Development of scientifically-derived nature-based solutions in river engineering using the example of micro groins

Développement de solutions scientifiques basées sur la nature dans le domaine de l'ingénierie fluviale à l'aide de l'exemple des micro-épis

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RÉSUMÉ

À partir de l'exemple des micro-épis, une approche de recherche multicritères a été développée pour trouver solutions basées sur la nature pour les cours d'eau urbains qui, outre les objectifs écologiques, répondent également aux exigences liées à l'utilisation de la méthode de construction et aux aspects économiques. Dans un premier temps, les connaissances pratiques en ingénierie sont acquises sur la base de l'expérience et des projets mis en œuvre. L'étude parallèle des processus naturels dans les cours d'eau permet de réunir l'expertise éco-hydraulique interdisciplinaire nécessaire des biologistes, des géo-écologistes et des ingénieurs. Des méthodes de construction potentiellement appropriées sont identifiées et comparées pour les conditions limites urbaines. L'objectif de ce travail étant de mettre en pratique les résultats obtenus, des méthodes de pointe sont utilisées pour étudier les prototypes. À cette fin, des expériences sur le terrain sont menées sur des projets de référence et des essais en laboratoire avec un lit fixe et mobile pour évaluer l'impact des structures sur les paramètres hydromorphologiques. Ces essais sont complétés par des études numériques pour la modélisation de l'habitat physique. La dérivation nécessaire d'aides à la conception pour une utilisation pratique permet la diffusion future des nouvelles méthodes de construction.

ABSTRACT

Using the example of micro groins, a multi-criteria research approach was developed to derive nature-based solutions for urban watercourses, which, in addition to the ecological objectives, also meets the use-related demands on the construction method and economic aspects. Initially, practical engineering knowledge is gained based on experience and implemented projects. Through the parallel study of natural processes in watercourses, the necessary interdisciplinary eco-hydraulic expertise of biologists, geo-ecologists and engineers is brought together. Potentially suitable construction methods are identified and compared for the urban boundary conditions. As the aim of this work is to transfer the findings into practice, state-of-the-art methods are used to investigate the prototypes. For this purpose, field experiments are carried out on reference projects and laboratory tests with a fixed and movable bed to assess the impact of the structures on the hydromorphological parameters. These are supplemented by numerical investigations for physical habitat modelling. The necessary derivation of design aids for practical use enables the future dissemination of the new construction methods.

KEYWORDS

Ecohydraulics, Habitat Modeling, Micro groins, Morphodynamics, Nature-based solutions

Ecohydraulique, Micro-épis, Modélisation de l'habitat, Morphodynamique, Solutions basées sur la nature

1 CHALLENGES FOR THE REVITALIZATION OF URBAN AND OTHER SPATIALLY RESTRICTED WATERCOURSES

The requirements of the EU Water Framework Directive are a key motivation for implementing measures for the ecological upgrading of urban watercourses. As a consequence of the river regulations in the past, the morphology of the watercourse and its floodplains changed. In urban areas, all important physical and chemical factors are influenced to a greater or lesser extent and the conditions for the respective habitats are sometimes extremely altered. In particular, the homogenization of the river bed and bank areas, together with the altered discharge dynamics, has negative consequences. The loss of habitat diversity reduces the number of animal and plant species in and around watercourses. Specialized species are particularly affected. The low structural diversity thus promotes the occurrence of ubiquists and neozoa, as the uniform hydraulic parameters do not require specialization. Moreover, the high risk of catastrophic flooding necessitates the stabilization of both the riverbanks and riverbed. These factors considerably limit the potential for river restoration. The options for counteracting habitat loss in urban areas are therefore to provide replacement habitats with the help of nature-based solutions and to replace lost habitat structures in a targeted manner in the limited space available.

The level of knowledge of type-specific hydromorphological planning and implementation of measures for common and widespread watercourse types has improved significantly in recent years and there are numerous information and training courses available. Many state authorities provide their own, often very practical instructions for near-natural construction methods and environmentally compatible watercourse maintenance. Nevertheless, there is still a lack of knowledge in planning offices and among those responsible for implementing measures as to which measures are suitable for developing typical watercourse structures (UBA, 2022).

2 DESIGNING NATURE-BASED SOLUTIONS IN RIVER ENGINEERING

2.1 Approach

Using the example of micro groins, an approach for the development of nature-based solutions was developed (see Figure 1). A micro groin (German: “Lenkbuhne”) is a type of groin that is already completely overflowed at low water discharge. As an essential feature, it induces a spiral flow around the longitudinal axis in the direction of flow at higher discharges and thus influences the velocity distribution and bedload transport. Their compact design makes them suitable for use in confined spaces, such as in urban areas. The areas around micro groins exhibit varied flow patterns, leading to a wide range of sediment distribution and hydraulic depths. As a result, the use of micro groins can create habitats with diverse structural characteristics. There is mainly practical experience with the construction method and only a few scientific studies on bank protection and the effects on the water level.

