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| <b>Description</b>                                    | <p>plant mats, pre-cultivated with plants that are suitable for the area of application and pierced by roots; tight area-wide installation on the slope and fixation to the subsoil with stakes and crossbars (<i>tight contact with soil is essential</i>)</p> <p><b>desired vegetation</b></p> <p>indigenous and site-adapted vegetation comprising different types of reed, tall forbs, grasses and herbs (<i>specific zonation according to tolerance range of the plant species corresponding with the site properties</i>)</p>   |
| <b>Bank protection</b>                                | <p>in case of area-wide and tight coverage, immediately effective all-over protection of the bank against surface erosion induced by flows and waves</p> <p>filter stability through composition of plant mats or through the installation of an additional geotextile between soil and plant mats</p> <p>only applicable at waterways without or with minor water level fluctuations and on slopes with an inclination of 1:3 or smaller</p> <p>not applicable in permanently or temporarily submerged slope areas<sup>4) and 6)</sup></p>  |
| <b>Ecological potential in comparison with riprap</b> | <ul style="list-style-type: none"> <li>- increase in vegetation structure diversity and species diversity</li> <li>- enhancement of natural succession through initial planting</li> <li>- reduced occurrence of neophytes</li> <li>- improvement of habitat structures, particularly for terricolous and planticolous species (insects, spiders, ground-breeding birds)</li> <li>- feeding habitats for insectivorous species, e.g. birds and mammals</li> <li>- no structural improvement for aquatic biocenosis</li> </ul>  |
| <b>Advantages and disadvantages</b>                   | <p><b>advantages</b></p> <ul style="list-style-type: none"> <li>- manual installation and fixation, no special equipment necessary</li> <li>- quick vegetation through pre-cultivated and collectively planted site-adapted plants</li> </ul> <p><b>disadvantages</b></p> <ul style="list-style-type: none"> <li>- long planning period necessary (<i>early order for plant mats at appropriate specialized nurseries since the availability of plant species with proof of origin put out for tender is not always guaranteed; pre-cultivation period of at least one growing season is required</i>)</li> <li>- limited installation period (<i>weather conditions, growing season</i>)</li> <li>- overall success depends to a high degree on the right choice and quality of delivery of the pre-cultivated plants, quality management is required</li> <li>- possible high amount of non-degradable materials, depending on the amount of plastic in the supporting fabric of the plant mats</li> </ul> |

| 2) Components and installation                 |  |
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| <b>Components</b>                              | <p><b>plant mat</b><br/>pre-cultivated supporting fabric (for small charges e.g. coir, strengthened with plastic fabric if necessary)<br/>planted with 20-25 plants/m<sup>2</sup><br/>choice of plants is oriented towards a natural bank zonation (relating to MW-line) and site conditions at the place of installation; if necessary, various plant species for different slope zones, e.g. different types of reed, tall forbs, grasses and herbs<br/>common mat dimensions:<br/>width: 0.5 m / 0,75 m / 1.0 m<br/>length: 5 m<br/>thickness: approx. 4 cm</p> <hr style="border-top: 1px dashed black;"/> <p><b>Filter</b><br/><b>geotextile filter</b><br/>if necessary (<i>if filter stability is not solely guaranteed through plant mats, e.g. in case of fine-grain soil</i>), installation of a geotextile filter between plant mats and subsoil (<i>to be dimensioned according to MAG<sup>10)</sup></i>)<br/>ideally: entirely biologically degradable geotextile that is easily accessible 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 synthetic non-woven fabric (<math>\geq 300\text{g/m}^2</math>), stable but pierceable for roots may be used as well<sup>2)</sup></p> <hr style="border-top: 1px dashed black;"/> <p><b>Securing material</b><br/><b>stakes and crossbars</b><br/>any non-shoot-forming woods<br/><math>\varnothing_{\text{stake}}</math>: 8 - 10 cm<br/><math>L_{\text{stake}}</math>: at least 80 - 100 cm<br/><math>\varnothing_{\text{crossbar}}</math>: approx. 10 - 12 cm (<i>if possible, crossbars should be straight for better soil contact</i>)<br/>distance of the crossbars parallel to water line: 0.5 to 1.0 m<br/>stakes: at least 5 pieces per m<sup>2</sup><br/><b>bracing wire</b><br/>(<i>to tie stakes and crossbars</i>)<br/>diameter: 0.3 cm, annealed</p> |
| <b>Pre-cultivation and installation period</b> | <p><b>pre-cultivation</b><br/>at least one growing season<br/>mats must be entirely vegetated at the time of installation (<i>ongoing quality management through contracting authority is necessary</i>)</p> <p><b>installation of plant mats</b><br/>(<i>during dormancy period, on frost-free days</i>)<br/>ideally: March/April (<i>roots form immediately after installation</i>); depending on location and weather, installation until May<br/>limited suitability: October/November (<i>root formation not until next spring</i>)</p>   |

