



**IMPACT - Developing an integrated model
to predict abiotic habitat conditions and
biota of rivers for application in
climate change research
and water management**

First progress report

February 2011

Table of contents

1	Project outline	1
2	Modelling approach	3
3	Workplan and work packages	4
4	Work status	6
4.1	Website (task 7.1)	6
4.2	Kick-off meeting (task 6.1)	6
4.3	Data collection for catchment and dispersal models (tasks 1.1, 1.2, 3.1.1, 3.1.2)	8
4.4	Study site selection (task 2.1)	9
4.5	Channel planform prediction (task 2.3.2)	12
4.6	Fish dispersal model	13
4.7	Other tasks (1.3, 2.3.1, 3.4.1)	15
5	Prospects	16

Figures

Fig. 1: Spatial scales and pressures influencing river biota in a restored or natural „receiving“ reach.	2
Fig. 2: Flow chart of the integrated modelling approach. The different models, input parameters and interfaces are given.	4
Fig. 3: Gantt chart of the tasks which started or had to be completed in 2010.	6
Fig. 4: Treene candidate study reach.	10
Fig. 5: Célé candidate study reach.	11
Fig. 6: Sites sampled for fish dispersal modelling (genetic approach).	14

Tables

Tab. 1: Basic model runs or scenarios.....	8
Tab. 2: Research questions that can be investigated by comparing model runs or scenarios.	8
Tab. 3: Data availability in the three study catchments.	9
Tab. 4: Treene candidate study reach characteristics.	10
Tab. 5: Célé candidate study reach characteristics.	11

1 Project outline

European streams and rivers have been altered by man throughout ancient and modern times, from deforestation, erosion and alluvial deposition in the Mesolithic Age to straightening, damming, water pollution, and increase in impervious cover in the 19th and 20th century. These human alterations led to a severe degradation of stream ecosystems. Restoration of streams and rivers has become a widely accepted social objective in developed nations, which increasingly becomes established in law like in the European Water Framework Directive. Because this directive requires a good ecological status of all European rivers to be achieved by 2015, there is presently a strong demand for cost-effective restoration measures.

However, knowledge on the effect of restoration measures, which usually are applied at the reach-scale, is still incomplete. The few monitoring results indicate that many local restoration measures did not significantly improve the ecological status. It has been widely stated that processes at larger spatial scales may constrain the effect of local restoration measures, but information on the limiting effect of the remaining anthropogenic pressures at larger scales are missing, including the effect of Climate Change. There is statistical evidence that pressures at different spatial scales influence river biota and that pressures at larger scales may limit the effect of restoration measures. River restoration projects are often restricted to the reach-scale and water management can – at best – address pressures at the catchment scale. The remaining pressures at larger scales may limit the effect of restoration measures and river management actions at smaller scales. However, there are limited information on the governing processes and an urgent need for experiments and modelling to investigate how river network and catchment scale pressures constrain the effect of local restoration and management measures, especially in the light of Climate Change.

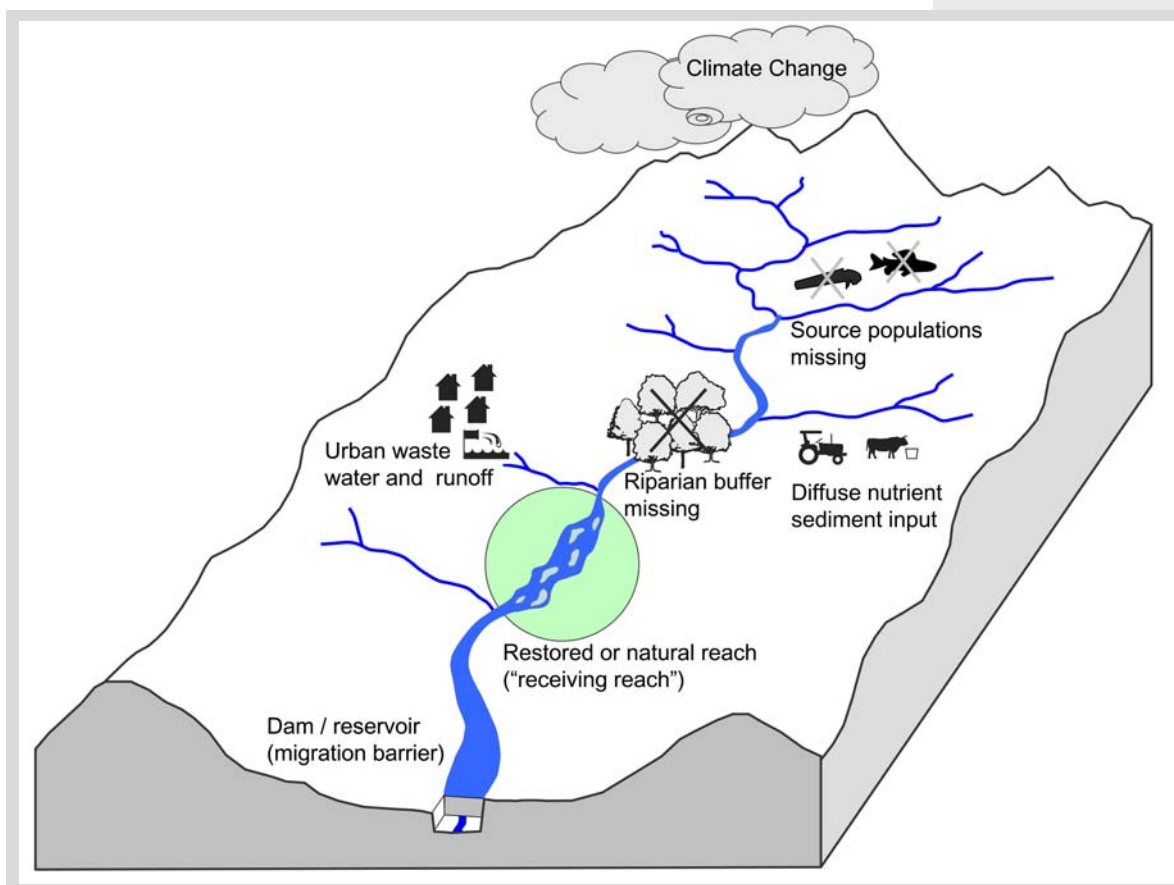
The basic idea of the IMPACT project is to assess the relative importance of anthropogenic pressures operating at different spatial scales, to identify the main bottlenecks for river biota, and to answer the following research questions:

