The ecotechnological principle —The use of ecosystem properties as management tool is based on the first and second principles of EH and related to ecological engineering *(Figure 3).* This principle features three steps of implementation:

(1) "Dual regulation" – biota by hydrology and, vice versa, hydrology by shaping biota or controlling interactions.
(2) Integration at the basin scale of various types of biological and hydrological regulations toward achieving synergy to improve water quality, biodiversity and freshwater resources.
(3) Harmonization of ecohydrological measures with necessary hydrotechnical solutions (dams, irrigation systems, sewage treatment plants, etc).

Achievements and limits of ecohydrology

Pollution is one of the key issues and greatest challenges of ecohydrology. An implicit but major goal of EH is to reduce input to, and regulate excess nutrient and pollutant load in aquatic systems by considering important pools like soils, sediments, vascular plant biomass, and conversion of matter by organisms. However, EH methods are less efficient and have a lower potential when the carrying capacity of the ecosystem is exceeded, e.g., in the case of hypertrophy (Zalewski 2000). Ecological biotechnology used in the framework of EH is becoming the fundamental tool for successful implementation of Integrated Water Resources Management.

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Applying meso-scale habitat modeling to waterway management

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Introduction

Riverine ecosystems and their habitats are inherently complex and contain many relationships between biotic and abiotic components. Habitat models can be an appropriate instrument to study the ecological functions of these systems. They allow for the quantitative and qualitative assessment of habitat conditions for resident indicator species such as fish.

In the past, habitat modeling has focused primarily on ecological impacts at the local scale using short (hundreds of meters) investigation reaches. In recent years, there was a growing need for tools allowing for an integrated analysis at larger scales. To satisfy this demand MesoCASiMiR (Schneider et al. 2006; Eisner et al. 2007), as meso-scale habitat model was developed at the University of Stuttgart. It acts conceptually as a decision support system at a scale of larger river segments, or even river catchments and is an extension of the micro-scale, fuzzy-logic model CASiMiR (Jorde 1996; Schneider 2001; Wieprecht et al. 2008).

Fish habitat modeling in waterways requires a focus on factors which may differ substantially from those of natural rivers. Special attention must be given to the bank and overbank areas. Main navigation channels are usually less important for fish due to their poor morphology and frequent disturbances by passing ships. Habitat modeling is a promising approach when improving the ecological integrity of waterway banks. However, current model concepts must be extended to conform to the specific conditions and requirements of large waterways.

Two-staged model concept

MOFIR (Model for Fish Response) is a fish habitat model developed as complement of the platform INFORM designed by the German Federal Institute of Hydrology (BfG 2003). It provides a decision-support-system for hydraulic engineers and biologists to be utilized in the early planning and design stages of a project. Fish have been chosen as indicator species for riverine ecosystems since they are highly sensitive to both structural and hydraulic changes. Additionally, measures and alterations in and around river banks account for the largest and most severe impacts to fish habitats. MOFIR, based on the original CASiMiR model system which combines habitat requirements of fish with abiotic conditions, provides quantitative information of habitat quality and availability to support environmental impact assessment.

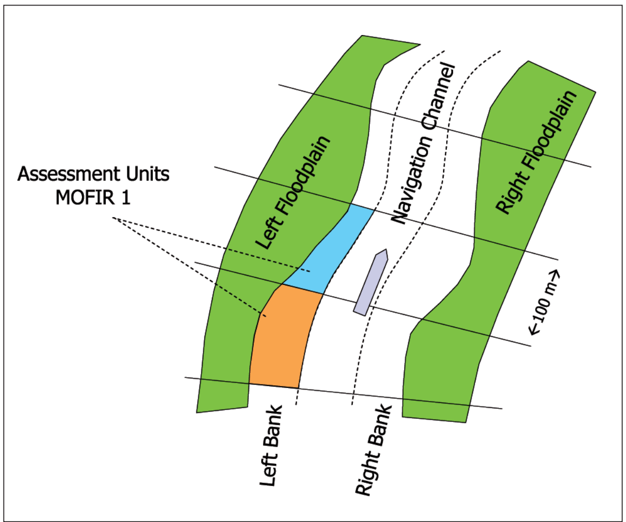
MOFIR incorporates two separate versions, each having its own focus of application. MOFIR 1 has been tailored for those working in the water and navigation management sector to provide a first critical look at potential ecological impacts of design options. The program must rely on a limited set of model parameters which do not require complicated or time-intensive data retrieval methods. The more detailed version MOFIR 2, on the other hand, must be able to carry out thorough, site-specific analyses. The model base is designed to enable an accurate prognosis through user-defined analysis. MOFIR 2 can make use of an expanded set of input data and parameters.

