Additional short text supporting the training presentation on

soil bio-engineering

for the expert target group:

‘2Urbem-Techniques_IWHW-BOKU_Soil-Bioengineering_Target_Experts.ppt ‘

Links to the relevant slides are marked with the slide No, e.g.
No 23

For more details, please refer to the paper
‘New Materials and Techniques IWHW-BOKU 05_2005.doc’.

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No 2

Introduction

Implementing living plants in urban river rehabilitation can serve different purposes, e.g. decoration, shadowing or as parts of technical structures. The latter function is the subject of soil–bioengineering.

Methods of soil-bioengineering play a central role in nature like slope stabilisation and in river rehabilitation and revitalisation. Soil bioengineering structures base on synergies of living plants and dead materials as stones, timber or geotextiles and auxiliary objects. These structures aim on creating stable native riparian vegetation, which sufficiently protects riverbanks and improves the landscape’s aesthetics and ecology.

Working with living native plants in river regulation schemes has a long tradition. The utilisation of tree spurs was documented in the Roman Empire. Although none of today’s technical machinery and constructions existed the middle ages, durable protection of waterways was achieved with natural and living materials.

When there is enough space for urban river rehabilitation, soil-bioengineering methods, developed for rural watercourses may be implemented: But facing spatial and other typical urban constraints, new innovative solutions are required.

Soil-bioengineering methods are often combined and complemented with materials of hard regulation, especially under the conditions of high physical loads, pollution, uplifting forces due to groundwater flux or limited space. Dead materials also play an important stabilizing role in the initial phase of a structure. We have to keep in mind that soil-bioengineering can not completely replace technical measures.

As river regulations in mid Europe mainly focus on flood protection, the performance of soil-bioengineering methods during floods is of particular high interest.

No 4

Vegetation Zones

Plants an rivers may be classified according to the vegetations zones, as this is relevant to soil-bioengineering methods.

- Flood-zone of regularly to scarcely inundated areas.
- Transitional zone below high water level. Governing for this zone's upper parts are erosion processes, waves or ice forces. Therefore robust materials as grass-sods and elastic willows are preferred.
- Cane brake zone below mean water level. For species selection, their tolerance of varying water levels during the vegetation period is of great importance. Considerations shall also cover potential sedimentation and sufficient sunlight.
- Floating leaf zone below low water level. Due to the sensitivity of typical species, difficulties arise in organisation, transport and implementation.

No 6

Selection of species

A number of reflections shall govern the selection of appropriate species. Lists of adequate species for Mid-Europe and their characteristic properties are described e.g. in Schiechtl & Stern (2001) or in Pratt, Jürging & Kraus (2004). Here, basic considerations for species selection are listed:

- Aim of the scheme and framing conditions
- Ecological considerations: Interaction of the scheme with the environment, tolerance of species against varying conditions (ecological amplitude), size and growing form, pioneer species, symbiosis, soil enhancement, self purification…
- Technical considerations as mechanical resistance, bearing of flooding and sedimentation, vegetative reproduction, regeneration after damage or cutting, ability to establishing roots from sprouts or floating roots, soil stabilizing root systems, resistance against salt or pollution…
- Native provenience of species in terms of region and altitude

No 8

Hydraulic impacts

Whenever a hard-regulated urban river is rehabilitated, the engineer has to demonstrate, that the project improves the current situation. This requires an estimation of the hydraulic behaviour of the rehabilitated river and the soil-bioengineering methods during different flow conditions. In hydraulic engineering, the most common hydraulic effects are characterised in terms of flow velocities and shear stresses. Several numerical and empirical studies have investigated flow properties of planted channel profiles. Although research is still going on in this field, currently a number of calculation methods are available.

The hydraulic behaviour of vegetated channels banks is of major interest. As the vegetation cannot be practically modelled in detail, a simplified conservative assumption is to regard all plants as rigid flow obstructions. On the other hand, juvenile plants are flexible and cause no major flow barriers. A rough classification of vegetation can be made according to the hydraulic flow resistance as issued by Gerstgraser (1998b).