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| <p><b>Boundary conditions for installation</b></p>         | <p><b>distance to water level</b><br/>above mean water level / normal water level<br/><i>(not applicable in permanently or temporarily submerged slope areas)<sup>4)6)</sup></i></p> <p><b>slope inclination</b><br/>≤1:3</p> <p><b>lighting</b><br/>sun or partial shade</p>  |
| <p><b>Installation instructions</b></p>                    | <p><b>tight area-wide installation (see appendix 1 and 2)</b><br/>non-woven geotextile and plant mats installed in the direction of slope dip (<i>maintain right installation order on the slope in case of differing plantation for different slope zones</i>)</p> <p><b>water supply</b><br/>irrigation after installation and if necessary (<i>e.g. at low water level and during dry periods</i>)</p> <p><b>fixation</b><br/>fixation of filter mats and plant mats with crossbars and stakes tied with bracing wire; transitions and intersections of single construction elements must feature an end-to-end, solid and stable connection<br/>if necessary, angular installation of stakes against the flow (<i>enhanced fixation</i>)</p> <p><b>procedure (see Appendix 2)</b><br/>1) prepare subgrade (<i>remove bigger stones or roots from the slope</i>)<sup>8)</sup><br/>2) install filter mats on the subgrade mat-by-mat and area-wide in the direction of slope dip, ensure 30 cm overlapping; embed lowermost mats at the slope toe underneath the water surface in the existing riprap or in trenches parallel to the bank line – fixation through deadwood fascine and stakes<br/>3) install plant mats mat-by-mat and edge-on-edge in the direction of slope dip (without overlapping); embed lowermost mats at the slope toe in the existing riprap (at or above MWL) or in trenches parallel to the bank line – fixation through deadwood fascine and stakes<br/>4) fix filter mats and plant mats with crossbars and wooden stakes including bracing wire fixation; finally, shorten stakes to the height of the crossbars<br/>5) all-over irrigation of plants after installation</p> <p><b>ensuring filter stability</b><br/>filter stability through plant mats or through installation of an additional geotextile filter (<i>proper root penetration and complete biological degradability</i>)</p> |
| <p><b>3) Mode of action and load-carrying capacity</b></p> |  |
| <p><b>Mode of action</b></p>                               | <p><b>protection against surface erosion induced by currents and waves</b></p> <p>right after installation      through area-wide, filter-stable cover with filter mats and plant mats including fixation</p> <p>in the long term                through a near-surface network of roots of the growing, pre-cultivated plants and their aerial shoots<br/><i>(filter mat and fixations become increasingly dispensable)</i></p>   |

