Sixth framework programme of
the European Commission

GOCE-CT-2003-505401

RIVERTWIN

A regional model for integrated water management in twinned river basins

Instrument: Specific Targeted Research Project (STREP)

Priority: Sustainable development, Global Change and Ecosystems

D 7 Prototype of submodel for interaction between hydromorphology and river ecology in the Neckar basin

Due date of deliverable: 30.4.2005
Actual submission date: 31.7.2005

Start date of project: 01.03.2004 Duration: 3 years

Organisation name of the lead contractor for this deliverable

Revision: Final

Project co-funded by the European Commission within the Sixth Framework programme (2002-2006)		
Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including Commission Services)	
RE	Restricted to group specified by the consortium (including Commission Services)	
CO	Confidential, only for members of the consortium (including Commission Services)	

Table of contents

1 Background

The upscaling of habitat models is one of the most important tasks in the near future in order to establish them as a standard tool for the assessment of river status. Currently the application of habitat models is mainly concentrated on the local scale and the investigation of spatially delimited problems like ecological flow regulations or morphological enhancements. However for water management according to the EU Water Framework Directive and strategic planning, modeling tools have to cover larger areas respectively river sections. In the WFD the management units of river basins are waterbodies with an extension of about 200 km².

While the habitat simulation system CASiMiR in the current version as most other habitat simulation models is focussed on the microscale covering reaches with a length of several ten meters up to maximum several kilometers, the mesocale version of CASiMiR named MesoCASiMiR is supposed to be applied to whole river systems. Basic unit of current river habitat models usually are elements defined by a hydraulic model delivering detailed information about e.g. water depth and flow velociites. These elements can have a size of much less than one meter depending on river morphology. In contrast the basic unit of the Mesoscale models are Meso-habitats with a size reaching from several meters up to several hundred meters.

2 Model description

2.1 Data collection

Providing suitable habitat mapping methods is one of the crucial aspects in the development mesohabitat models. Without an objectified method, fast enough to cover large systems but detailed enough to enable habitat assessment the broader practical application of habitat models in the mesoscale can be questioned.

Since MesoCASiMiR was not supposed to be based on purely descriptive parameters but rather on quantitative information it was decided to use a compromise method. Mesohabitats are described by representative values for hydraulic and morphological parameters. However the hydraulic parameters as flow velocity and water depth are classified and classes are partly overlapping in order to facilitate the assignment of a mesohabitat to one of the classes (Eisner et al. 2005).

Fig 1 PDA with interface of software speficially developed for mesohabitat mapping

But another crucial aspect is the support of the mapping by use of a PDA stored in a waterproof box (Fig.1). A commercial software was adapted to enable a fast registration of habitat parameters. Not only hydromorphological information is collected but also information on e.g. current flow rate, closest gaging station, migration barriers, water extraction etc. Furthermore the shape and size of mesohabitats is drawn as a sketch directly on an interface of the mapping software. These sketches together with coordinates registered by a GPS are used later on to draw habitat polygons in a GIS shape file.

2.2 Model Concept - Three step model

Habitat modeling with MesoCASiMiR is planned to be performed in three steps.

2.2.1 Hydromorphological habitats

As in "conventional" physical habitat models in the first step morphological and hydraulic habitat parameters are considered. It is well known that e.g. flow velocity, water depth, substratum at the river bottom and available cover have strong influence on the habitat use of many fish species. Usually habitat modeling is performed for selected indicator species. Since the habitat requirements of different life stages are quite different the output of this modeling step is a "patchwork" of habitats. In most cases the availability of habitats for all life stages is regarded when interpreting model results and additionally seasonal aspects are considered. However the interaction between different habitat types is mostly neglected.

One of the linkages with the other submodels is focussed on the change of river bottom substratum by the introduction of fine sediments from agricultural areas, delivered by the submodel for land use. On the other hand habitat conditions change with flow rate. So the information from the hydrological submodel is used to describe habitats depending on altered water depth and flow velocity. These linkages are performed in the first model step (see Fig 4).

2.2.2 Networking -"Living space" and Migration

The expression "habitat" is often used by modelers when talking about physical conditions for a certain fish life stage as target of the modeling process. But the suitability of a river stretch depends on the availability of different habitat types and their spatial context.

To give an example: A good spawning habitat will only be useful for a fish population if good habitats for juvenile fish are close and located downstream of the spawning ground. This is why the expression "living space" is introduced. It is meant to indicate that even though in a river stretch there might be optimum habitats for different life stages of a species this doesn't necessarily mean that this species can survive in that stretch. This is because distances, orientation and connectivity between different habitat types are defining the suitability of a river stretch.

Another aspect of habitat networking is the passability of migration barriers. Usually fish tries to overcome migration barriers mainly during the spawning period to make its way to suitable spawning grounds. So even though a "living space" as defined above can cover a wide range of different habitat types and provide good conditions for any life stage throughout the year it can hardly contribute to the survival of a fish population if at a certain time of the year suitable spawning grounds are not reachable. In that sense the suitability of a whole living space is affected by the disconnection to reproduction areas and has to be considered when developing management concepts for rivers in the larger scale.