- Flexible brush willow fringe (requiring continuous maintenance)
- Rigid brushes and trees with branches below flood water surface (particular care has to be taken for the growth-period)
- Rigid brushes and trees without branches below flood water surface
- Herbal vegetation

The density of brush vegetation plays a mayor role for morphological development: Sedimentation is observed in strips of dense willow-brushes, whereas erosion is induced by solitaire tress without inundated branches. For the practical application, design concepts and guiding values of material resistances are available but moreover, understanding the local processes is indispensable.

No 11

Techniques

River rehabilitation employs a large number of soil-bioengineering methods and techniques. The selection of the most suitable types encompasses several considerations:

- Aim of the construction
- Technical feasibility including financial and maintenance efforts
- Availability of plants
- Season, vegetation period

Soil-bioengineering methods are punctual, linear or areal structures. Punctual measures may serve as initial plantings or in compound with other materials. Linear measures have influence on strips of various widths. Under heavy load situations, areal measures perform most protectively.

Soil-bioengineering measures may be classified according to their main function (Schiechtl & Stern, 2001). In practice, schemes combine several elements and functions.

- Covering structures are used on surface areas to stabilize, protect and enhance soil. Usually, large numbers of plants are employed. Shallow surface-measures do not primarily transfer loads in deeper soil layers.
- Stabilizing structures transfer forces by point- or linear elements into deeper soil layers. Combinations with covering areal measures or parallel applications of numerous linear units are possible.
- Composite measures combine living and dead materials for gained performance and life time
- Auxiliary and complementary measures support initial state and succession.

Soil-bioengineering cannot fulfil all tasks in a rehabilitation scheme. In order to obtain a satisfying result, the designer must be aware of restrictions:

- Biological limits due to pollution, climate and site conditions
- Technical limits due to flow velocity, shear force, stream forces, turbulences or bank slopes etc.
- Timing limitations due to vegetation season. Preferred period for measures utilizing reproducible woods in Mid-Europe is October / November to March / April if woods are not extracted and implemented quickly.

No 12

Willow-brush mattress

Construction

Bank slopes up to 2:3 are covered with an dense layer of long willow branches transversely to the flow direction, fastened to the ground with wooden poles and wire or coco-ropes and embedded into the subsoil. When high hydraulic loads are expected, the distance between the poles shall be no more than 1 – 1.2 meters. Coco-ropes can be used for fixation, but they expand from moisture and can be damaged from bed load transport. The soil layer upon the willow brushes shall not extend 3 - 4 cm in order to enable the plants to also sprout vitally.
For water supply and stabilisation, the foot-ends of the branches are fixed under the low water level and protected with riprap, fascines, a live-crib structure (Krainer-wall) or a tree-spur. Higher species diversity is achieved by utilising different kinds of willows and to implement some vegetative reproducible poles of other leafed species.

Conclusions

Brush mattresses are characterised by intensive vegetative growth and a rapid protective functionality. Increasing diameters and lengths during the first five years are documented. This intensive growth induces on one hand a concurrency situation, which reduces the individual plants per unit area and on the other hand an increasing flow resistance due to higher plants of lower flexibility, resulting in a increase of water levels.

The experience from the test flume on the Wien River in Vienna revealed, that the density and flexibility of three months old sprouts could highly protect the sandy gravel from flow erosion, although lots of leaves were ripped off. (Gerstgraser, 1998b)

No 13

Fascines

Fascines are long bundles of branches, completely made of living brush as ‘live fascines’ or filled with rocks as ‘sink fascines’. These rolls are tied together with wire or other cables in a spacing of approximately one meter. Fascines are used in many different ways in soil-bioengineering.

Live fascines

Construction
Living fascines of 20 to 40 cm diameter and some meter length are implemented in the bank foot at the summer mean water level and fixed with wooden poles. Within some moth, flexible willow brush will develop from the live branches.

Fascine walls

Construction
Fascine walls are vertical structures implemented parallel to the flow direction, protecting rather a very narrow strip of the riverbank. In the Wien River test flume, vertical structures of 5 to 6 willow fascines were fastened with wire behind poles. The lowest sink-fascine is made of rock and brush. The wall is refilled with sandy gravel and the inclining bank protected with a Geotextile, which is fastened with iron hooks.