- What can you expect from local reach-scale restoration given the remaining pressures on larger spatial scales?
- How important are discharge changes due to Climate Change compared to other anthropogenic pressures?
- Will Climate Change have a major influence on natural reference conditions?

A novel modelling approach will be developed to answer the research questions: Models for pressures at different spatial scales will be coupled to assess the effect of climate change on discharge and in turn on river morphology and stream biota compared to the impact of other anthropogenic pressures like water quality, hydromorphological alterations, and altered re-colonization potential. The project will focus on macroinvertebrates and fish and for the first time include dispersal models of aquatic taxa to predict temporal scales of restoration success and population recovery. Based on the predicted abiotic habitat conditions as well as the species pool available for colonization, the fish and invertebrate assemblage that can be expected in the “receiving reach” (Fig. 1) will be assessed. Based on current knowledge, the following spatial scales and pressures were selected, which are known to strongly influence river biota (Fig. 1):

- Global scale: Climate change
- Catchment scale: Discharge changes, water quality, nutrient input, (fine) sediment input
- River network scale: River fragmentation (dams, weirs), missing riparian buffers, missing source populations
- Reach scale: River training

Fig. 1: Spatial scales and pressures influencing river biota in a restored or natural „receiving“ reach.



The modelling approach will be applied and tested in three study catchments ranging from a perennial meandering lowland sand-bed stream in northern Germany to a intermittent gravel-boulder river in south Portugal. In each catchment, one restored or near-natural reach will be selected, where the effect of discharge changes on reach-scale channel morphology will be modelled and which is considered as a “receiving reach”, impacted by large scale pressures.

Since IMPACT considers the effect of other anthropogenic pressures on biota too, the project will also deliver important information for developing the second River Basin Management Plans in catchments where climate change will have minor effects only. The integrated model can help to more realistically assess the ecological status that can be reached in a water body by the selected set of measures, given the remaining anthropogenic pressures.

2 Modelling approach

In the IMPACT project, different models will be coupled to predict the abiotic habitat conditions and the species pool available for colonizing a restored or natural reach. Finally, the fish and invertebrate assemblage that can be expected in the study reach given the modelled abiotic and biotic conditions will be assessed (Fig. 2):

- A catchment rainfall/runoff model (e.g. SWAT) will be used to predict the effect of climate and land-use change on discharge, nutrient and fine sediment load.
- Different geomorphological approaches will be tested to predict the effect of discharge changes on channel pattern and dimensions (channel width, depth, slope).
- A 2D morphodynamic model will be used to predict the effect of discharge changes on the general bathymetry and channel dynamics. A 3D morphodynamic model will be used to model channel bathymetry in more detail and at a spatial scale relevant for invertebrates.
- Dispersal models for selected fish and invertebrate species will be developed to assess which species can reach the natural / restored reach within an engineering time scale, i.e. to describe the species pool available for colonizing the “receiving reach”.
- Different “habitat models” (using preference curves, niche models, more conceptual approaches) will be tested to describe the fish and invertebrate assemblage that can be expected in the reach given the modelled abiotic conditions and the (re-)colonization potential.

Input parameters which potentially will change due to environmental and climate change and which will be varied in the different model runs are underlined in Fig. 2. For some of the models, software packages are readily available (e.g. catchment model SWAT 2005, reach-scale habitat models, 2D hydro- and morphodynamic models like ADH and MIANDRAS), some have to be tested and modified (e.g. empirical equations and 1D morphological models to assess mean river morphology), some are presently developed (macroinvertebrate dispersal model) and will be adapted, and the fish dispersal model will be developed in IMPACT.

