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„Development of a web-based spatial decision support system (WSDSS) for river restoration: a framework contributing to the implementation of the EU Water Framework Directive (WFD) in Austria”

vorgelegt von

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Preface and acknowledgements

For me as a landscape ecologist and scientist strongly related to river systems and fish in the last years Geographical Information Science & Systems have increasingly become a part of my everyday work within the last years. Retrospectively therefore it was a crucial step for me to start the UNIGIS MSc studies at the Paris-Lodron University in Salzburg, especially to be up to date with recent developments of spatial management related to environmental issues at both, a global and European scale. Therefore I want to thank the whole UNIGIS team for the good and co-operative support throughout the whole time of my studies, and the high quality of information that was offered to us. Especially I want to thank Cornelius Roth, Michael Fally and Erika Blaschke for their very friendly and obliging efforts to guide me to the end of my studies. Special thanks also go to Josef Strobl, the “heart” of the UNIGIS-movement, assessor of this thesis. I also want to thank Stefan Schmutz, the project leader of the MIRR project (“Model based Instrument for River Restoration”) forming an important basis for the work presented here, for co-supervising this thesis. Mainly the challenging spatial analyses of different available datasets on multiple ecologically relevant scales that had to be resolved within the MIRR project were the reason for beginning my UNIGIS studies at Salzburg. Furthermore I want to acknowledge Arnulf Christl, member of the Where Group, for supporting the development of the framework for the Decision Support System based on open source tools. Special thanks go also to my partner Bettina and my son Alwin, who had to spend many weekends without my active presence within the last two and a half years due to my studies, especially for their support and motivation. I also want to thank my mother Ulrike Kurahs who laid the foundation for my ability to consequently conduct and manage self directed learning efforts. Special thanks also go to my father Dietmar Zitek for all the hours that he spent with me and brother in nature, which formed the basis for my unremitting interest in keeping and restoring good relationships between humans and their surrounding natural, cultural and social landscapes. I strongly believe that only a holistic understanding of our existence in time and space allows us to develop a deeper and respectful contact to everything that exists. Geographical Information Science & Systems, when creatively used, due to their ability to structure, present and communicate all types of information related to a spatial object might be able to significantly contribute to connecting people with people and people with their physical and biological environment, an indispensible basis for a real sustainable development and liveable future.

Statement of originality

Hereby I state, that this thesis is the product of my own work, and that any ideas or work of other people are fully referenced in accordance with standard reference practices. The work has not been submitted previously for any other degree, nor is it presently under consideration by any other degree awarding body.

Vienna	30. December 2008	
Location	Date	Signature

Abstract

The EU Water Framework Directive (EU-WFD) currently represents the main driving force of river restoration across Europe. The focus of the WFD is on whole river catchments, the natural hydrologic unit of rivers, a scale that has never been tackled during past river restoration efforts in Austria. The central target is the restoration of the ecological status of rivers measured by four organism groups (algae, fish, macrozoobenthos and macrophytes) till 2015, latest till 2027 under certain circumstances. Besides ensuring the ecological efficiency of restoration measures, the WFD requires the integration of the public and an economically commensurable restoration. Sound ecological knowledge and strategic instruments and decision support for a timely, ecologically successful and economically optimized implementation of the WFD are therefore strongly needed to support politicians, decision makers and planners within the complex process of river restoration at catchment scales. Up to now existing tools that could be accessed via the web by the public (Water Information System Austria – WISA or Water Information System Europe – WISE) only allow to select and view data, but do not allow any further interaction with the existing GIS data. Within this thesis therefore a framework for a Web based Spatial Decision Support System (WSDSS) allowing to model and share the results of different river restoration strategies to enhance the ecological status of rivers for fish created by multiple users is being developed. The proposed WSDSS allows for removing single and multiple pressures from 500 m river segments and the calculation and aggregation of the ecological effects and costs on different spatial scales relevant for the EU-WFD (water bodies, catchments, national planning areas). Different scenarios can be created by multiple users via the WWW using an HTML interface, and the results are stored within a server-side database and can be shared with other users. Due to their free availability, the presented WSDSS framework is based on available open source technology under free license. The integration of latest multi-scale river ecological knowledge is assured by the strong relatedness of this thesis to the MIRR project (“Model based Instrument for River Restoration), a project that has been run at the University of Natural Resources and Applied Life Sciences (BOKU) in Vienna between 2005 and 2008 aiming at the development of a strategic instrument to identify hydro-morphological restoration measures for rivers based on comprehensive multivariate analyses of fish/pressure relationships. Finally future steps needed to implement such a system based on the results of the MIRR project for the whole Austrian river network are described, and the advantages and limitations of the presented approach are discussed.