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| Mode of action<br><i>(continued)</i> | <p><b>protection against slope-sliding due to drawdown/excessive pore water pressure</b><br/>not relevant as only applicable above mean water level / normal water level<br/>no application on permanently or temporarily submerged slope area</p>  |
|                                      | <p><b>protection against hydrodynamic soil displacement due to drawdown/excessive pore water pressure</b><br/>not relevant as only applicable above mean water level / normal water level<br/>no application in permanently or temporarily submerged slope area</p>   |
|                                      | <p><b>general</b><br/>aerial plant parts can reduce impacts from waves and currents as well as enhance local sedimentation and aggradation at a sufficient growth height and shoot density</p>  |
| Tolerance to hydraulic loading       | <p><b>basis: present experiences gained at navigable waterways<sup>2) to 7)</sup> considering experiences gained at watercourses without navigation<sup>9)</sup></b></p> <ul style="list-style-type: none"> <li>- drawdown: no specification as not relevant<br/><i>(no application within the area on influence of ship-induced water level drawdown)</i></li> <li>- wave height: 0.2m<sup>*)</sup> <i>(derived from experiences gained at watercourses without navigation for waterbodies with navigation)<sup>9)</sup></i><br/><br/>0.2m <i>(measured load until present at relevant water level heights at the river Rhine test stretch at test section 7)<sup>4)</sup> comment: plant mats in this higher, rarely submerged slope area have proved to be stable<sup>4)</sup>, hence only applicable at waterways without or with minor water level fluctuation<sup>4)6)</sup></i></li> <li>- flow velocity close to the bank: 1.3m/s<sup>*)</sup> <i>(derived from experiences gained at watercourses without navigation for waterbodies with navigation)<sup>9)</sup></i><br/><br/>1.0m/s <i>(measured load until present at relevant water level heights at the river Rhine test stretch at test section 7)<sup>4)</sup> comment: plant mats in this higher, rarely submerged slope area have proved to be stable<sup>4)</sup>, hence only applicable at waterways without or minor low water level fluctuation<sup>4)6)</sup></i></li> </ul> <p><sup>*)</sup> values for the critical initial state</p> |
| Flooding tolerance                   | <p>diverging – depending on the installed plant species<br/>high flooding tolerance for <i>Carex</i>-species acute sedge (<i>Carex acuta</i>) and streambank sedge (<i>Carex riparia</i>), determined at the river Rhine test stretch</p>   |
| <b>4) Miscellaneous</b>              |   |
| Maintenance                          | <ul style="list-style-type: none"> <li>- as a matter of principle, reed and tall forb communities have to be excluded from maintenance (<i>maintenance mowing or shrub clearance for the purpose of promoting desired species if necessary; only sectional and manual mowing, e.g. with string trimmer</i>)</li> <li>- if necessary, irrigation during month of low rainfall (<i>in particular during the initial state</i>)</li> <li>- regular control of possible neophyte growth ; occurrences have to be removed immediately (<i>entirely with roots</i>)</li> <li>- control of mat fixations in the area of wave run-up during the initial phase of plant development</li> </ul>   |