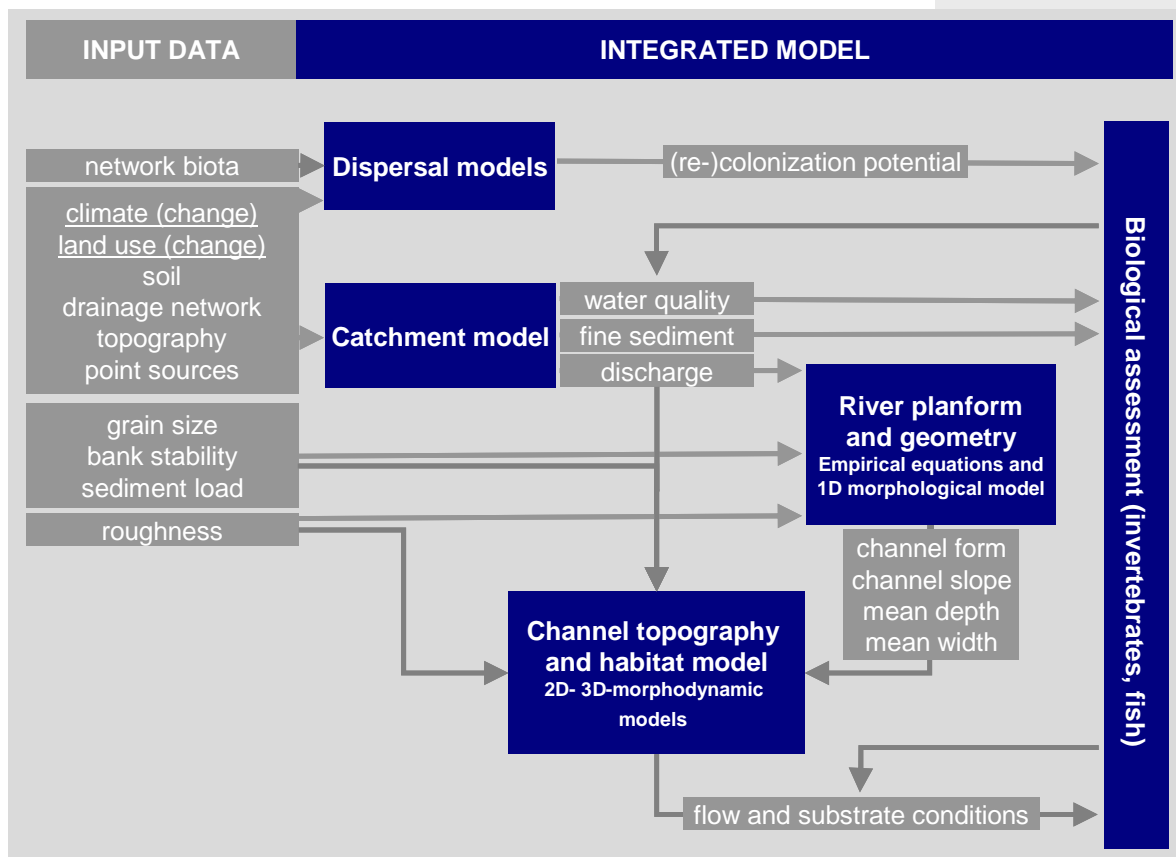


Fig. 2: Flow chart of the integrated modelling approach. The different models, input parameters and interfaces are given.

3 Workplan and work packages

In the first phase of the project (M1-M18), the catchment models will be set up and calibrated for the case-studies using the present-state data. Discharge will be modelled in all three study catchments. Moreover, water quality will be measured and modelled in the Treene catchment (M24). As far as possible, water quality will be assessed in the other two catchments based on the data available. Furthermore, a hydrodynamic model will be calibrated for one short restored or near-natural reach in each study catchment, to assess the potential effect of climate and environmental

change given the present channel topography. Moreover, the empirical equations and 1D morphological models will be tested and further developed, and the dispersal models will be developed.

In the second phase, once all models are available, they will be coupled and a sensitivity analysis will be carried out (M19-M36). Finally, the models will be used to assess the effect of climate and environmental change on abiotic habitat conditions and biota (ending 09/2013). Hence, the results of the IMPACT project will be available to help water managers to consider the impact of environmental and climate change as well as to better assess the effect of restoring natural channel dynamics and the re-colonization potential and to consider these aspects in the second River Basin Management Plans.

The five work packages and their objectives are listed below:

Work package 1: Catchment models

Setup and calibration of three catchment models with the eco-hydrological model SWAT for the three study catchments to model streamflow in all three and additionally water quality in the Treene catchment at the catchment outlet and at the study sites.

Work package 2: Reach-scale habitat models

Development of a reach scale habitat model - testing and adapting morphological models to predict stable channel topography and habitat conditions at the study reaches.

Work package 3: Development of dispersal models

Development of dispersal models for the three catchments for invertebrates and fish as well as development of a general approach to model fish dispersal.

Work package 4: Development of dispersal models

Integrated model simulations (catchment, reach scale river planform, geometry, topography, and habitat model, dispersal models) for each catchment / study reach.

Work package 5: Developing and applying methods to assess the effect of modelled abiotic conditions and re-colonization potential on biota

Validating methods to assess the effect on biota and assessing the effect of modeled habitat conditions and re-colonization potential on stream biota (invertebrates and fish)

The work and time schedule given in the project proposal was further developed and detailed before and during the kick-off meeting (see Appendix 1). The tasks which started or had to be completed in 2010 are given in Fig. 3.