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Glossary & Abbreviations

AMap 3D Austrian map 3 D 1:50 000, available on CD

ANF/KLF Ausweisung naturnaher Flussstrecken/Kulturlandschaftsforschung

BEV Bundesamt für Eich- und Vermessungswesen

BMLFUW Bundesministerium für Land- und Forstwirtschaft, now called Lebensministerium (Ministry of Life)

BOKU Universität für Bodenkultur, Wien (University of Natural Resources and Applied Life Sciences, Vienna)

CGI Common Gateway Interface

CORINE Coordination of Information on the Environment

digHAÖ Digitaler hydrologischer Atlas Östereichs - Digital hydrological atlas of Austria

DSS Decision Support Systems

ERM Entity Relationship Model

EU-WFD EU Water Framework Directive

Fish ecological river regions River regions characterized by typical dominant fish species and fish communities (from upstream to downstream: Epirhithral, Metarhithral, Hyporhithral, Epipotmal, Metapotamal, Hypopotamal)

GEP Good Ecological Potential, is the ecological situation that has to be established at heavily modified water bodies

GIS Geographic Information Systems

GML Geography Markup Language, OGC conform XML grammar to express geographical features and exchange geographical data over the WWW

GNU Gnu is not UNIX, free computer operating software developed by the GNU project

GPL (GNU) General Public License

IHG Institut für Hydrobiology und Gewässermanagement (Institute for Hydrobiology and Aquatic Ecosystem Management), BOKU

HTML Hypertext Markup Language

HTTP Hypertext Transfer Protocol

IVFL Institut für Vermessung, Fernerkundung und Landinformation **(**Institute of Surveying, Remote Sensing and Land Information), BOKU

HQ1, HQ1,5 und HQ2,33 Flow rates at flood events of different annularity

Hydropeaking Human induced artificial short time changes of the natural discharge regime related to the pulsed production of energy

Residual flow water remaining in river sections where water is abstracted for the purpose of energy production

SDSS Spatial Decision Support System

SINUS Spatial Indicators for Landuse Sustainability

SQL Structured Query Language, a database language used to process data within relational databases

MAF Mean Annual Flow

MALF Mean Annual Low Flow

MIRR Model based Instrument for River Restoration (a project run at the BOKU)

MSS Management Support Systems

NÖMORPH Name of a structural river mapping project in Lower Austria

NPA National Planning Area, an administrative spatial unit fir the implementation of the WFD

OGC Open Geospatial Consortium

OGR OpenGIS simple features reference implementation

Open source/free (GIS) software the software code is open, and can be changed/a free license allows for changing, copying and re-distributing the (GIS) software freely

PHP Hypertext Preprocessor

SLD Styled Layer Descriptor, XML scheme of the OGC

SOS Sensor Observation Service, a web interface for processing real-time sensor data

UBA Umweltbundesamt

Water abstraction Water is abstracted for the purpose of energy production

WCS Web Coverage Service, OGC standard for processing raster data related information over the WWW

WFD Water Framework Directive

WFS Web Feature Service, OGC standard to process vector data related information over the WWW

WISA Water Information System Austria

WISE Water Information System Europe

WMC Web Map Context documents, XML documents that contain all information need to display a set of maps for a selected area and size over the WWW

WMS Web Map Service, OGC standard to create and display maps over the WWW

WSDSS Web based Spatial Decision Support System

WWW World Wide Web

XML Extensible Markup Language, represents a language used to exchange hierarchically structured information between computers, mainly over the WWW

1 Introduction

1.1 Goal and background of - and need for - this thesis

The main goal of this thesis is to develop a framework for a Web based Spatial Decision Support System (WSDSS) for supporting the development of river restoration strategies. Due to their free availability, open source/free GIS tools and technology are used to develop this decision support framework supporting a multi-user decision support platform via the web. The integration of latest multi-scale river ecological knowledge is assured by the strong relatedness of this thesis to a project that has been run at the University of Natural Resources and Applied Life Sciences (BOKU) in Vienna between 2005 and 2008 – the MIRR project ("Model based Instrument for River Restoration, http://mirr.boku.ac.at, 26.12.1008). By order of the Austrian Ministry of Life, being responsible for the implementation of the EU-Water Framework Directive (WFD 2000), a strategic instrument to identify hydro-morphological restoration measures for running waters to enhance the ecological status of rivers in Austria measured by fish was developed at the Institute of Hydrobiology and Aquatic Ecosystem Management (IHG) at the BOKU based on comprehensive multivariate analyses of fish/pressure relationships using data from Lower Austria (SCHMUTZ et al. 2008). The identification and quantification of the effects of the main relevant pressure types allowed the development of flow charts for guiding restoration activities at multiple scales. Up to now no tool exists allowing an automated evaluation of the effects of different restoration strategies on the ecological status of the so called water bodies, the relevant scale for action and reporting with regard to the EU-WFD. Furthermore existing web based GIS tools related to rivers and the implementation of the EU WFD in Austria and on an EU level do not allow any interaction with the data, and are therefore not well suited for decision support (for example the Water Information system of Austria "WISA"[1], or the Water Information System of Europe "WISE"[2]). The following parts of the MIRR project conducted under the supervision of the author of this thesis as work package leader (WP 1, SCHMUTZ et al., 2007), and can be seen as part of this thesis, although mainly content relevant for the development of the WSDSS framework is reproduced here.