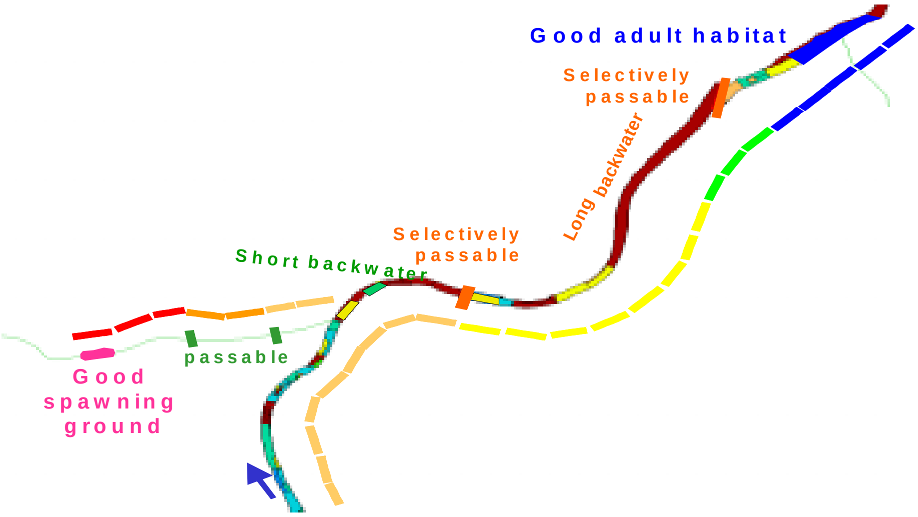


Fig 2 Aspects of migration, cumulative effect of migration barriers and visualization in mesohabitat model

An advantage of the mesoscale is that the cumulative effect of migration barriers can be considered. Furthermore it is not only the barrier and the migration facility itself but additional factors like the location of the facility in lateral direction and the extension of the backwater zone upstream of the barrier that are effecting fish passage. These effects can be integrated and visualized in a mesocale model (Fig. 2).

As the spatial relations between different habitat types can only be investigated after these habitat types are known consequently this step is the second one within the modeling process and provides linkages to morphological measures on the river system.

2.2.3 Water quality

Water quality can be considered as governing factor for the usability of habitats. As mentioned before fish habitats can be optimum from the hydromorphological point of view, but as long as they are not in a certain spatial context they won’t make up a suitable “living space”.

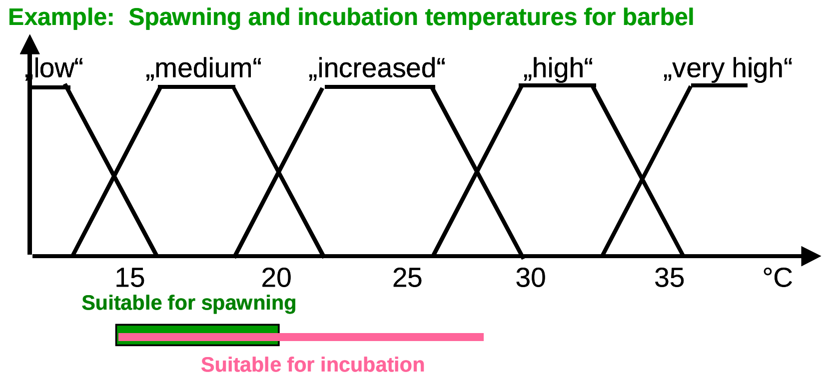
But even if the available “living space” comprises all kinds of habitat types - with a high avialability and spatial connectivity - insufficient water quality will defeat these principally highly suitable conditions.

One problem in integrating water quality parameters in fish habitat modeling is that for many parameters the effects on fish physiology are hardly known. This is why in the current model development the focus is on two parameters, that comparatively most information is available for: water temperature and oxygen concentration. For water quality even more than for other habitat parameters the transition between suitable and unsuitable ranges is fuzzy. Several authors distinguish between an optimum range and an lower and upper restricted, critical and lethal range.

Beside the absolute values of water temperature and oxygen concentration the duration of the impact is of high importance. Many fish can resist unfavourable conditions as long as they are not present for a longer time period.

These issues are hardly to describe by exact numbers. This is why a fuzzy rule based approach, successfully applied in the microscale, was chosen to describe the linkages (see example in Fig. 4).

- Strength of impact (absolute temperature, O_2-concentration)
- Duration of impact
- Combination with hydromorphology



IF temperature „medium“ THEN suitability for spawning „High“
IF temperature is „low“ and duration is „short“ THEN suitability is „medium“

Fig 3 Temperature ranges and related expert rules defining habitat suitability

Since water quality is more or less independent of the other two steps but dominating the overall habitat suitability it is considered in the third model step and provides a linkage to the water quality submodel. Fig 4 gives an overview of the model principle.