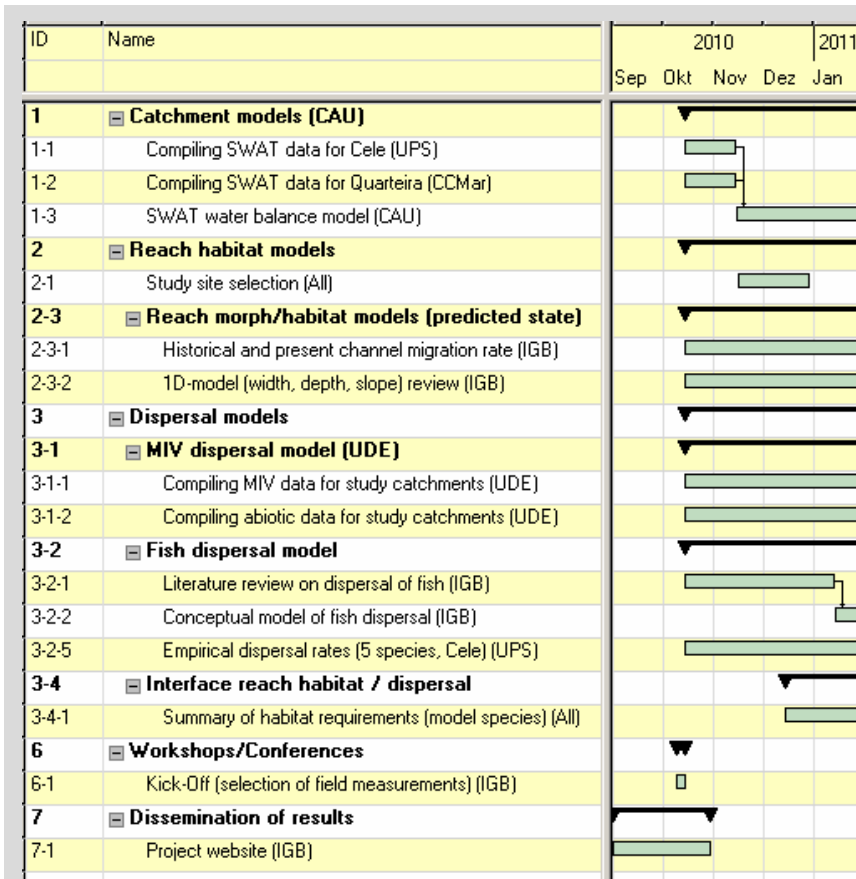


Fig. 3: Gantt chart of the tasks which started or had to be completed in 2010.

4 Work status

4.1 Website (task 7.1)

The website has been developed and is hosted at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (project coordinator):

<http://www.impact.igb-berlin.de/>

The objective was to give a short and concise summary of the projects basic idea, objectives, and research programme. A separate SMTP server was set up as an intranet since large data sets will be uploaded and exchanged and for security reasons.

4.2 Kick-off meeting (task 6.1)

The kick-off meeting was held in Berlin 07.-08.10.2010. The objective of the meeting was fivefold:

- to exchange information on the research background and approach in IMPACT,
- to identify model interfaces and to list the parameters (including information on the accuracy needed) which are the output of one model and the input for the following modelling steps,
- discuss the parameters to be mapped during the field campaign,
- select one near natural study site per study catchment
- develop and agree on the scenarios to be modelled.

Each partner presented their research background and approach in IMPACT.

In the project, there are many model interfaces and it is crucial to clarify in advance, which parameters are needed (including characteristics and accuracy) for the following modelling steps and if they can be provided. Since the objective of the project is to model invertebrate and fish assemblages and ecological quality from habitat composition, the needs of the ecologists define which parameters have to be mapped and modelled as well as the accuracy needed. Therefore, the partners agreed to discuss the model interfaces between the biological and abiotic models at the kick-off meeting first, and to clarify the data needs for the other model interfaces bilaterally after the kick-off (by the partners involved). The partners will finally agree on the parameters and the accuracy modelled after the model species have been selected and habitat requirements of these species have been identified and described.

The partners presented detailed information on the three study catchments:

The *Treene* naturally is a freely meandering lowland river. Presently, it is in a poor hydromorphological state and the catchment is dominated by agricultural land-use. Some short meandering reaches are present, one of which will be used as a “near-natural” study reach. A larger number of invertebrate and fish samples are available in the catchment (taken by regional authorities for monitoring purpose).

The *Célé river* naturally is a gravel-bed river. Land-use in the catchment is dominated by agricultural land-use and large parts are forested, especially in the downstream part. It is much less degraded compared to the *Treene* river and only few dams or weirs limit fish and invertebrate migration. In the main river, data on 10 biological sampling sites are available, and a larger number in neighbouring catchments.

The *Quarteira* naturally is a gravel-boulder river. It differs from the *Treene* and *Cele* since discharge is intermittent and excessive macrophyte growth occurs due to high nutrient inputs. Data on nine invertebrate and 5 fish samples are available for the *Quarteira* river and about 50 samples in the whole Algarve region.

The participants agreed to map a near-natural reach at the Treene river 07.-09.03.2011, as a kind of training, directly before the next workshop (10.-11.03.2011) at the University of Kiel, and to provide detailed information on candidate study sites before the next workshop.

The partners agreed on some model scenarios and further developed and detailed the research questions and hypothesis.

The coupled models will be run for several scenarios differing in respect to climate change and land-use conditions:

Code	Scenario description	Climate	Land-use
A	Baseline	Present	Present
B	Natural reference conditions (present)	Present	Nat. veg
C	Natural reference conditions (future CC)	Future	Nat. veg
D	Future conditions (climate change, CC)	Future	Present
E	Future conditions (land-use change)	Present or Future	Future

Tab. 1: Basic model runs or scenarios.