- Literature research and definition of relevant parameters to model fish/pressure relationships on multiple spatial and temporal scales (ZITEK 2006)

[1] http://wisa.lebensministerium.at/, 26.12.2008
[2] http://water.europa.eu/, 26.12.2008

- Investigation and collection of the available GIS datasets in Austria, that might be of relevance for the MIRR project, and matching of criteria per pressures type with the availability of pressure data, a full list of the criteria finally assessed within the MIRR project can be found in SCHMUTZ et al. (2007)
- Development of geographical data analysis strategies, geographical data analysis and guidance and supervision of the whole (abiotic) data gathering process of the project (POPPE und ZITEK 2006).

Although the analysis results of the MIRR study were evaluated within a case study, within that spatial explicit recommendations for restoration measures together with a prioritization scheme were developed, there is no tool available to simulate the outcome of different restoration strategies on the level of surface water bodies (detailed and basic), catchments or national planning areas, which represent the most important spatial scales for the implementation of the EU-WFD. Although the MIRR project delivered a strategic scheme for river restoration based on quantitative criteria, it did not directly relate this scheme to water bodies or catchments. The DSS developed within this thesis will be based on the ecologically relevant criteria that were identified within the MIRR project, and will allow for a spatially explicit analysis of the outcome of different restoration strategies on spatial scales relevant for the EU-WFD (surface water bodies, catchments and national planning areas). The web based decision support framework presented here was not part of the MIRR project, but centrally builds up on the results of the MIRR project and represents a first innovative step towards a decision support system supporting a collective decision support via the www. Following the structure of the development of general Management Support Systems (MSS) described by TURBAN et al. (2004) this master thesis contains the planning, analysis and design phases of the development of a MSS, but not the implementation of a prototype (Fig. 1). The general need for decision support was the reason, why the Ministry of Life charged the IHG with the development of a model based instrument for river restoration. The development of the presented WDSS can be seen as consequent continuation of the MIRR project, making added value of the valuable results by making them available for a collaborative spatial explicit decision support via the www.