Conclusions
In this construction, sprouts grow mainly in the upper quarter. Due to sufficient water supply and sunlight, the structure’s upper edge develops vigorously, but it shadows the lower fascines, which may die off, decay and cause side erosion.
The stability of the bank bases on two elements: First, the fascine wall itself, which is mainly governed by the performance of the wooden poles and second, the stability of the backfilled bank, which is not directly protected by the vertical wall. In the Wien River test flume, the wall structure itself resisted the artificial and the natural floods, but the upper bank, protected by a Geotextile was completely eroded.
In practical application, this structure shall be used only when vertical walls are imperative and when a temporarily limited lifetime can be accepted, as the poles are not durable. Particular attention shall be paid for sufficient exposure to sunlight. Therefore the heights over one meter and a north-side exposition shall be avoided. Further, possible upper bank erosion must be considered which may be intensified by changes in bed roughness due the fascine wall’s willows (Gerstgraser, 1998b).

No 14

Fascines with brush layer

<u>Construction</u>
Sink-fascines and live-fascines are placed behind vertical poles, fixed with wire and backfilled. Upon the fascines, a layer of 1 – 1.5-meter branches is laid, transversely to the flow direction in a moderate inclination of 10 – 20 %. The brush layers are covered with 10 cm of soil and a row of fascines fixed with wooden poles. This sequence of brush layers and fascines forms a step of 15 – 60 cm widths. Within several levels, 4 – 5 brush layers and 6 – 7 fascine rows were constructed. The uppermost bank was covered with a geotextile.

<u>Conclusions</u>
After 15 months, the brush layers have developed much better than the fascines due to their deeper soil contact. As the fascines are completely shadowed by the brushes and may die off in the long time run, the structure provides barely linear protection.
The 10 cm spacing between the branches could not prevent erosion of subsoil compartments, which exposed the fascines to further erosion and drought. This process increases the risk of structural failure, which was observed during the natural flood in the test flume.
This work-intensive structure has not performed satisfactorily for the slope 2:3, so generally, it cannot be recommended. When a fascine is placed upon a brush layer, it must be reassured, that no subsoil-erosion occurs and sufficient moisture is available. (Gerstgraser, 1998b)

No 15

Live stakes

Cuttings from living branches of some 2 - 5 cm diameter minimum are inserted into the ground, so that only a few centimetres protrude in the air. Sufficient sunlight and water supply cause vital rooting and sprouting within some months.

Live stakes are an alternative to planting rooted stock. These cuttings may be combined with various living or dead materials as e.g. an existing rip-rap bank protection.

No 16

Geotextile and live stakes

Soil-bioengineering and geo-technique cover numerous applications of degradable and durable geotextiles. On the Wien River test flume, 700 g/m^2 coco-fibre mats and an effective mesh-widths of 0.5 – 1 cm were used in different ways. For other applications, 300 g/m^2-mats were employed.

Construction
The inclining bank was covered with the geotextile. At its edge, a certain length of the Geotextile is upending into the soil for the transfer of tensional forces.
Live stakes are living, unbranched, vegetative reproducible parts of 3 – 8 cm diameter branches with a minimum length of 60 cm. Some authors name smaller figures. They are driven or inserted with the thick end into the ground vertically or inclined. Growing roots and sprouts provide erosion protection.

Conclusions
Below the geotextile mats, selective erosion of fine material and motion of coarser material may take place during floods and bed load transport can damage the fibres. Under smaller loads, point stabilisation with live stakes or other dead auxiliary materials can reduce these negative effects. Due to willow contraction, an effective areal surface erosion protection cannot be provided. During the natural and artificial floods in the test flume, this construction was completely destroyed in the Wien River Test flume (Gerstgraser, 1998b).

Geotextiles can therefore be used for mild bank slopes which are not exposed to higher hydraulic forces or bed load transport. High rates of coarse material reduce erosion risk. In general, degradable fibres shall not be exposed to frequent moisture. Measures to stabilize points (e.g. with live-cuttings) or line-reinforcements (e.g. with brush-lines) should be used in combination with auxiliary materials if high stresses are expected. Geotextiles on steep banks should be combined with sufficiently dense brushes or cuttings (Gerstgraser, 1998a).
The ends of the live stakes shall not protrude more than 3 – 8 cm in the air to prevent solar radiation damage, which may cause desiccation and inhibit sprouting.