The following research questions can be investigated by comparing the modelled abiotic and biotic conditions of the scenarios:

Comparison	Research question
A/B	What can you expect from local reach-scale restoration given the remaining pressures on larger spatial scales under the present conditions?
B/C	Will Climate Change have a major influence on natural reference conditions?
A/D	How important is Climate Change for river biota compared to other large-scale pressures (catchment scale land-use and missing source populations)?
A/E	What will be the effect of future land-use changes on river biota compared to other pressures; will it be possible to compensate for Climate Change?

Tab. 2: Research questions that can be investigated by comparing model runs or scenarios.

4.3 Data collection for catchment and dispersal models (tasks 1.1, 1.2, 3.1.1, 3.1.2)

The data requirements of the catchment SWAT model has been discussed at the kick-off meeting. These data have been compiled for the Treene catchment and requested from regional authorities for the Célé catchment.

The data requirements of the dispersal models has been discussed at the kick-off meeting. These data have been requested from regional authorities for the Treene and Célé catchment.

The data that are already available, requested or not available are listed in Tab. 1 for each of the three study catchments.

Data	Treene	Célé	Quarteira
Climate (present)	available	available	requested
Climate (CC scenario)	requested	available	requested
Discharge (gauge nearby study sites)	available	available	requested
Land-use (CORINE, ATKIS)	available	available	requested
Soil	available	requested	requested
Digital Elevation Model	available	available	requested
River network	available	available	requested
Dams / weirs in river network	available	available	requested
Impoundments / reservoirs (river network)	available	available	requested
Water quality in river network	available	available	requested
Hydromorphological state in river network	available	not avail.	requested
Aerial photos (time series at study sites)	available	not avail.	requested
Invertebrate samples (river network)	requested	requested	requested
Fish samples (river network)	requested	requested	requested

Tab. 3: Data availability in the three study catchments.

4.4 Study site selection (task 2.1)

The effect of large scale pressures will be modelled in the three study catchments. In each study catchment, one restored or near-natural site has to be selected, where the effect of discharge changes on reach-scale channel morphology will be modelled and which will be considered as the “receiving reach”, impacted by large scale pressures (Fig. 1).

Candidate study sites were pre-selected based on the following criteria:

- Near-natural or restored sites with natural morphodynamics (channel form in equilibrium state and adjusted to natural controls like discharge and sediment supply).
- Located in the middle or lower part of the catchment.

- Reach-scale data on channel morphology, channel evolution, and biota already available as far as possible.
- Reach length about 300m (including several meanders in naturally meandering streams).
- No major tributary entering the reach (reach-scale hydrodynamic and morphodynamic models assume steady flow conditions).

In the Treene and Célé catchment, candidate study reaches have already been identified (Tab. 4, Fig. 4, Tab. 5, Fig. 5).

Study catchment:	Treene
Candidate study reach name:	Sollerup
Location (lat/long):	54°35'2.65"N, 9°20'22.10"E
Catchment size:	~270 km ²
Channel width and depth:	~10m (depth unclear due to high flows)
Dominant bed material:	Sand, gravel locally
Dominant bank material:	Cohesive material

Tab. 4: Treene candidate study reach characteristics.



Fig. 4: Treene candidate study reach.

Study catchment:	Célé
Candidate study reach name:	Moulin Vieux
Location (lat/long):	44° 35' 8.58" N, 1° 50' 2.59" E
Catchment size:	~1194 km ²
Channel width and depth:	~20m, ~45cm
Dominant bed material:	Gravel
Dominant bank material:	Gravel overlain by cohesive material

Tab. 5: Célé candidate study reach characteristics.



Fig. 5: Célé candidate study reach.

4.5 Channel planform prediction (task 2.3.2)

Discharge and sediment load changes due to environmental and climate change potentially affect channel planform (meandering, braiding) and dimensions (width, depth, sinuosity, slope). Moreover, stable channel-width is a necessary input for the meander migration model MIANDRAS. In principal, there are three different approaches to assess stable channel planform and dimensions of alluvial channels: empirical equations, regime models, and fully physically based models. Based on a literature review, information on the existing approaches and models have been compiled. In the following tasks, model accuracy will be assessed and appropriate approaches will be selected to predict changes of channel planform and dimensions in the IMPACT project.

Empirical equations

Empirical hydraulic geometry equations are derived from observed channel form, i.e. channel width, depth, and slope. These parameters are considered dependent variables which adjust to driving or independent variables. Bankfull discharge is the most important geomorphic control which is considered in all hydraulic geometry equations (e.g., Leopold and Maddock 1953). Other driving variables which are considered in some (but not all) hydraulic geometry equations are: river bed grain size (Bray 1982, Andrews 1984), silt/clay content of bank material (Shields 1996, Schumm 1971), and riparian vegetation (Hey and Thorne 1986, Andrews 1984). The only empirical equations derived for streams in Central Europe have been developed by Harnischmacher (2002). Hydraulic geometry equations are a practical tool to predict the channel form of rivers. However, as any other empirical relation, they are (a) restricted to the region they were developed in and transferability is limited to streams which are similar in respect to other driving variables which are not considered in the empirical equation and (b) restricted to the range of values of the observed channel forms. Moreover, they are purely empirical and give no insight in the governing processes.

