Rivers without Obstacles for Fish Migration – Demands on River Stabilisation Methods

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Abstract: The main purpose of this contribution is to stimulate the hydraulic research to develop bed stabilisation measures for practice, to reduce the environmental influence of human activities on our rivers. Therefore, this issue is generally addressed in order to present some basic ideas for future research. Due to bed degradation many rivers in the alpine region are stabilised with help of different kinds of sills. Usually the fish migration in upstream direction is interrupted at these sills. In many rivers, bed degradation constantly continues and must be stopped and/or transferred into a controlled aggradation process to prevent further damage. Currently different bed stabilisation methods exist for practical use. But many of these methods are not sufficiently examined from all points of view such as bed stabilisation, morphology, fish migration, land use, costs or leisure activities. Each method has its own advantages and disadvantages, e.g. many bed stabilisation measures are passable only for certain fish species. Nevertheless, each adult fish specie, which is typical for a bio region, should be able to ascend towards its spawning-ground without running into an obstacle. For biological, morphological and financial reasons, each type of watercourse needs its own bed stabilisation method. Some examples are rough ramps, which are used mainly in the salmon region, fixations in sections of the river bed keeping the original bed slope or being slightly steeper in potamal river regions and river widening. Naturally, these measures are to be in equilibrium with the bed load regime of the concerned river reach.

Keywords: river stabilisation, morphology, fish migration, sustainable solutions
1. Why river stabilisation and what are the problems?

1.1 Morphological basics

![Diagram of river degradation](image)

Each river with a current mean slope higher than the balance slope shows a state of degradation (see fig. 1). The difference in elevation $\Delta H$ which results from this slope difference mainly depends on the river hydrology, bed load (amount and grain size) and the cross sectional geometry and causes a surplus kinetic energy. To stabilise a degrading river bed either means increasing the balance slope by, e.g. increasing the bed load transport rates, widening the river bed, lengthen the river reach, or dissipating the surplus kinetic energy at one special, manageable location such as sills, weirs, ramps or hydroelectric power plants. The latter was the main used solution in the past with energy dissipation by means of a hydraulic jump (sills, weirs, hydroelectric power plants) and the roughness of the ramp surface (ramps), respectively.

The current discrepancy between the mean river slope and the balance slope of many European rivers such as Salzach, Isar, Inn, Danube or Drau has evolved from various human activities in the past. Rivers which originally took up the whole valley bottom were significantly straightened and constricted in order to gain new agricultural areas and to reduce annual floods. These measures, causing an increased bed load transport capacity, deliberately initiated an erosion process. In addition, the river was forced into a fixed bed. Bed load is often entrapped in the higher regions of the catchment (e.g. sediment-control dams to prevent settlements from debris flows) or upstream of hydroelectric power stations with too little bed load transport capacity. And finally, gravel was dredged from the river bed for various purposes. Thus, as a typical consequence the river system adjusts in a long-term geomorphological manner to these human influences.

1.2 Ecological problems

Sills and ramps used to be built mainly to stabilise the river bed without considering fish migration, because questions addressing the river ecosystem were less important than river
stabilisation and directives to account for, e.g., fish habitats were missing. Consequently, sills and ramps often act as migration barriers.

![Figure 2](image-url)  
**Figure 2** Example of a fish migration barrier due to bed erosion downstream of a ramp

In case of a balance slope lower than the current slope of the river and, thus, ongoing erosion, the bed stabilisation structure can interrupt fish migration also if the structure itself is suitable for fish migration (see fig. 2). At the same time, this might endanger leisure activities such as rafting and canoeing. In case of subsidence of the foundation due to a wrong ramp construction, formerly ecologically favourable ramps can also develop to ecological barriers (see fig. 3).

The present situation in Austria shows that only 60% of all river reaches with catchment areas larger than 100 km² are expected to meet the demands of the Water Framework Directive. The reasons are mainly barriers for fish migration due to measures to stabilise the river bed such as sills, ramps, hydroelectric power plants.

### 1.3 Why is river stabilisation still needed?
Many rivers are still in a state of degradation. Since no changes of bed load budget are to be expected, existing obstacles such as sills must not be removed without offering appropriate alternatives.
Sometimes, bed erosion can progress to such an extent that bridge piers as well as bank structures and, consequently, buildings and infrastructure near the banks become endangered. The groundwater table decreases remarkably. The river wetlands are cut off from the river itself, which is closely connected to a loss of habitats and of population diversity in the wetland ecosystems.

Additional to degradation processes, river aggradation might also cause problems. Wrongly estimated morphological changes following river restoration measures, which for example initiate an aggradation process, can lead to flood protection problems. In this case, sustainable bed stabilisation measures (river adjustments) are also needed.

2. **What are the demands?**

The European Water Framework Directive and national water laws prescribe rivers without barriers for fish migration in accordance with the concerned bio region. Additional demands, which must be considered too, are the stability of the construction in case of floods, assured flood protection, consideration of possible changes of the ground water level and the ecological and morphological sustainability, i.e. the long-term stability of the construction as well as the adjacent river reaches upstream and downstream of the structure.
The necessity to achieve a state of sustainable dynamic equilibrium does not entail armouring the river bed, i.e. fixing the bed at one specific level. Rather, it means that the river bed varies within acceptable limits according to time dependent sediment transport and discharge, respectively. In this manner, the river bed can adapt to both time-dependent and morphological boundary conditions. Nevertheless, the range of bed level changes should not conflict with other demands, such as recreational activities (rafting, canoeing) or costs and maintenance of the measures. Finally, the design of the measures should also settle esthetical claims, since controversial discussions sometimes occur in the field of architecture as experience shows.