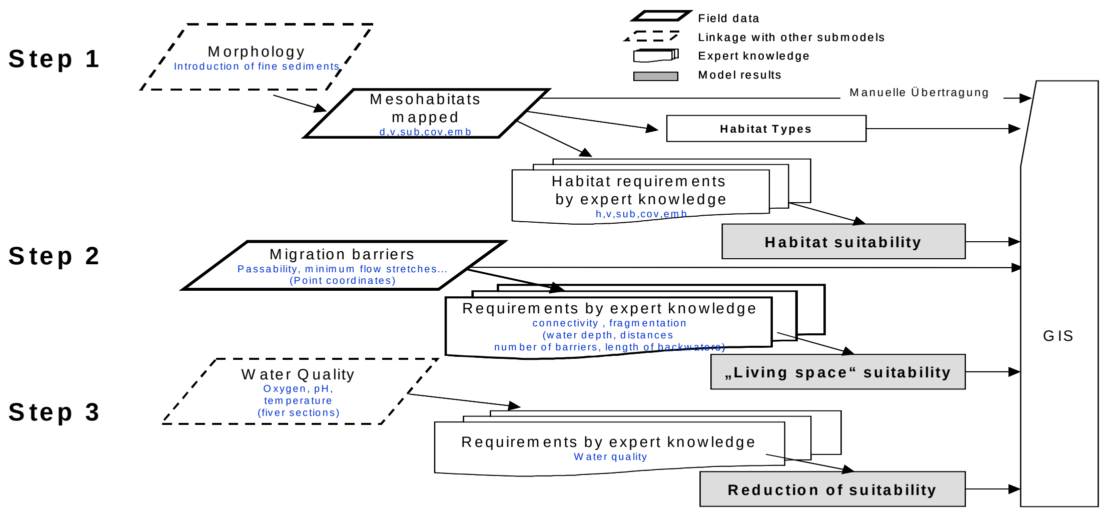


Fig 4 Three step model principle of MesoCASiMiR integrating hydromorphology, connectivity and water quality aspects

2.3 Model Platform

The current version of Mesocasimir is a software program coming in the form of the Avenu extension for Arcview GIS. It allows calculation of the suitability index (SI) for the target species with the use of a fuzzy rule - based approach. The total number of the input parameters can be chosen arbitrary and is restricted only by the complexity of the fuzzy rules' generation. Together with the ordinal parameters (like water depth, velocity), also nominal parameters (like presence of cover etc.) can be used. SI result can be generally obtained for any data structured in the form of the DBase table. As Arcview allows association of the tabular data with graphical entities (shapes), the direct visualization of the results becomes straightforward and allows direct control of the computation.

2.4 Fuzzy rule-based approach

The knowledge about ecological linkages in most cases is not available in terms of clearly defined mechanisms and functions but rather as expert judgement which is based on experience and however may be supported by field data. An example for an information about habitat requirements for fish is the statement “IF flow velocity is ‘high’ AND water depth is ‘medium’ AND substratum size is ‘high’ THEN habitat suitabilty for fish species A is ‘High’ “. This kind of semiquantitative knowledge can be implemented into a numerical model by building up so called fuzzy sets that define what range of e.g. flow velocities should be covered by the terms ‘low’, ‘medium’ and ‘high’ . These fuzzy sets then are used for setting up rule bases describing habitat requirements dependent on selected habitat parameters. A separate program in terms of a “fuzzy sets editor” was designed in order to enable an easy, visually supported definition of the fuzzy sets. Fig 8 is showing the example of defining fuzzy sets for the habitat parameter flow velocity.

The expert rule bases for the description of habitat requirements are given in form of Tables that can be saved and introduced into the modelling process as Text files. An example is given in Table 1 (see also software interface in Fig 6).

Table 1 Extract of expert rule base defining habitat requirements of spawning grayling, based on fuzzy sets for three ordinal parameters and one nominal parameter (cover)

#[grayling spawning, Neckar]

#					#				
vel	dep	sub	cov	si	vel	dep	sub	cov	si
A	1	2	3	4	A	1	2	3	4
B	4	5	6	7	B	4	5	6	7
C	7	8	9	10	C	7	8	9	10
#					#				
H	VH	H	A	L	M	M	H	A	L
H	VH	H	B	L	M	M	H	B	L
H	VH	H	C	L	M	M	H	C	L
H	VH	M	A	L	M	M	M	A	L
H	VH	M	B	L	M	M	M	B	M
H	VH	M	C	L	M	M	M	C	M
H	VH	L	A	L	M	M	L	A	L
H	VH	L	B	L	M	M	L	B	L
H	VH	L	C	L	M	M	L	C	L
H	H	H	A	L	M	L	H	A	L
H	H	H	B	L	M	L	H	B	L
H	H	H	C	L	M	L	H	C	L
H	H	M	A	L	M	L	M	A	H
H	H	M	B	M	M	L	M	B	H
H	H	M	C	M	M	L	M	C	H
H	H	L	A	L	M	L	L	A	L
H	H	L	B	L	M	L	L	B	L
H	H	L	C	L	M	L	L	C	L
H	M	H	A	L	L	VH	H	A	L
H	M	H	B	L	L	VH	H	B	L
H	M	H	C	L	L	VH	H	C	L
H	M	M	A	L	L	VH	M	A	L
H	M	M	B	M	L	VH	M	B	L
H	M	M	C	H	L	VH	M	C	L
H	M	L	A	L	L	VH	L	A	L
H	M	L	B	L	L	VH	L	B	L
H	M	L	C	L	L	VH	L	C	L
H	L	H	A	L	L	H	H	A	L
H	L	H	B	L	L	H	H	B	L
H	L	H	C	L	L	H	H	C	L
H	L	M	A	VH	L	H	M	A	L
H	L	M	B	VH	L	H	M	B	L

3 Short user's guide

3.1 System requirements

The current version of the program was tested under the operational systems Windows 2000 and Windows XP using Arcview GIS version 3.3.