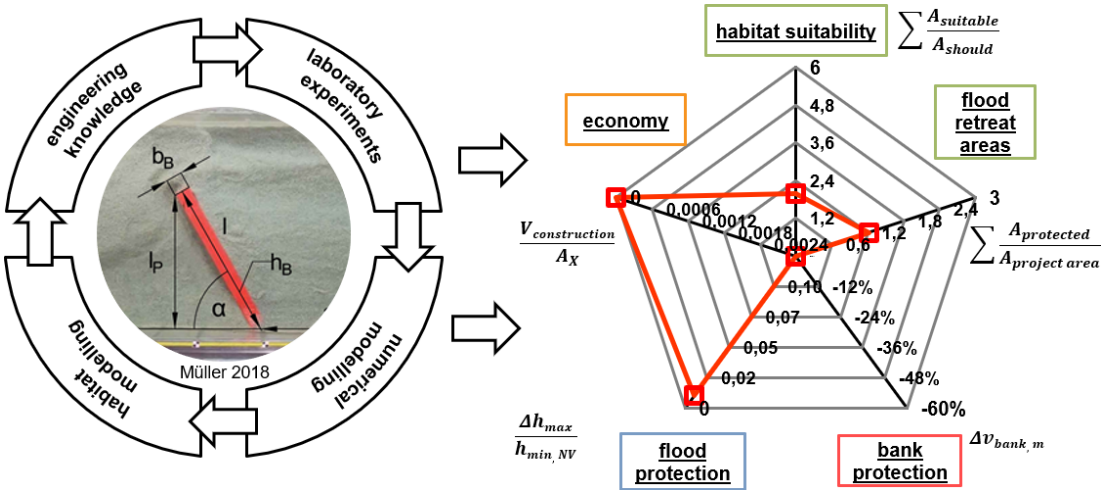

Figure 1 : Multi-criterial variant evaluation for micro groins

As the aim of this work is to transfer the findings into practice, methods are used that correspond to the current state of the art. Practical engineering knowledge is gained on the basis of experience and implemented projects, which were accompanied by an intensive monitoring program. Through the parallel study of natural processes in flowing waters, the necessary interdisciplinary eco-hydraulic expertise of biologists, geo-ecologists and engineers is formed and suitable variants are pre-selected (Müller et al., 2022).

The chosen designs are analysed using advanced hybrid hydraulic modelling techniques, which include mobile bed experiments, complementary numerical simulations, and field monitoring campaigns. Based on the hydraulic results, habitat suitability for all relevant flow conditions is assessed through aquatic habitat simulations. The most promising options are then optimized and evaluated in terms of their ecological impact and hydraulic requirements, such as flood and bank protection for all morphologically significant discharge events (see Figure 1). The aim is the multi-criteria evaluation of the variants to derive design recommendations for nature-based solutions (Müller et al., 2022).

A detailed final comparison of the different investigation methods is important in order to ensure the transferability between the three methods: field experiments and laboratory experiments with fixed and movable bed.

2.2 Development process & Evaluation Criteria

The procedure for developing a nature-based solution in river engineering can be divided into nine steps:

1. definition of the scope of the study
2. derivation of the evaluation indicators
3. pre-selection of suitable variants
4. theoretical analysis
5. field experiments on reference projects
6. hydraulic optimization through laboratory experiments with fixed bed
7. holistic analysis in laboratory experiments with movable bed
8. comparison of methods
9. implementation of a reference project with optimized design parameters

The catalogue of holistic evaluation criteria - ecology, use, boundary conditions, structural stability and economy - takes account of the requirements in urban areas (see Figure 1).