No 17

Geotextile on brush layer

Construction

Behind a row of vertical poles, sink fascines and live fascines are placed, fixed with wire and backfilled with soil. Upon the fascines, a layer of 1 to 1.5-meter long branches of 3 to 8 cm diameter are laid transversely to the flow direction in a moderate inclination of 10 – 20 %. The brush layers are covered with 10 cm of soil on which a geotextile was placed, reaching 1.6 m into the ground. The geotextile is used to envelope a 50 to 65 cm high sandy gravel body and fixed backwards with wooden poles. Again, a 5 to 10 cm soil layer with brushes inside covers the geotextile elements. The 20 – 30 cm of branches protruding from the geotextile are covered with some centimetres of soil for sun-protection, but no material should be placed directly below, as it is exposed to erosion.
For that construction, non-cohesive material is preferred, and the bank slope should not exceed the material’s natural slope angle. At the Wien River test site, this alternating construction comprises three rows of brushes and three geotextile elements.

Conclusions

The protective effects of willows act only on relative small strips and large compartments are exposed to selective erosion since the geotextile is porous. Further, bed load transport or the edges of the branches may damage the geotextile, which decays over time.
The structure may be used on mild bank slopes of 1:3 up to the natural bank inclination when larger hydraulic forces are not expected. In general, geotextiles of natural fibres shall not be exposed to long-lasting moisture as it looses strength.
On the Wien River Test flume, the entire structure was eroded during the natural flood (Gerstgraser, 1998b).

No 18

Wattle fence

<u>Construction</u>
Long, flexible branches of at least 3 cm diameter are alternating braided around wooden poles of 1 to 1.2 m spacing. The construction is backfilled and covered. For higher resistances, branches of 3 to 8 cm diameter are recommended. Crack Willows *(salix fragilis)* should not be used, as they may easily break. For water supply, branches should not be implemented in parallel to the river but with a slight inclination, thick stem-ends placed on the lower bank side.

<u>Conclusions</u>
Vegetation develops similar to the fascine wall: The uppermost parts grow fast due to good light and moisture-conditions and shadow the lower elements, which may cease, so the height of this construction should not exceed 0.6 m. As long as leaves have not developed, branches on south-exposed sites may suffer sunburn, so they may die of and the bank may fail.
During the tests and the natural flood in the Wien River, this construction resisted. The wattle fence may be used on smaller brooks, where a linear measure is sufficient. When the bank receives additional protection, it may also be used, when higher floods and forces are expected. (Gerstgraser, 1998b)

No 19

Fascine layer

Construction
On a foundation structure of fascines fixed behind vertical poles, rows of fascines are placed on the inclining embankment. At the Wien River Test flume, 6 rows of fascines were laid tight on the subsoil, each stabilised with poles of 1 to 1.2 m spacing and covered with 5 to 10 cm of sandy gravel. Fascines of 30 to 40 cm diameter are constructed using willow branches, which were tied up with a wire cable each meter. The fascines are implemented, with the branches' thin ends in flow direction, embedded in the subsoil for water supply and covered with few centimetres of sandy gravel in order to prevent desiccation.

Conclusions
As Fascines were closely fitting and had a sufficient moisture supply, vegetation developed densely on the entire covered area. This causes a reduction of flow velocities and the accumulation of sediments.
Water supply is the crucial point in planning fascine layers. Therefore slopes shall not be steeper than 1:3 and not too high.
Generally, the structure resisted the artificial and natural floods and the technique can be recommended for mild bank slopes and high hydraulic loads. In comparison to other structures, this technique provides immediate protection from completion on. Among a number of tested techniques, fascines perform very good on smooth banks due to the more stable soil coverage and better conditions for developing roots (Gerstgraser, 1998a & b).

No 20

Row of tree stumps

Construction

Behind a 30 to 40 cm fascine, fixed to vertical poles of 1.1 to 1.4 m spacing, tree stumps are implemented into the smoothly inclining bank. They mainly comprise of willows, poplars, few ash trees and ash-leaved maple *(Acer Negundo)*. The stumps next to the water are fastened to the poles with steel cables, whereas the other stumps were built in between larger rocks. Then the bank is covered with sandy gravel, so the stumps protruded less than 20 to 50 cm from the ground.