Special attention: the decimal separator in the system regional settings should be set to the point character (".").

3.2 Installation

The present version of the installation package consists of:

1. Arcview extension "fuzzy_si.avx".
2. Arcview example project.
3. Fuzzy Sets Editor.
4. Program dll's.

To install the software package, start the program "setup.exe", and follow the instructions of the InstallShield Wizard.

Under "Destination folder", specify the Arcview extension folder. The "fuzzy_si.avx" extension will be installed there.

The user can choose the "Custom" setup type to disable the installation of the Fuzzy Sets Editor and example files. The Fuzzy Sets Editor and example files will be by default installed in the subdirectory "sje\mesocasimir" in the system program directory.

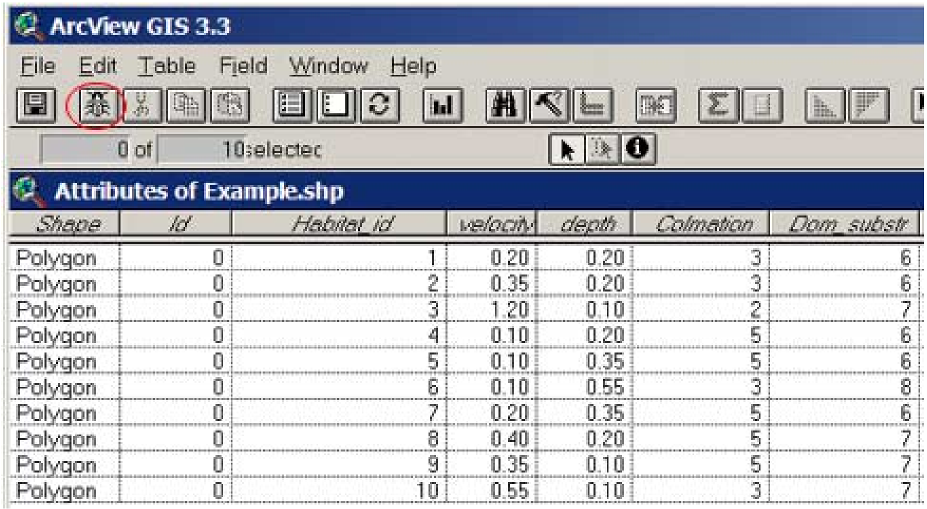
3.3 Running the Arcview extension

3.3.1 Input files

The required input files are a fuzzy sets file (extension ".SRFZS") and a fuzzy rules file ".SRfzy".

3.3.2 Calculation steps

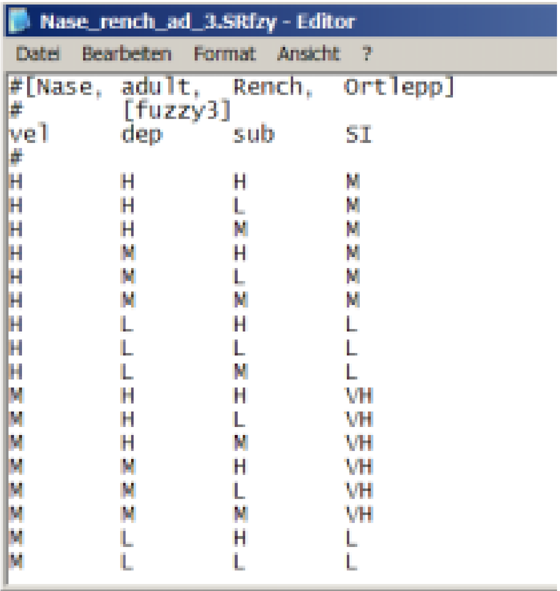
1. Prepare a DBase table with the input data columns and open it in Arcview. Alternatively, the attributes of the shape theme can be used as an input:
2. Prepare the fuzzy sets file with the use of the Fuzzy Sets Editor (see 3.4). **Attention:** the fuzzy sets have to include the suitability index fuzzy set with the name "si".



Shape	Id	Habitat_id	velocity	depth	Colmation	Dom_substr
Polygon	0	1	0.20	0.20	3	6
Polygon	0	2	0.35	0.20	3	6
Polygon	0	3	1.20	0.10	2	7
Polygon	0	4	0.10	0.20	5	6
Polygon	0	5	0.10	0.35	5	6
Polygon	0	6	0.10	0.55	3	8
Polygon	0	7	0.20	0.35	5	6
Polygon	0	8	0.40	0.20	5	7
Polygon	0	9	0.35	0.10	5	7
Polygon	0	10	0.55	0.10	3	7

Fig 5 Input table with data columns

3. Prepare the fuzzy rules file. The parameter names in the fuzzy rules file should resemble those in the fuzzy sets file. The parameter "si" should be in the last column of the fuzzy rules file (it does not matter whether upper-case or lower-case letters are used):




```
#[Nase,  adult,  Rench,  Ortlepp]
#        [fuzzy3]
vel      dep     sub     SI
#
H        H       H       M
H        H       L       M
H        H       M       M
H        M       H       M
H        M       L       M
H        M       M       M
H        L       H       L
H        L       L       L
H        L       M       L
M        H       H       VH
M        H       L       VH
M        H       M       VH
M        M       H       VH
M        M       L       VH
M        M       M       VH
M        L       H       L
M        L       L       L
```