Regime models

In regime models, it is assumed that channel geometry adjusts to the imposed water discharge, sediment load, and sediment properties (e.g. grain size distribution). A set of equations, which usually includes equations on continuity, flow resistance, and sediment transport, is numerically solved to calculate channel geometry of stable alluvial channels (Chang 1979, 1980; Yang et al. 1981; White et al. 1982; Millar and Quick 1993, 1998; Millar 2005, Eaton et al. 2004, Eaton 2006). Typically, the input data include formative discharge (e.g. mean annual flood), flow resistance (e.g. Manning's n), grain size distribution, sediment load, and in some models bank strength. The model output includes bankfull channel width and depth as well as channel slope. However, since there are more unknown dependent variables than equations available for solution in all these

models, the system of equations is indeterminate and there are infinite possible solutions. To overcome this problem, an extremal hypothesis is used to choose one unique optimum solution. According to the extremal hypotheses, rivers develop towards a stable channel form (dynamic equilibrium) where a specific parameter is maximised or minimised. Such an optimality criterion is, among others, stream power, whereby rivers will develop towards the minimum stream power which is necessary to transport the imposed water and sediment discharge.

Stream width predicted by some regime models is invariably smaller than observed width in many regime models (Griffiths and Carson 2000; Valentine et al. 2001; Shields et al. 2003). However, by including an equation on bank stability as an explicit constraint on the optimum solution, the bias can be substantially reduced and regime models more precisely replicate the observed empirical hydraulic geometries of natural streams (Eaton et al. 2004). Nevertheless, the extremal hypotheses is often considered a workaround which lacks a physical basis (Griffiths 1984; Ferguson 1986; Darby and Thorne 1995; Mosselman 2000).

Fully physically based models

There are only few fully physically based approaches to assess channel planform (e.g. Crosato and Mosselman 2009). However, mean channel width of the stable channel has to be known in advance since it is an input parameter for the models, and hence, they can only be used in combination with empirical or regime approaches to assess the effect of discharge changes on channel planform.

The review will be finished in February 2011 and results will be presented at the second project meeting in March 2011.

4.6 Fish dispersal model

Task 3.2.1: Literature review on dispersal of fish

The existing literature on fish dispersal was reviewed with a special focus on the spatio-temporal patterns of fish movements, environmental factors triggering and influencing dispersal, ontogenetic habitat shifts, home ranges, and the dispersal (swimming) ability of fish. It is obvious that fish populations comprise of a stationary component and a mobile component which is decisive for dispersal and individual exchange between populations. Main external factors influencing dispersal are habitat quality (e.g. cover), migrations barriers (e.g. weirs), flow conditions and water temperature.

Task 3.2.2: Conceptual model of fish dispersal

The intended model is based on a heterogeneous diffusion that can be easily expressed as the combination of two superimposed normal distributions (representing the stationary and the mobile component of a fish population). The incorporation of a habitat specific factor, which affects the

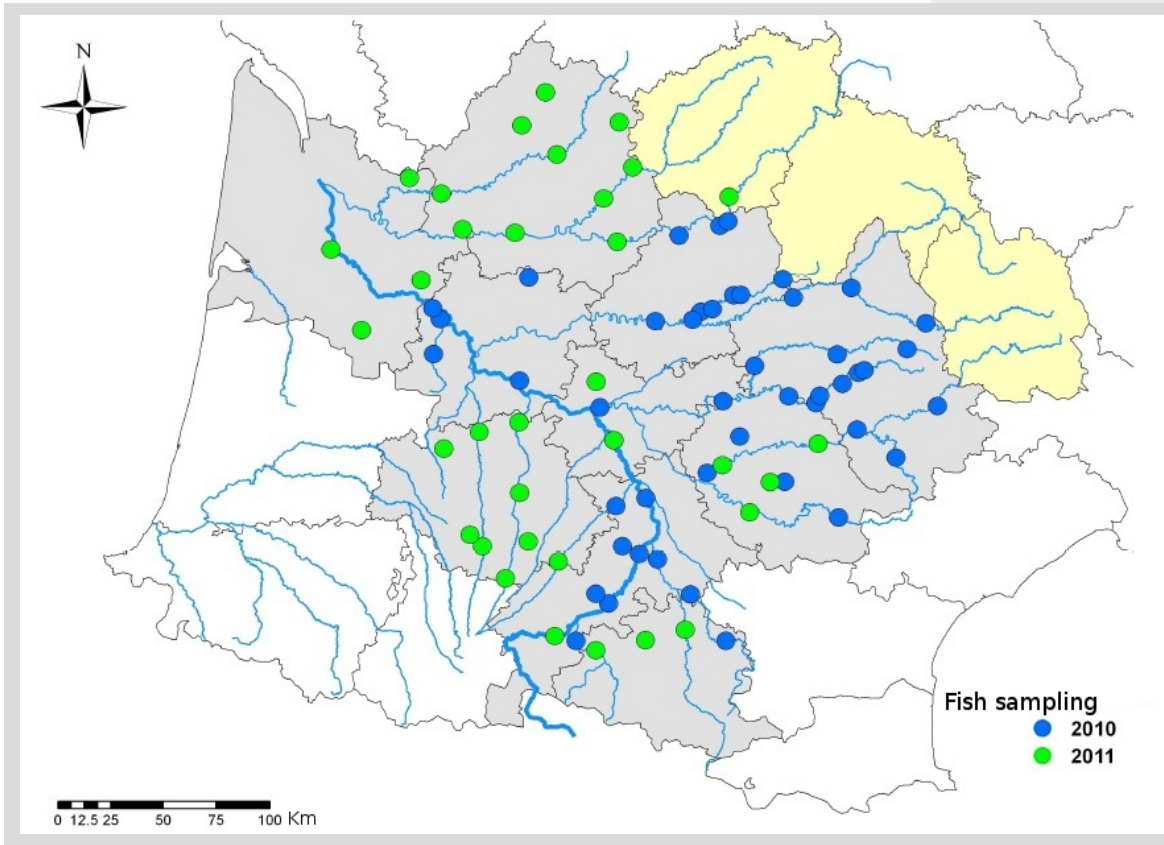
diffusion function, and of migration barriers (e.g. weirs) in the catchment should complement this mathematical diffusion based approach. The modelling approach itself is conducted with GIS-Software products (ArcGIS and GRASS GIS) and is therefore a scientific novelty. The main part of the calculations will be based on the Raster-GIS approach, where the river will be segmented into raster cells (pixels) of approximately 10 x 10 m. The heterogenous diffusion-dispersal function will be applied in all raster cells of the river network. Thus, the emigration and immigration of each cell can be calculated and the spatial distribution of selected fish can be displayed for various explicit time intervals.