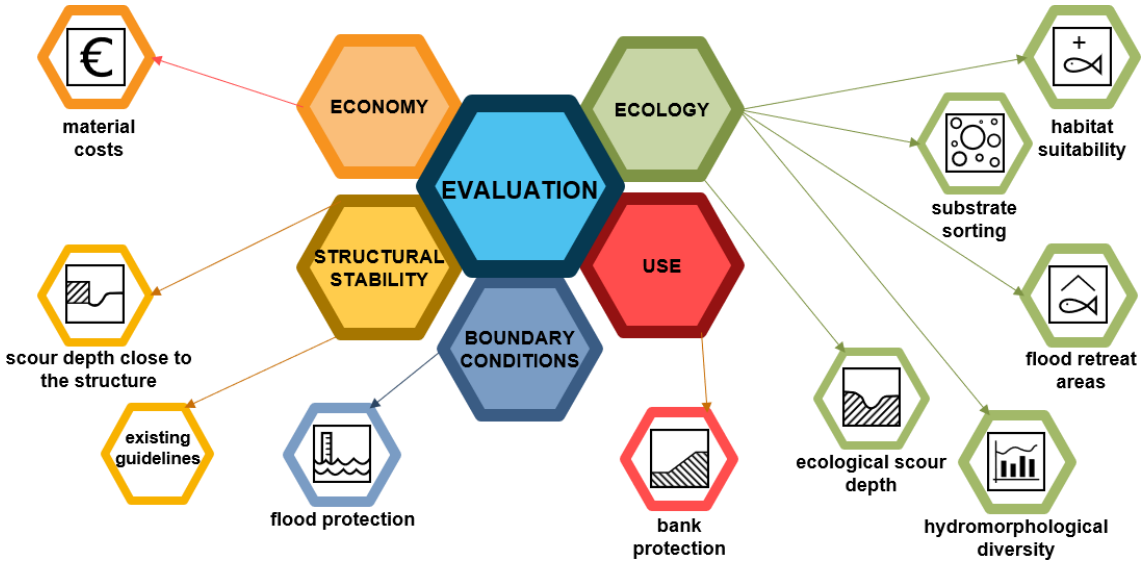

Figure 2: design criteria for nature-based solutions in urban watercourses

Erosion of the banks often cannot be permitted due to the fact that in urban and other spatially restricted areas, use often extends right up to the upper edges of embankments. In this case, at least the bank protection guaranteed before the implementation of measures must be maintained. Nevertheless, in view of the diverse usage requirements for inner-city watercourses, a change in bank protection would be welcome from the perspective of local recreation and ecology in order to create the potential for redesign, e.g. with technical-biological bank protection. This would reconnect the water exchange zone with the surrounding area and the shade provided by the growing vegetation also would have a positive effect on water temperatures in summer. The root system also provides shelter for fish fauna, especially for juvenile fish.

The structural stability of the structure can be represented by the scour depths on the structure. These must be minimized or at least considered structurally in order to prevent damage caused by progressive scour formation from endangering the integrity of the structure. Otherwise, the variants investigated for this research work are limited to those for which the stability was calculated according to the state of the art or the state of knowledge.

In urban areas, flood protection must be considered as a boundary condition. In many places, there is little or no hydraulic leeway for design floods, partly due to climate change. Therefore, the rise in water levels must be minimized through the clever choice of design parameters for the nature-based solution to be developed.

Ecology can be represented by different indicators. Habitat suitability or the creation of suitable water structures quantify the benefit as a habitat. The creation of protected areas during floods prevents individual organisms from being washed out of the redesigned section. Hydromorphological diversity, ecological scour depth and substrate sorting complete the selected indicators.

As it is difficult to estimate personnel costs, profitability is determined by material costs.

2.3 Outputs

For practical implementation, it is important to provide the planning engineer with suitable design aids for the dimensioning of the structures. The relevant dimensionless parameters of micro groins were identified as part of the parameter study in the experiments with fixed bed. With the inclusion of literature data, the data sets obtained from the laboratory tests, estimation formulas for the influence of the newly developed nature-based solutions on the water level rise and the bank protection effect can be developed. Further Information on the structural design of the construction method, e.g. integration into the bank or proper protection of the structure itself against erosion damage, are also important to promote the spread of the new construction method. The hydromorphological analyses on micro groins, for example, revealed the need for bank protection in the direct vicinity of the structure due to possible erosion.

3 OUTLOOK

The presented research approach offers a wide range of opportunities for the further development of scientifically-derived nature-bases solutions for the ecological upgrading of degraded watercourses with difficult boundary conditions, also outside of urban areas. The holistic approach of field and laboratory investigations provides reliable findings for the optimization and new development of multifunctional structures in river engineering. Their application is becoming increasingly important, especially with regard to climate change. This has laid the foundation for a paradigm shift in the field of revitalization planning, enabling the transition from trial & error and towards well-founded development processes.

Therefore, it is planned to use the approach in the context of “Germany's Blue Belt Programme” which aims for the restoration of federal waterways in Germany. Due to its multifunctional effect, there are many possible applications of micro groins which give reason to see the potential of a wide spread and also large-scale use of the construction method in federal waterways in the future.

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