Fig 6 Example of the fuzzy rules file

4. Before running the extension "fuzzy_si", it should be activated in Arcview under "Files"- "Extensions", as a result, the button with the "bug" picture will appear in the GUI "Tables" (see Fig 2). Start the extension by pressing the "bug" button. Following the Fuzzy Wizard, specify at first the fuzzy sets file, then the fuzzy rules file. The program will try to relate the columns of the input table with the parameter names specified in the fuzzy sets and fuzzy rules automatically. If the columns are not related correctly, user can adjust the relations by pressing the right mouse button at the line with the parameter and selecting the appropriate column from the list (see Fig 7, Fig 8):

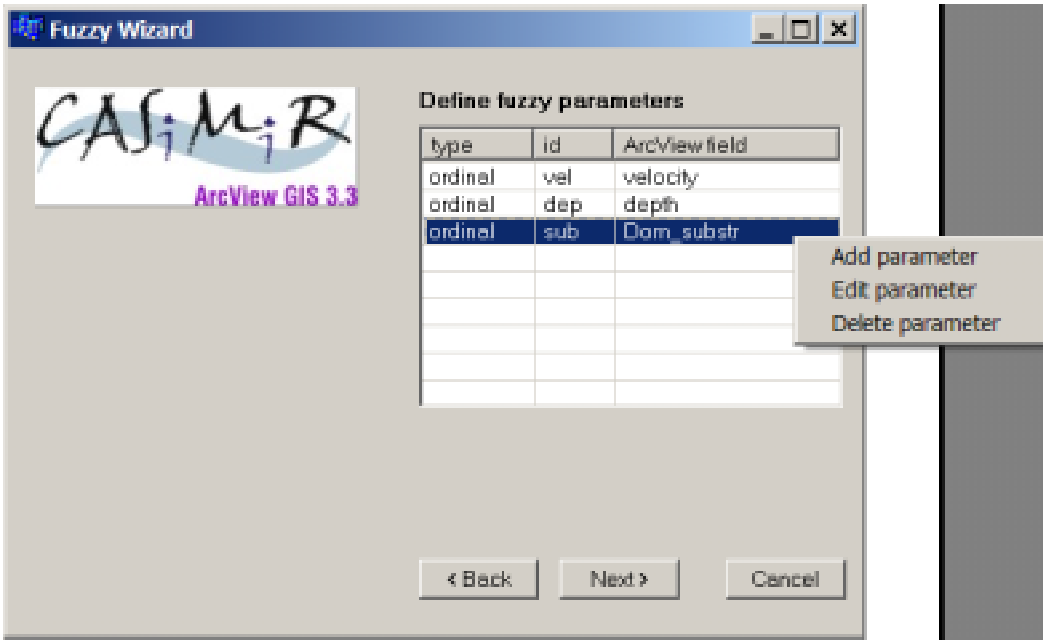


Fig 7 Selecting the parameter to edit

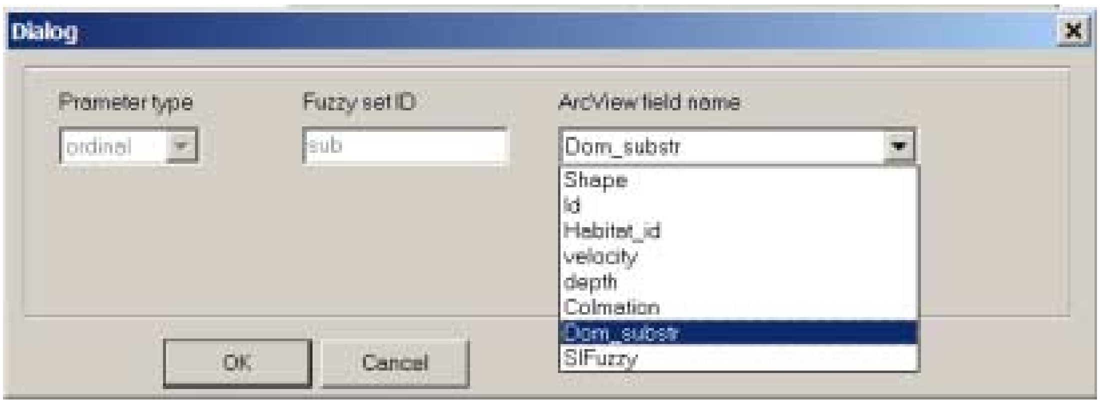
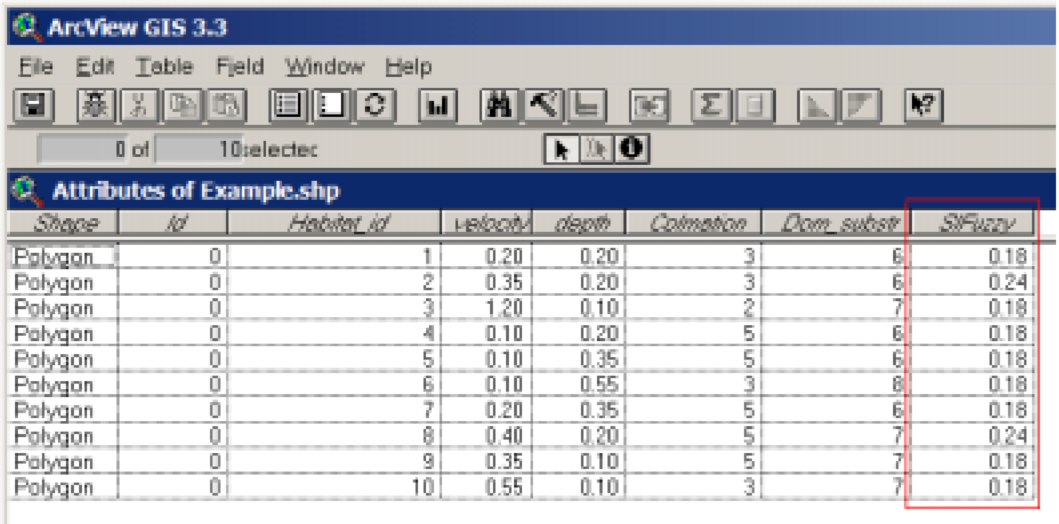