Riparian zones, connections between main channel and floodplains as well as tributaries are of particular importance as fish habitats, whereas the main channel itself often has little or no value due to poor morphologic conditions, high turbidity and frequent disturbances by passing ships. For these reasons, the development of MOFIR is focused on the bank and floodplain areas only. Motivated by the cross section data available for German waterways the smallest assessment unit length in MOFIR 1 is set to a default value of 100 m and the left and right floodplains are accounted for separately *(Figure 1).* In MOFIR 2 the smallest assessment unit depends on the available grid resolution of the digital elevation model (usually a few m²).

MOFIR 1

Hydraulic conditions near banks and in riparian zones are often complex due to heterogeneous morphology or engineering measures such as groynes, parallel hydraulic structures, excavations or restoration efforts. Since MOFIR 1 is equipped with a one-dimensional hydrodynamic model only, it should be used to gain an overview of potential impacts of planned changes.

Figure 1. Assessment Units in the MOFIR 1 Program



To account for the fundamental impacts of various measures on fish species, MOFIR 1 deals with ecological groups, rather than focusing on specific fish species and their life stages. The following ecological groups are considered:

- Group A: Juvenile fish and hatchlings *(Group reacts sensitively to changes to the shallow bank areas)*
- Group B: Limnophilic fish *(Group is sensitive to hydraulic changes on the scale of groyne fields, and pool areas)*
- Group C: Rheophilic fish and gravel spawners *(Group is sensitive to changes in local hydraulic conditions as well as to the substrate composition)*
- Group D: Gap residents, e.g. Eel *(Group is sensitive to changes in the coverage properties)*

Beside water quality, fish are also strongly affected by local hydraulics and morphology. Flow velocity and water depth may be taken directly from an integrated hydraulic model (1D) using cross section data usually available for navigable rivers. The other key parameters for habitat modelling using MOFIR 1 are substratum and coverage. These input parameters can be transferred from existing databases and supplemented by local experts. Through these key parameters, it is possible to quantify a basic habitat suitability of a 100 m reach for fish. The model also allows for the inclusion and interpretation of aerial photographs (orthophotos) with regard to fish habitat-relevant structures such as groynes, different bay types, side channels, steep or flat banks.

Habitat suitability ordered in five classes is derived in a first step by the section-wise evaluation of expert-rules including the key parameters. In a second step the structural parameters are assessed by another rule-set. Thus, for each ecological group the identification of suitable or unsuitable habitat areas can be determined.

For scenarios of future technical measures the model data base is different. Since, e.g., there are no orthophotos available for planning alternatives an additional set of rules predicting the effects of management measures on certain model parameters was established. Whereas parameters such as mean water depth and flow velocity can be derived by hydraulic calculations on the basis of a new bathymetry defined for one measure, other parameters like flow diversity cannot be derived directly. At this point the rule-system comes into play. E.g., it is predicted that the construction of a groyne will create a cross-sectional structure, and consequently the flow diversity and depth variability will be "high". With further fuzzy-logic processing habitat suitability is derived (Wieprecht et al. 2008).