3. On-hand solutions and what is unsatisfying?

According to the state of the art, there are different possibilities to stabilise a degrading or aggrading river bed and, thus, to reach the balance slope. The measures can either influence the mean or the balance slope to reduce the discrepancy between mean and balance slope. One is to vary the length of the course of a river. Shortening the river course means to increase the mean slope and lengthening means to reduce it. Another is to vary the river width. Widening the river means to increase the balance slope, constricting the river to reduce it and, thus, aggradation and degradation, respectively, might be stopped.

To lengthen a river or, to be more precise, to reconnect bayous or old meanders, is the easiest way to approach to the balance slope. Usually, this solution fails due to agriculturally used, river adjacent areas which are either unavailable for river restoration measures or too expensive to acquire. In addition, in some cases even nature conservation prevents a change of the river course due to, e.g., rare species in the concerned area. In case of river widening, the same problems of conflicting interests between river ecology and nature conservation can occur. Furthermore, it is difficult to precisely estimate which river width the river will sustainably accept. It is well known that a formerly braided river morphology may pass into a flat and narrow river bed with a considerably reduced balance slope in case of bed load shortage (Zarn, 1997).

Generally, all methods like ramps, rip raps or groynes use different sizes of stones or boulders. For dimensioning the boulder size, usually a characteristic stone diameter, the equivalent spherical diameter, is calculated from design equations. But slightly changing the diameter also means enormously changing mass and volume of a stone, e.g. a 10 % increase in spherical diameter results in a 33 % increase in weight and, thus, also in costs. At worst, the general acceptance is refused because the stones used for bed stabilisation are significantly larger than the natural stone sizes in the river.

The ecological impacts of ramps and rip raps on different kinds of bio regions are still not fully understood. An example is the acceptable (maximum) slope for a ramps in salmon regions. Should it be 1:8 or 1:10 or 1:12 or even less inclined? An unnecessary flat ramp might lead to unnecessary expensive measures, since a flatter ramp increases the ramp length
and, thus, the material requirements. At the same time, a flatter ramp does not necessarily mean unfavourable effects on costs, since a flatter ramp might also improve the energy dissipation on the ramp due to its increased length compared to a steep, but shorter ramp and, therefore, might reduce the necessity of scour protection downstream of the ramp.

4. What is needed?

This chapter invites researchers to take part in developing new measures and improving existing methods which meet the demands mentioned above. The output might be a catalogue of possible measures for each bio region and morphological situation with advantages and disadvantages regarding ecology, morphology, costs, land use etc. (see fig. 4). Additionally, it is not sufficient to develop a morphologically and ecologically satisfying solution for a certain situation. The measures should also afford a kind of flexibility to be adjusted in accordance with the demands and adapted to changing boundary conditions, such as a changing or uncertain bed load budget (Hengl, Stephan, 2003).

For a successful design of a measure, it is important to likewise consider ecological, hydraulic and morphological principles. To define future research questions it would be even more important to encourage interdisciplinary co-operation between biologists and engineers, since hydraulically and morphologically suitable measures for stabilising a river bed are not necessarily ecologically suitable and vice versa.

![Diagram](image-url)

**Figure 4** Development of sustainable river bed stabilisation measures
4.1 **Enlarge the ecological knowledge**
What are the limits for fish migration for different species? Which species need migration? Can natural reproduction be assured without migration facilities because of adequate spawning grounds within the concerned river reach and connected waters? During which period is migration needed - during the whole year or only during spawning season?

It would further be helpful to reduce the conflicting interests between ecology focusing on natural dynamic of waters and species and nature conservation preserving the existing system without changes to a common denominator.

4.2 **Enlarge the hydraulic knowledge**
What is the flow resistance of different bed stabilisation methods like ramps to ensure flood protection? Which local flow velocities and turbulence must not be exceeded during the migration season? These data should be available during the planning process for not constructing a migration barrier finally. What is the minimum stone size to ensure the stability for the whole range of discharges for ramps and similar stabilisation methods? Is it possible to use different stone sizes in different parts of the bed stabilisation measure? How much kinetic energy is dissipated in a particular river reach?

4.3 **Enlarge the morphological knowledge**
How does a bed stabilisation measure influence the general morphology of the river reach (including habitat change)? The morphological knowledge is closely connected to the hydraulic knowledge since flow velocity and turbulence are the driving forces for each morphological change. Thus, developed methods should improve the quality of balance slope estimation and answer the question which bed level ranges are to be expected upstream and downstream of a bed stabilisation measure (e.g. weir height upstream and scour depth downstream of a ramp).

4.4 **Develop design equations or models which are easy to handle for engineers**
If new measures are planned, the planner needs to know how the river system will adjust to this measure in the future. Thus, it is important to develop design equations for an easy and convenient handling. One possible way to solve such kind of problems effectively could be more co-operation between engineers, biologists and professional software developers. A database with main information on range of application, necessary data to run the model, model output and last but not least how to license the model or who offers model applications would be useful to get a general idea about existing and available models.
Summary

A large amount of problems, mainly concerning rivers, which are not in a state of morphological equilibrium, is highlighted, since many of these questions are not fully answered yet. Therefore, a joint effort of the scientific community is needed to develop ecological, economical and sustainable solutions for river stabilisation. The water management administrations need good answers to achieve a high or at least a good ecological status for our rivers as demanded in the EC Water Framework Directive.

References


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