Fig 8 Editing the parameter's relation table

At last, select the inference method for the calculation and press “calculate”.

5. If there are no errors in the input files, the new column with the calculated SI will be added to the input table:



Shape	Id	Habitat_id	velocity	depth	Colmation	Dom_substr	SIFuzzy
Polygon	0	1	0.20	0.20	3	6	0.18
Polygon	0	2	0.35	0.20	3	6	0.24
Polygon	0	3	1.20	0.10	2	7	0.18
Polygon	0	4	0.10	0.20	5	6	0.18
Polygon	0	5	0.10	0.35	5	6	0.18
Polygon	0	6	0.10	0.55	3	8	0.18
Polygon	0	7	0.20	0.35	5	6	0.18
Polygon	0	8	0.40	0.20	5	7	0.24
Polygon	0	9	0.35	0.10	5	7	0.18
Polygon	0	10	0.55	0.10	3	7	0.18

Fig 9 New column with results in the input table

3.4 Using Fuzzy Sets Editor

With the Fuzzy Sets Editor it is possible to create new and edit existing fuzzy sets files which are stored in ASCII format.

Within the “File”-menu, fuzzy sets collections can be loaded for editing, saved in an ASCII file or as a bitmap for presentation purposes. The menu “Fuzzy Set” allows the user to add new and remove existing fuzzy set from the fuzzy sets collection, and also navigate through the collection. For speed up, the toolbar buttons with the functions as in the main menu are supplied (see Fig 10). The functionality hint pops up if the mouse pointer is held for a second over the toolbar button.

To add a new fuzzy set to a collection, the user has to provide the Editor with the fuzzy set NAME (or identificator), fuzzy set DESRIPTION and UNITS of the parameter (see Fig 11). Fuzzy set NAME should match the corresponding parameter name specified in the fuzzy rules file.

To ensure the correct functioning of the Arcview extension, fuzzy sets file should necessarily include the suitability index fuzzy set with the NAME “si”. If it is missing in the collection, the warning message will appear during saving of a file.

As a template the old SORAS fuzzy sets files (*.SRFZS) or integrated template (in menu “File”) can be used.