MOFIR 2

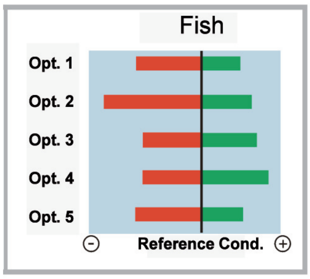
MOFIR 2 is designed for more detailed investigations. By the intersection with a digital terrain model a high level of accuracy and resolution (few m² per cell) for the river bank areas can be provided when assessing fish habitats. Instead of ecological groups, in MOFIR 2 specific species and life-stages are considered. The high resolution of the model enables the input of detailed data on water depth and velocity as well as direct incorporation of structures such as shallow zones, groynes, bays, etc. The rule systems of MOFIR 2 are based on the fuzzy-logic approach of the habitat model CASiMiR (Schneider 2001). Using the results of a two-dimensional hydraulic model, habitat conditions for a wide range of flow rates can be assessed. The habitat model assigns a habitat suitability index to each cell ranging from 0 to 1 (SI = 0: not suitable; SI = 1.0: highly suitable).

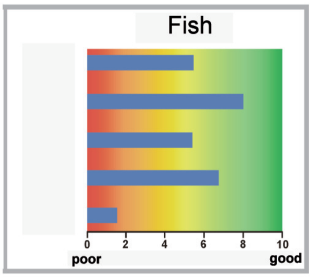
Model evaluation

MOFIR evaluation is performed by comparison with a reference status. In contrast to other reference-based approaches this reference status is not the one prior to human impacts but the current status. Thus, the evaluation delivers quantitative information on the degree of amelioration or deterioration in comparison to the existing situation.

Using the habitat suitability index a Weighted Usable Area (WUA) as equivalent of habitat availability is determined. The WUAs for each design scenario are compared with the one for the reference condition. *Figure 2* shows an exemplary result of an evaluation. The horizontal bars reflect the various planning alternatives and their consequences. Green bars extending to the right of the vertical line represent the total of areas with improved habitats, red bars show the sum of areas with decreased habitat suitability. Areas with a large change of suitability receive a higher weight to emphasize heavily affected river parts. The same applies to reaches/grid cells with a high suitability index (SI> 0.7) indicating good habitat quality. The model results for a planned design option will be depicted as a change of state in relation to the reference condition and displayed in a bar chart format *(Figure 2, left).* In addition to the presentation of negative and positive impacts, an ecological assessment of the design options based only on the negative impact is performed on a scale from 0 to 10. The value 0 is given to the variant with the largest negative change, the variant with the lowest negative change is assigned 10. The values of the other variants are interpolated linearly *(Figure 2, right).*

Figure 2. Example of the evaluation result showing a comparison of design options **left:** *Chart representing the changes of status, red bar as equivalent of areas with decreased habitat quality, green bars as equivalent of areas with increased habitat suitability, weighing of areas with large change and areas with high habitat suitability index (SI>0.7) is included*
right: *Chart depicting the overall ecological impact assessment based on the negative impacts in terms of loss in habitat suitability*





Since calculations are performed for each species or ecological group separately, the interim results can be traced back to the fish's ecological function (e.g. habitat suitability for juveniles). By weighting results of certain ecological groups, such as e.g. gap residents, development objectives can be incorporated in the evaluation. Results for the species or groups are summarized to a combined result "fish" (e.g. by averaging). This end result can then be included into a large scale assessment using the INFORM platform, and compared to other modules (Wieprecht et al. 2008).

Conclusions

The presented MOFIR models extend basic fish habitat modeling principles from non-navigable rivers to waterways by respecting bank structures, wave action and fish requirements. This tool may be applied for Environmental Impact Assessment (EIA) on actual navigation projects in the "Green Corridor" of the Danube River. As such, it can help to implement the EU Water Framework Directive in the framework of the Danube River Basin Management Plan. Due to a two-staged model concept mitigation measures and their impact on fish habitats can be considered in the early planning and design stages (MOFIR 1) as well as analyzed in more detail (MOFIR 2). Since the model concept allows for the integration of existing data into the modeling framework, MOFIR may be applied without additional time-expensive data collection.

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