Conclusions

Many sprouts develop in the height of 20 to 30 cm above ground, which is relative high over the surface so the protective effects concentrated to some spots. Although a greater number of sprouts developed, they grow rather point-wise and do not provide an areal cover.

These highly structured features cause flow deviations and point-wise scours during flood conditions, which was observed during the artificial and natural events.

Tree stumps have to be living, vegetative reproducible woods. Branches have to be cut off, as they would dry out otherwise. For stability purposes, stumps should not be higher than 20 cm, the subsoil should include large rocks and stumps close to the river should be cabled to anchor structures.

This construction can be used on banks with minor inclination, where lower loads are expected or small damages are accepted. (Gerstgraser, 1998b)

No 21

General Desin Recommendations

From the scale tests and the observed flood damages on different soil-bioengineering constructions during the 1997 events in Vienna, several lessons become evident (compare Gerstgraser, 1998b).

- During extreme conditions, the reliability of the riverbank depends to a large extent on an intact bed.
- Three month after completion, the root systems were partly not able to sufficiently strengthen the soil. Sufficient time and space are required for obtaining a strong root system.
- If the riverbed and the roots resist, the density and flexibility of vegetation-mats are governing for bank protection. Worthwhile mentioning is the strong reduction of flexibility of willow branches of more than 40 mm diameter.
- Vertical bank structures in outer bends tend to face intensified bed erosion and bank foot scouring, so an adequate bank foundation is required. Soil-bioengineering measures with inclined banks, sufficient deep foundations and a larger channel width may also withstand this load situation.
- Turbulences and higher stresses develop at the intersection of river-bed and bank, where the channel geometry or the roughness changes due to varying slopes, edges or materials.
- Governing for plant growth and durable strength are sufficient water supply and sunlight. Solitude, juvenile plants in particular may also suffer damage from sunlight.
- In the initial phase, auxiliary materials are useful for stabilizing banks.
- Bed, banks and river morphology have to be considered as an entity. The protection design shall cover the entire wetted perimeter probably affected by an extreme flood

No 21

Stability considerations

Hydraulic issues are closely related to safety and risk of failure during high flow conditions. Conventional hard regulations structures provide a high level of reliability from completion on, which is slowly decreasing within the construction's lifetime. Soil-bioengineering methods may also reach a high level of safety after some time of intensive maintenance (Stern, 1993).

According to safety considerations, four states of plant development in soil-bioengineering measures can be distinguished (Gerstgraser,1998b).

1. Initial Vegetation period. During the first months, sprouts have not developed sufficiently and auxiliary materials are required for preventing erosion.
2. Development from second to fifth year. This phase is characterised by high plant density and a not fully developed root system. Auxiliary materials are still required although flexible branches provide good surface protection.
3. Transitional phase to tree-wood. Flexibility and the number of boles decrease, so that plants do not bend during floods and rather act as flow obstructions. Auxiliary materials may have been decomposed and roots care for erosion protection.
4. Matured timber. Trees decay and loose stability causing risk if appropriate maintenance activities are not conducted. Adequate means instead help keeping a high level of safety over a long period.

Technically speaking, the stability of soil-bioengineering constructions relies on the interaction of water, plants and soil. In particular, the resistance depends on:

- Construction type
- Plant age and density
- Habitat properties, vitality, damages
- Soil material
- Maintenance
- Time
- …

Stress depends on:

- Discharge
- High flow duration
- Bank inclination, unsteady shapes
- Roughness differences
- Fluid density, bed load transport
- Bed material
- Channel geometry in plain view and cross section
- …

No 22

Critical design values

Technical standards for soil-bioengineering have to cover numerous different construction types and load and resistance situations throughout their lifetime. It takes no wonder that published numbers of critical limit states vary in wide ranges, depending on many specific parameters. In a contemporary survey and comparison, deviations up to 200 % were found in various sources. Only a small number of researchers base their published figures on their own scale tests or re-calculations. Due to the complexity of the problem and the dynamically changing character of numerous parameters, there are no generally valid calculation methods for determining actual forces. Owing to many unknown parameters, it is recommended to consider ranges of τ and *v* as governing parameters, as well as the angel between main flow and bank Gerstgraser (1998b).