Task 3.2.5: Empirical dispersal rates

During the 2010's summer, electric fishing was carried out at 47 sites spread along the Garonne drainage basin (South-western France, Fig. 6).

A total of 4,007 individuals of 6 species (*Squalius cephalus*, *Leuciscus leuciscus*, *Gobio gobio*, *Phoxinus phoxinus*, *Barbatula barbatula*, *Parachondrostoma toxostoma*) were sampled (i.e. collection of pelvic fins). Currently, all the molecular analysis necessary are performed to establish a microsatellite genetic database. To date, DNA from about 1,800 individuals has been extracted. Some of these samples (~300/1800) have also been genotyped, while some others (~1000/1800) are ready-to amplify microsatellite markers.

Fig. 6: Sites sampled for fish dispersal modelling (genetic approach).



4.7 Other tasks (1.3, 2.3.1, 3.4.1)

Task 1.3: SWAT water balance model

For the Treene catchment, data were compiled and the project partners (catchment modellers, morphologists, and ecologists) discussed and agreed on common catchment borders, river network, and spatial data projection. This is essential to ensure that all project partners use the same or comparable data for their models and to avoid problems in latter stages of the project when model-output data will be exchanged. Moreover, data pre-processing for the Treene SWAT model started.

Task 2.3.1: Historical and present channel migration rates

Channel migration rates are a necessary input for the 2D morphodynamic meander migration model MIANDRAS, which will be used to assess the changes in channel planform caused by discharge changes. Meander migration in MIANDRAS strongly depends on the migration coefficients E_u and E_n that are used to calibrate the model. They can not be determined on the basis of flow and eroding bank material characteristics alone since modelled migration rates depend on specific model choices (e.g. numerical filter used). They rather have to be assessed based on historical migration rates.

For the Treene river, a time series of air photos was compiled from regional authorities (1953, 1974, 1985, 1997, 2008). These data will be ordered to assess the historical channel migration rates at the study site.

Task 3.4.1: Summary of habitat requirements (model species)

Since the objective of the project is to model invertebrate and fish assemblages and ecological quality from habitat composition, the needs of the ecologists define which parameters have to be mapped and modelled as well as the accuracy needed. Therefore, the partners discussed the model interfaces between the biological and abiotic models at the kick-off meeting. The following model output parameters were identified being important descriptors for the habitat conditions: Discharge, flow velocity (2D depth averaged), shear stress, substrate, fine sediment, water quality, aquatic vegetation. The objective of the task that started in December 2010 is to summarize and describe the habitat requirements of the model species in respect to these parameters. These information will be compiled from literature and in addition, habitat needs will be assessed by analyzing existing data on the presence/absence of the species and abiotic data.

Macroinvertebrates: Literature concerning the dispersal capacities of macroinvertebrates has been compiled and reviewed partially. As there is thematical overlap with ongoing projects of the partner developing the dispersal model for invertebrates (University of Duisburg-Essen), a common database will be build including information regarding the dispersal of macroinvertebrates. A pre-selection of model species has been conducted

based on certain criteria and present occurrence of species in the study area of the Treene river.

The model data set for the habitat model has been successfully compiled. First analyses on habitat preferences of macroinvertebrates are performed at present. The habitat preferences identified in this analysis will be used to predict the absence/presence of the species and to identify source populations at the catchment scale. The information on source populations and dispersal rates will be used in the dispersal model to predict which species probably can reach the “receiving river reach” (natural or restored study site) (Fig. 1) in an engineering time scale.

5 Prospects

The progress report covers just the first four month of the IMPACT project. All project partners filled the Post-Doc and PhD positions prior to the start of the project in September 2010 (except CCMar) and started their work. The main objectives of the tasks, which started or had to be completed in 2010 were reached. The national funding contracts and sub-contracts have been signed or will most probably be signed in February 2011, except the contract for the Portuguese partner Centre of Marine Sciences of Algarve (CCMar). Therefore, it was not possible for CCMar to fully start their work and it is unclear if they can participate in the second workshop in March 2011. Fortunately, there is no need to adapt the work or time schedule since CCMar models the abiotic/biotic interactions (Fig. 2) and the other partners do not necessarily need the input of CCMar to start or finish most of the upcoming tasks (Appendix 1). However, important aspects (interaction model, Southern European model catchment) would be missing in the integrated model and case-studies if CCMar will not be funded. Furthermore, data are needed in the next month to build the SWAT model for the Portuguese catchment (Quarteira). Besides the funding problems in Portugal, there are presently no further foreseeable problems and no need to adjust the work or time schedule.