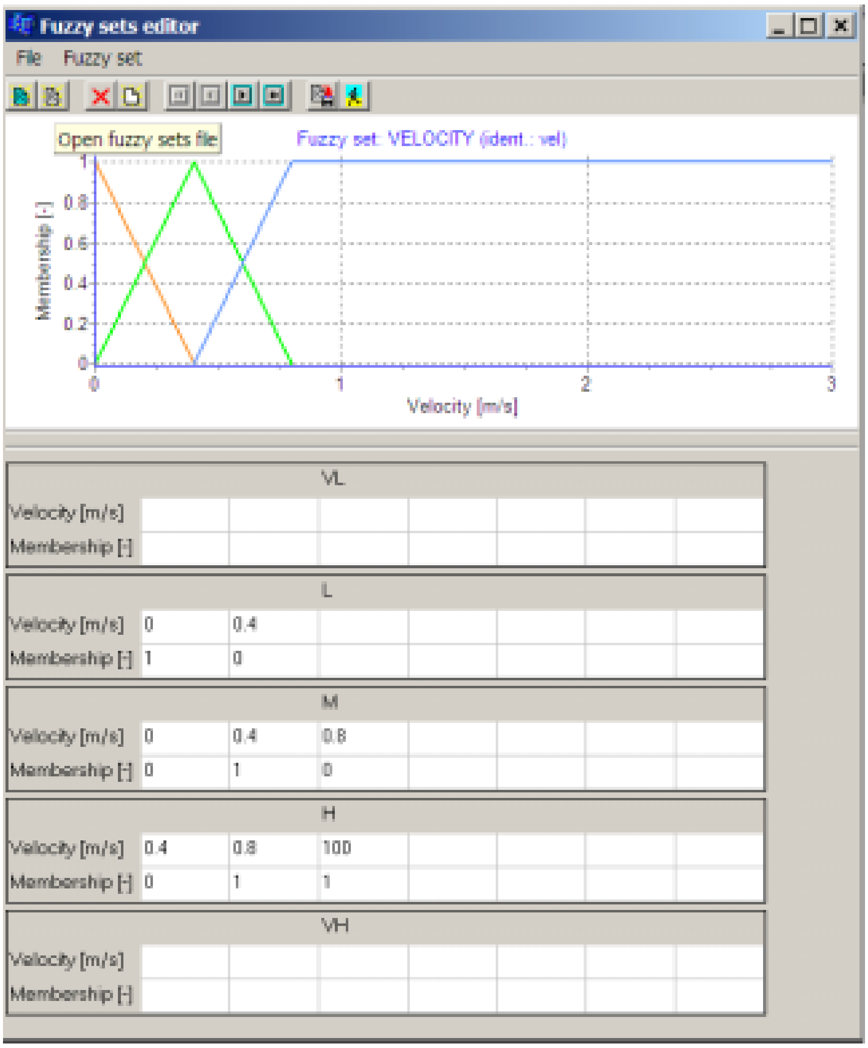


Fig 10 Fuzzy Sets Editor - editing fuzzy set "VELOCITY"

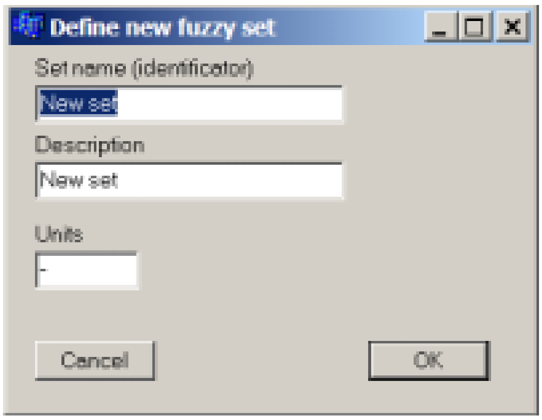


Fig 11 Defining new fuzzy set

4 Application in the Neckar Basin

The first step of model application in the Neckar Basin was the mapping of meso-habitats in the total length of the river. Whereas mapping was performed walking beside an wading in the river in the upper part upstream of Plochingen, downstream of Plochingen in the navigable part data collection was performed mostly from a boat (Fig 12).

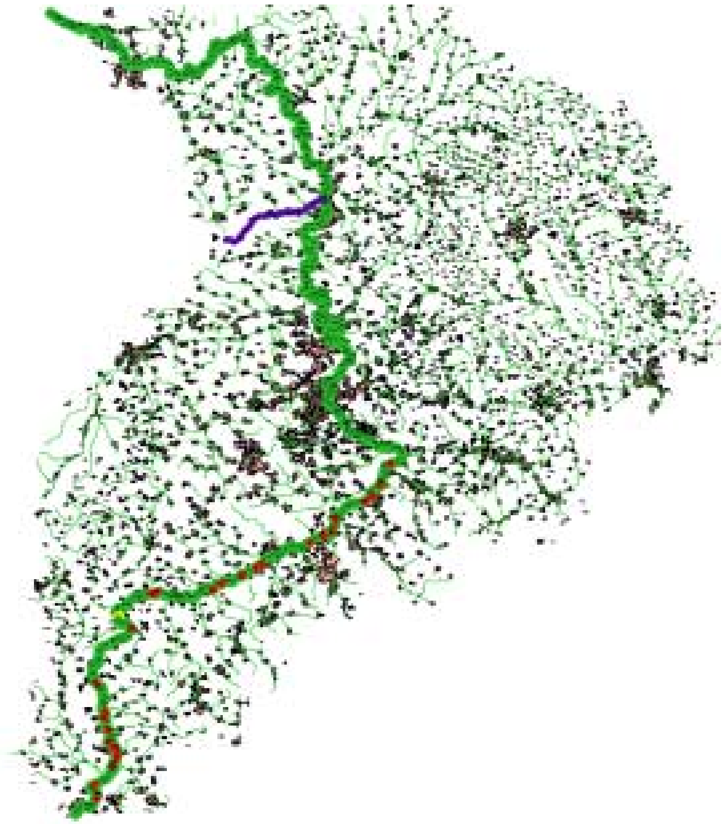


Fig 12 River sections of Neckar (green colored) and tributary Leinbach (purple colored) that where covered with mesohabitat mapping

The information collected in the field was transferred to the GIS by means of geo-referenced aerial photographs (see Fig 13).