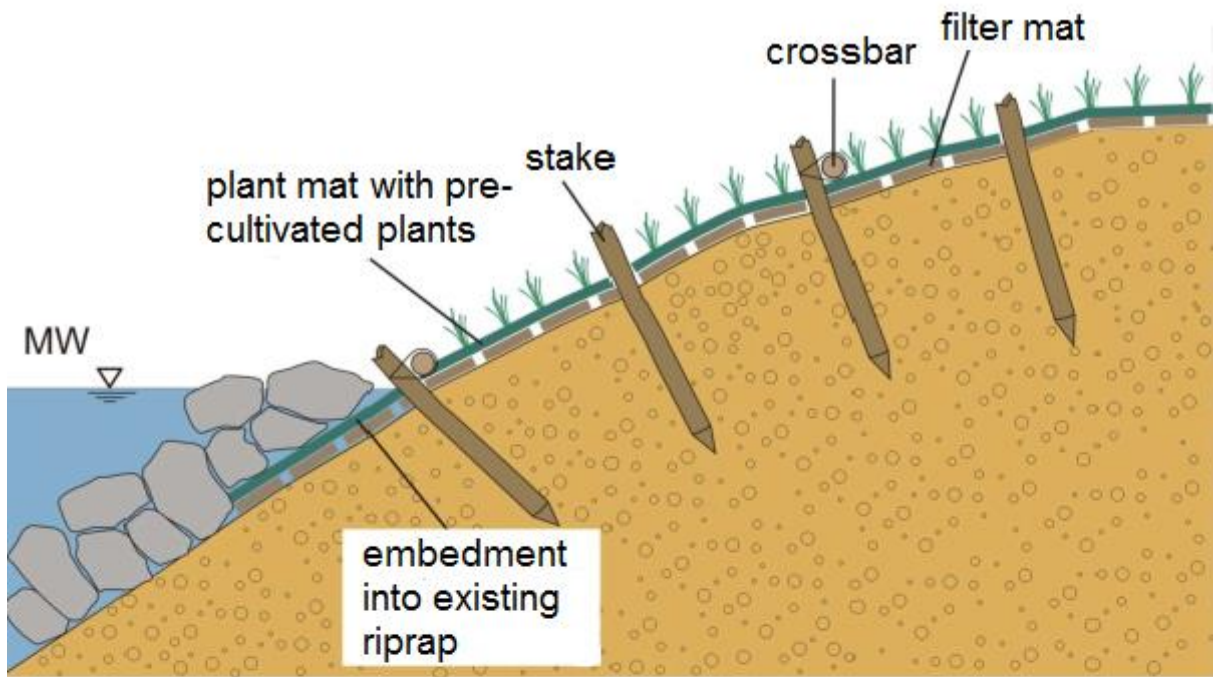
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| <p><b>Examples at German waterways</b></p> | <p>- test stretch at the river <b>Rhine</b> near Lampertheim, km 440.600 – 441.600, right bank, (test section 7), installation finished in 2011<sup>2) to 7)</sup><br/> <i>(positive experiences in higher, rarely submerged slope areas; in contrast to that, large loss of plants in frequently and longer submerged slope areas during the first three years: flooding, waves and currents lead to lifting and lowering of the mats between spotty and linear fixations, roots tear off repeatedly, no permanent and tight area-wide connection between soil and mats and thus no sufficient root penetration of the ground in the long term)</i></p>   |
| <p><b>Literature</b></p>                   | <p><sup>1)</sup> BAW (2011): Bundesanstalt für Wasserbau (Hrsg.), Grundlagen zur Bemessung von Böschungs- und Sohlensicherungen an Binnenwasserstraßen (GBB 2010), Eigenverlag, Karlsruhe 2011.<br/> <sup>2)</sup> 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 <a href="http://ufersicherung.baw.de/de/index.html">http://ufersicherung.baw.de/de/index.html</a><br/> <sup>3)</sup> 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 <a href="http://ufersicherung.baw.de/de/index.html">http://ufersicherung.baw.de/de/index.html</a><br/> <sup>4)</sup> 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 <a href="http://ufersicherung.baw.de/de/index.html">http://ufersicherung.baw.de/de/index.html</a><br/> <sup>5)</sup> 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 <a href="http://ufersicherung.baw.de/de/index.html">http://ufersicherung.baw.de/de/index.html</a><br/> <sup>6)</sup> 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 2015, 08/2016, abrufbar unter <a href="http://ufersicherung.baw.de/de/index.html">http://ufersicherung.baw.de/de/index.html</a><br/> <sup>7)</sup> BAW, BfG: Internetportal zur Thematik „Alternative technisch-biologische Ufersicherungen an Binnenwasserstraßen“, <a href="http://ufersicherung.baw.de/de/index.html">http://ufersicherung.baw.de/de/index.html</a><br/> <sup>8)</sup> Dunker, D., Herrmann, L., Seidel, V., Couret, S., Holland, D. (2015): Handbuch Naturnaher Wasserbau. Ökon Vegetationstechnik GmbH (Hrsg.)<br/> <sup>9)</sup> DWA (2016): Technisch-biologische Ufersicherungen an großen und schiffbaren Binnengewässern, Merkblatt DWA-M519, März 2016<br/> <sup>10)</sup> MAG (1993): Merkblatt Anwendung von geotextilen Filtern an Wasserstraßen (Ausgabe 1993)</p> |