Acknowledgements

This project is carried out with financial support from the Commission of the European Communities, specific RTD programme “IWRMNET”. It does not necessarily reflects its views and in no way anticipates the Commission’s future policy in this area.

This project is partly funded by the German Federal Ministry for Education and Research (grant number 02WM1134).

References

- Andrews, E. D. (1984) Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. *Bulletin of the Geological Society of America*, 95, 1225-11231.
- Bray, D. I. (1982) Regime equations for gravel-bed rivers. In: Hey, R. D., Bathurst, J. C. and Thorne, C. R. (eds.), *Gravel bed rivers*. Chichester: Wiley, 517-542.
- Chang, H. H. (1979) Minimum stream power and river channel patterns. *Journal of Hydrology*, 41, 303-327.
- Chang, H. H. (1980) Geometry of gravel streams. *Journal of the Hydraulics Division*, 106 (9), 1443-1456.
- Crosato, A. and Mosselman, E. (2009) Simple physics-based predictor for the number of river bars and the transition between meandering and braiding. *Water Resources Research*, 45, W03424.
- Darby, S. E. and Thorne, C. R. (1995) Effect of bank stability on geometry of gravel rivers. *Journal of Hydraulic Engineering*, 121 (4), 382-384.
- Eaton, B. C. (2006) Bank stability analysis for regime models of vegetated gravel bed rivers. *Earth Surface Processes and Landforms*, 31, 1438-1444.
- Eaton, B. C., Church, M., Millar, R. G. (2004) Rational regime model of alluvial channel morphology and response. *Earth Surface Processes and Landforms*, 29, 511-529.
- Eaton, B. C., Church, M., Millar, R. G. (2004) Rational regime model of alluvial channel morphology and response. *Earth Surface Processes and Landforms*, 29, 511-529.
- Ferguson, R. I. (1986) Hydraulics and hydraulic geometry. *Progress in Physical Geography*, 10, 1-31.
- Griffiths, G. A. (1984) Extremal hypotheses for river regime: an illusion of progress. *Water Resources Research*, 20 (1), 113-118.
- Griffiths, G. A. and Carson, M. A. (2000) Channel width for maximum bedload transport capacity in gravel-bed rivers, South Island, New Zealand. *Journal of Hydrology (New Zealand)*, 39 (2), 107-126.
- Harnischmacher, S. (2002) *Fluvialmorphologische Untersuchungen an kleinen, naturnahen Fließgewässern*. PhD-thesis, Geographisches Institut Ruhr-Universität Bochum, Bochum, 304.
- Hey, R. D. and Thorne, C. R. (1986) Stable channels with mobile gravel beds. *Journal of Hydraulic Engineering*, 112 (8), 671-689.
- Leopold, L. B. and Maddock, T. Jr. (1953) The hydraulic geometry of stream channels and some physiographic implications. *Geological Survey Professional Paper 252*, Washington, D.C, 16.
- Millar, G., Quick, C. (1998) Stable width and depth of gravel-bed rivers with

- cohesive banks. *Journal of Hydraulic Engineering*, 124, 1005-1013.
- Millar, R. G. (2005) Theoretical regime equations for mobile gravel-bed rivers with stable banks. *Geomorphology*, 64, 207-220.
- Millar, R. G., Quick, M. C. (1993) Effect of bank stability on geometry of gravel rivers. *Journal of Hydraulic Engineering*, 119, 1343-1363.
- Mosselmann, E. (2000) River width adjustment: 1. Processes and mechanisms – discussion. *Journal of Hydraulic Engineering*, 126 (2), 159-160.
- Schumm, S. A. (1971) Fluvial geomorphology. The historical perspective. In: Shen, H. W. (ed.), *River mechanics*. Volume 1. Fort Collins, 4-1-4-30.
- Shields, F. D. (1996) Hydraulic and hydrologic stability. In: Brookes, A. and Shields, F. D. (eds.), *River channel restoration. Guiding principles for sustainable projects*. Chichester: Wiley, 23-74.
- Shields, F. D., Copeland, R. R., Klingeman, P. C., Doyle, M. W., Simon, A. (2003) Design for stream restoration. *Journal of Hydraulic Engineering*, 129 (8), 575-584.
- Valentine, E. M., Benson, I. A., Nalluri, C., Bathurst, J. C. (2001) Regime theory and the stability of straight channels with bankfull and overbank flow. *Journal of Hydraulic Research*, 39 (3), 259-268.
- White, W. R., Bettess, R., Paris, E. (1982) An analytical approach to river regime. *Journal of the Hydraulics Division*, 108 (10), 1179-1193.
- Yang, C. T., Song, C. C. S., Woldenberg, M. J. (1981) Hydraulic geometry and minimum rate of energy dissipation. *Water Resources Research*, 17 (4), 1014-1018.

Appendix 1: Detailed work and time schedule (version January 2011)