A collection of published values of resistance limits of various soil-bioengineering methods is exhibited in the table. These figures either stem from investigations with an underlying hydraulic calculation or from primal publications of experiences and may therefore be assessed as representative, as it is suspected that other authors have taken and copied these figures or do not refer to an ultimate limit state (Gerstgraser, 1998b). The investigations of LfU (1996) base on one and two-dimensional recalculations of a flood event, two years after construction.

No 23

Maintenance

Within soil-bioengineering methods, the intended positive effects require some time for vegetative development and an amount of regulating interventions, particular in urban areas. Maintenance activities therefore cover a number of operative measures during the structure's lifetime. In general, plants can only protect a riverbank when they provide a dense and flexible layer and where there is enough space to create a strong root mat (Gerstgraser, 1998a). Solitaire, rigid plants instead may intensify erosion by inducing turbulences similar to bridge piers. In small rivers of limited space, the design flow capacity has to be maintained by keeping vegetation flexible. This can be achieved by cutting larger branch diameters. Some interference with natural succession has to be accepted in urban areas. Tight spatial constraints require higher maintenance efforts and to some extend the utilisation of auxiliary technical materials. For protecting young riparian vegetation, wood and geotextiles from natural fibres are often assessed as adequate materials as they immediately provide stability and decay, when the plant system has enough strength.

Accurate planning intends on minimizing the maintenance effort in the course of the scheme's lifetime and to increase the intervals between maintenance activities. Therefore, the interdependency of the river morphology and the plant development has to be accounted for. Two mayor conditions frame the mid to long term development goals:

- The accepted plant development from the flood protection's viewpoint. This concerns the maximal tolerated vegetation.
- The minimum vegetation is demanded from the ecological and aesthetical viewpoint.

At the beginning of maintenance efforts, one should ask three questions:

- Can we achieve the goals also without maintenance efforts? In some cases, no maintenance activity is the best maintenance (Geitz, 2004)
- Why are maintenance efforts necessary, what are the causes?
- How to minimize the efforts in the future?

Once the framing conditions are set and considerations on the aim of the maintenance efforts are made, a number of individual measures may be utilized throughout the structure's lifetime.

No 25

Maintenance master plan

A maintenance master plan shall serve the efficiency of maintenance efforts. The maintenance plan shall give guidance on the required works focussing on the development goals and communicate information in a appealing way. It shall inform about the flood protection’s requirements on the maximum tolerated vegetation and on the landscape-ecological goals. These two conditions exhibit the range of intended development. Experiences with these management plans have shown, that their implementation often lacks practical applicability and insufficient time of the maintenance workers (Geitz, 2000). So particular attention has to be given for the practical applicability for the working staff on site. As the maintenance works are mainly undertaken during the cold season, a minimum botanical knowledge of workers is required for identifying local species as various willows in the leafless state.

No 28

References – complete list

Felkel, K (1960): Gemessene Abflüsse in Gerinnen mit Weidenbewuchs. *Mitteilungsblatt der Bundesanstalt für Wasserbau*, Nr. 15, Karlsruhe

Florineth, F. (1982): Erfahrungen mit ingenieurbiologischen Maßnahmen bei Fließgewässern im Gebirge. *Landschaftswasserbau,* Bd.3 Hrsg. Institut für Wassergüte und Landschaftswasserbau, TU-Wien, pp.143-260

Florineth, F. (1995): Weidenspreitlage als Weg zur schnellen Uferbepflanzung und –sicherung. *Mitteilungen* 4, Hrsg: Gesellschaft für Ingenieurbiologie e.V., Aachen

Geitz, P., Kappich, H., Buettler, A. (2000): Musterunterhaltungsblatt Enz für den Streckenabschnitt der naturnah ausgebauten Pilotstrecken in Pforzheim. Erläuterungsbericht, Landesanstalt für Umweltschutz in Baden-Württemberg

Geitz, P. (2004): Entwicklung und Pflege der Ufervegetation – Beispielprojekte aus Baden Württemberg. *Ingenieurbiologie* 2/2004 pp.19-24