| 5) Institutions / link               |  |
|--------------------------------------|--|
| <b>Addresses, persons of contact</b> | <p><b>Federal Waterways Engineering and Research Institute</b><br/>           Earthworks and Bank Protection Section (G4)<br/>           Petra Fleischer (direction): +49 (0)721 9726-3570<br/>           @: <a href="mailto:petra.fleischer@baw.de">petra.fleischer@baw.de</a></p> <p><b>Federal Institute of Hydrology</b><br/>           Vegetation Studies and Landscape Management Section (U3)<br/>           Dr. Andreas Sundermeier: +49 (0)261 1306-5151<br/>           @: <a href="mailto:ag-ufersicherung@bafg.de">ag-ufersicherung@bafg.de</a></p> |
| <b>Link</b>                          | <p>For further information, please see:<br/> <a href="http://ufersicherung.baw.de/de">http://ufersicherung.baw.de/de</a></p>   |

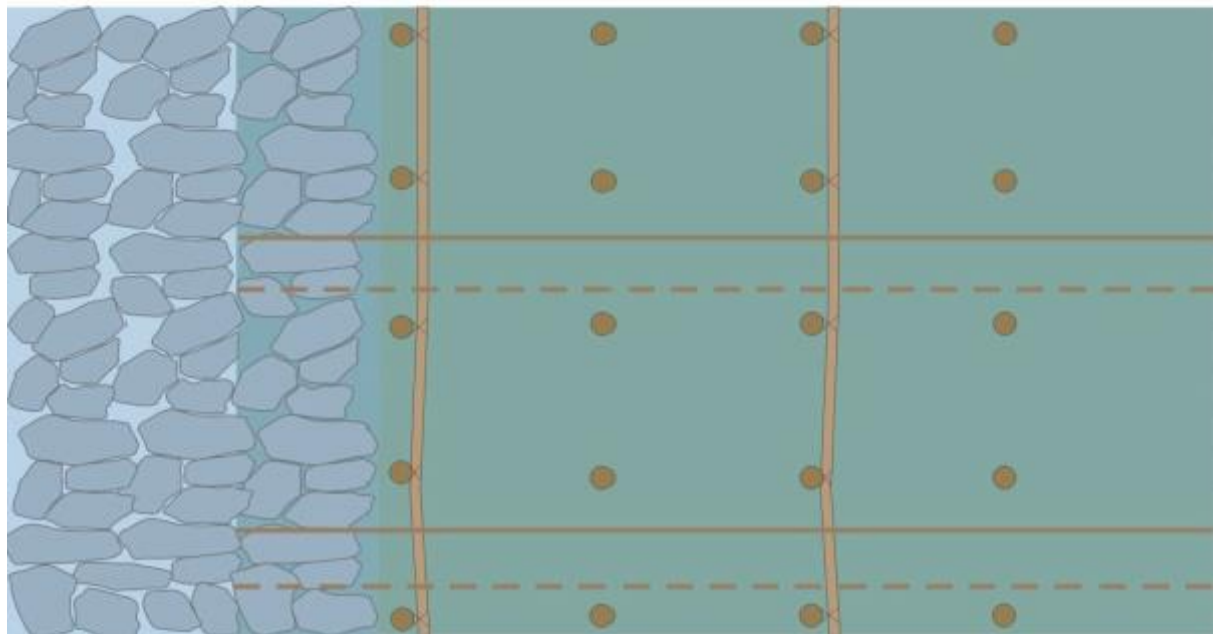


Appendix 1

Schematic Figure



installation scheme (plan view)



| Appendix 2  | Sample Photos  |
|---|--|
| Source: Test stretch Lampertheim/Rhine <sup>2) to 7)</sup>  | photos: BAW/BfG  |
|  <p>(1) Pre-cultivation of plant mats; 2010/11</p>                                 |  <p>(2) Plant mats after delivery; 2011</p>  |
|  <p>(3) Plant mats on filter mats and fixation during installation; Nov. 2011</p> |  <p>(4) State of construction after end of work; end of 2011</p>  |
|  <p>(5) Developmental stage six months after installation; May 2012</p>          |  <p>(6) Mowing operations in the fifth year after installation (June 2015) in the upper slope area</p> |