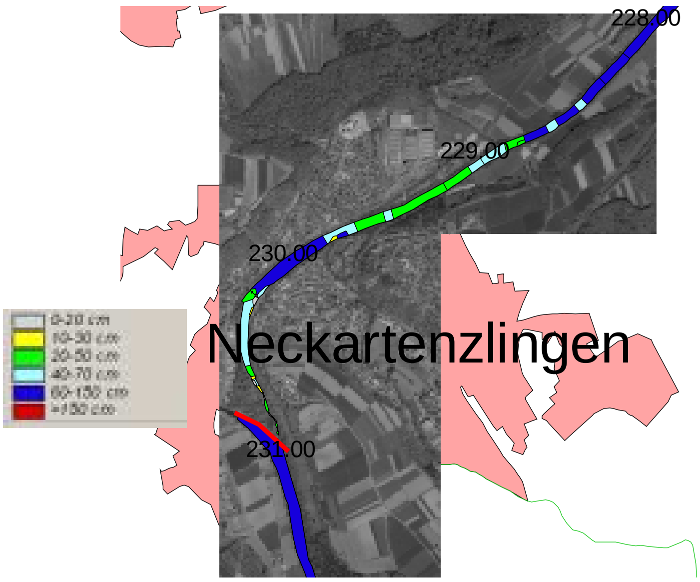


Fig 13 Transfer of mesohabitats to the GIS by drawing polygons and appointing collected field data (example water depth)

Fig 5 shows an example of an input table for the habitat model that is derived after this step. The hydromorphological habitat properties can now be linked with the expert knowledge defined by fuzzy rules, as given in Table 1, in order to calculate habitat suitability for selected fish species. In the Neckar basin habitat suitability was modelled for life stages of barbel (*Barbus barbus*). Since the adult life stage of this species is rheophilic (prefers medium to high flow velocities) and spawns in shallow areas with fast currents and gravel on the river bottom it is an it is a good indicator for several aspects of ecological river status.

First habitat simulations show, that habitat availability for barbel is limited and only little areas with highly suitable habitats for the adult fish are found. Spawning ground as precondition for reproduction have disappeared in long river sections. Fig 14 and Fig 15 show the example of the Neckar reach in and upstream of Tübingen.

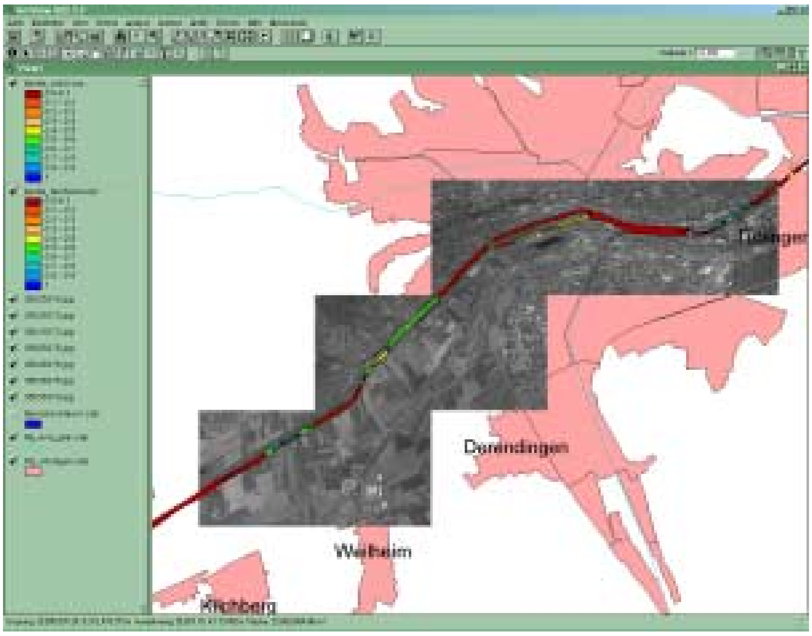


Fig 14 Simulated habitat suitability for barbel (B*arbus barbus*) life stage adult

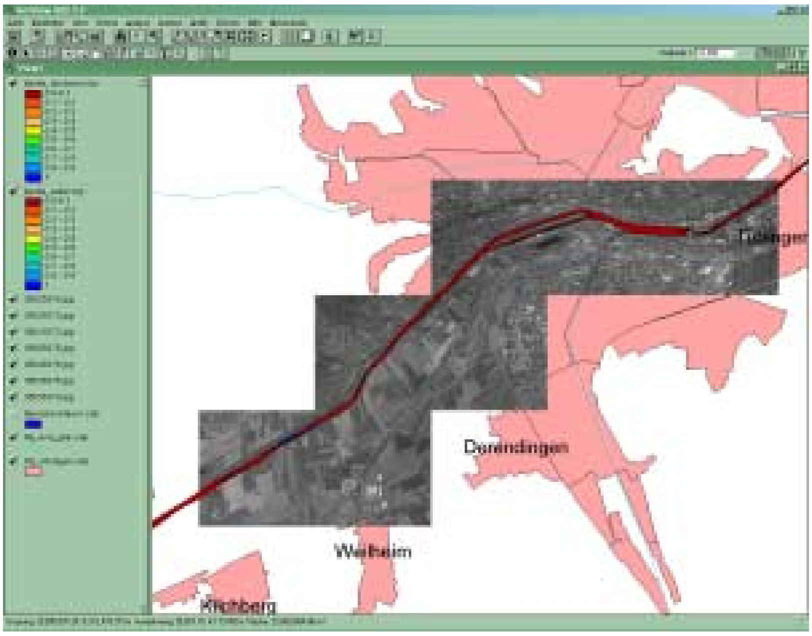


Fig 15 Simulated habitat suitability for barbel (B*arbus barbus*) in the spawning period

By combining the current model version with additional information on water quality (delivered by Partner AUTH), hydrology (USTUTT/IWS-SW) and on sediment introduction (UHOH/IBS) as described in chapter 2.2 the assessment of fish habitats as indicator for ecological status will be enabled..