Gerstgraser, C. (1998a): Soil Bioengineering Methods for Bank Protection. Proceedings of the Fourth International Conference on Headwater Control, Merano, Italy. Oxford & IBH Publishing Co. Pvt. Ltd, New Delhi

Gerstgraser, C. (1998b): Ingenieurbiologische Bauweisen an Fliessgewässern. Grundlagen zu Bau, Belastbarkeiten und Wirkungsweisen. Dissertationen der Universität für Bodenkultur, Wien, Band 52. Österreichischer Kunst- und Kulturverlag. Wien 2000

Gerstgraser, C. (1998c): Uferstabilisierung mit Pflanzen – was halten sie aus? *Österreichische Wasser- und Abfallwirtschaft*, Jg. 50 Heft 7/8 pp.180-187

Gerstgraser, C. (2000): Uferstabilisierung mit Lebendverbau. *Wasser & Boden* 52/5 pp.50-55. Blackwell Wissenschafts-Verlag, Berlin

Hohmann, J. Konold, W (1995): Renaturierung von Fliessgewässern. Untersuchungen zur Vegetationsentwicklung an der Enz in Pforzheim. Ecomed Verlagsgesellschaft, Landsberg.

Kari, F.G. (2004): Ausdohlung von Stadtbächen in Zürich. *Ingenieurbiologie* 2/2004 pp.47-52

LfU – Landesanstalt für Umweltschutz (1996): Naturnahe Bauweisen im Wasserbau. Hrsg. Landesanstalt für Umweltschutz Baden-Württemberg, Karlsruhe

MA 45, Vienna Municipal Hydraulic Engineering Department (2004): Liesingbach Life – Umwelt, http://www.life-liesingbach.at/

Oplatka, M. et. al (1996): Dictionary of soil bioengineering: English - Deutsch - Français – Italiano. Verein für Ingenieurbiologie (Ed.) Zurich, vdf

Oplatka, M. (1998): Stabilität von Weidenverbauungen an Flussufern. Dissertation, ETH-Zürich

Pratt, H., Jürging, P., Kraus, W. (2004): Naturnaher Wasserbau. Entwicklung und Gestaltung von Fließgewässern. Springer-Verlag Berlin, Heidelberg, 2. Auflage

Salzburger Landesregierung, Fachabteilung 6/6, Wasserwirtschaft (2002): Lebensraum Stadtbach. Alterbach, Söllheimer Bach

Schanze, J. et al. (2004) : Existing Urban River Rehabilitation Schemes. URBEM Work package 2, Final Report

Schiechtl, H.M., Stern, R (2002): Naturnaher Wasserbau. Anleitung für ingenieurbiologische Bauweisen. Ernst & Sohn, Berlin

Shields, A. (1936): Anwendung der Ähnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung. Mitt. d. Preußischen Versuchsanstalt für Wasserbau u. Schiffsbau, H.26, Berlin

Steiger v.A. (1918): Haltbarkeit der Uferbauten in Bezug auf die Schleppkräfte des fliessenden Wassers. *Schweiz. Bauzeitung*, Bd. LXXII, Nr.4, pp.32-35

Stern, R. (1993): Kritische Anmerkungen zur Ingenieurbiologie. TU Graz, *Schriftenreihe zur Wasserwirtschaft*, Band 11 pp.101–111

Vollsinger, S. (2000): Biegsamkeit von Ufergehölzen als Grundlage für Pflegemassnahmen. *Ingenieurbiologie* 2/2000 pp.19-21

Vollsinger, S., Meixner, H., Rauch, H.P. (2002): The soil bioengineering test flume in Vienna. Methods and Results. INTERPRAEVENT 2002 in the Pacific Rim – Matsumoto, Japan. Congress publications, Volume 2, pp.849-858

Weitzer, C., Doppler, F., Florineth, F. (1999): Untersuchungen über die Wirksamkeit von Pflanzen im Einzugsbereich des Forsttechnischen Dienstes der Wildbach- und Lawinenverbauung. 2. Auflage, Arbeitsbereich Ingenieurbiologie und Landschaftsbau. BOKU Wien, Ed: BMLF, Gruppe V/C, Wien

Witzig, A. (1970): Die Bepflanzung der Ufer längs fliessender Gewässer. Entwurf und ergänzende Unterlagen. Unpublished, Bern