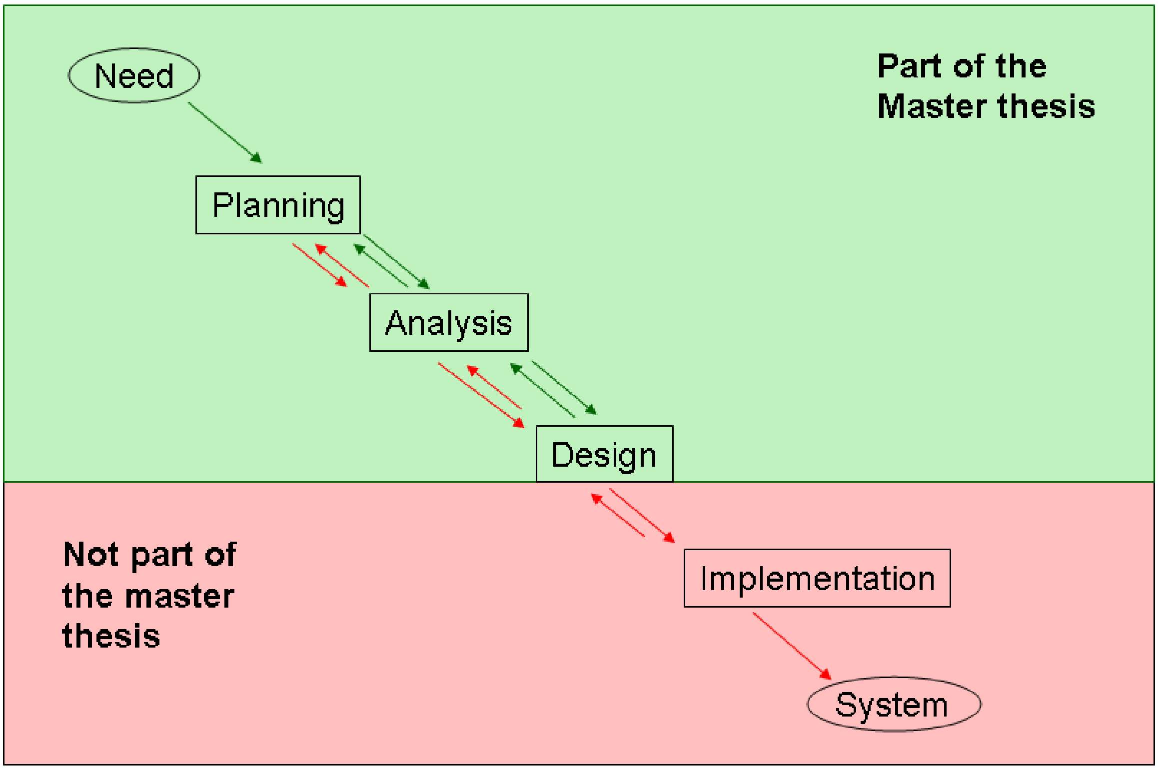

Figure 1: General structure of the development of a Management Support System in relation to this thesis, redrawn from TURBAN et al. (2004).

1.2 The EU Water Framework Directive

In 2000 the European Union launched the Water Framework Directive (WFD, http://www.euwfd.com) (WFD, 2000). The main focus of the WFD is the management of river basins, the natural geographical and hydrological unit following modern river restoration principles by developing and implementing actions ameliorating impacts at entire catchments of large rivers, expressly to enhance natural attributes that have been measurably degraded (STANFORD und WARD 2001). One of the key objectives of the WFD is to achieve "good ecological status" of running waters by 2015 being measured by fish, macrozoobenthos, algae or macrophytes. The good ecological status thereby allows only "slight changes in species composition and abundance from the type-specific communities attributable to anthropogenic impacts on physicochemical and hydro-morphological quality elements" (WFD 2000). Generally, for a successful restoration of the ecological status multiple spatial and temporal scales (GEORGE und ZACH 2001; FEIST et al. 2003; ALLAN 2004; ZIEMER 1997) together with social and natural science integration (MACLEOD et al. 2007) have to be considered. Furthermore the WFD requires the assessment of restoration measures with regard to their economic commensurability, they must not be "disproportionately expensive" (WFD 2000). The use of spatial data in reporting and public participation at various stages in the planning cycle is explicitly required by the WFD, and GIS has become a key technology for the implementation of the WFD (EC 2003). Especially web based client/server are offering a variety of opportunities that might significantly help to fulfil the requirements of the WFD and to support a successful implementation of the WFD (DIETRICH und SCHUMANN 2006). Generally the required focus on integrated management of river catchments and, in particular, on ecological quality, raises major scientific and technical questions (WHEATER und PEACH 2004).

Table 1: Definitions of the high, good and moderate status in rivers defined by fish (WFD 2000).

High status	Good status	Moderate status
Species composition and abundance correspond totally or nearly totally to undisturbed conditions. All the type-specific disturbance-sensitive species are present. The age structures of the fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the reproduction or development of any particular species.	There are slight changes in species composition and abundance from the type-specific communities attributable to anthropogenic impacts on physico-chemical and hydro-morphological quality elements. The age structures of the fish communities show signs of disturbance attributable to anthropogenic impacts on physico-chemical or hydro-morphological quality elements, and, in a few instances, are indicative of a failure in the reproduction or development of a particular species, to the extent that some age classes may be missing.	The composition and abundance of fish species differ moderately from the type-specific communities attributable to anthropogenic impacts on physico-chemical or hydro-morphological quality elements. The age structure of the fish communities shows major signs of anthropogenic disturbance, to the extent that a moderate proportion of the type specific species are absent or of very low abundance.

1.3 The implementation of the EU-WFD in Austria

As a basic step for the implementation of the WFD the current state of Austrian rivers had to be assessed following a special scheme, the DPSIR-method (Driver-Pressure-State-Impact-Response) (Fig. 2) and reported to the EU (BMLFUW 2005). An important point is, that the response (definition and implementation of measures) could apply to drivers, pressures, states and impacts, and a integrated approach can be seen as basis for a sustainable restoration of rivers. The main pressures on Austrian rivers identified were mainly of hydro-morphological character (channelization, water abstraction, hydro-peaking, connectivity interruptions) (BMLFUW 2005), as water quality problems have been solved during the last two decades.

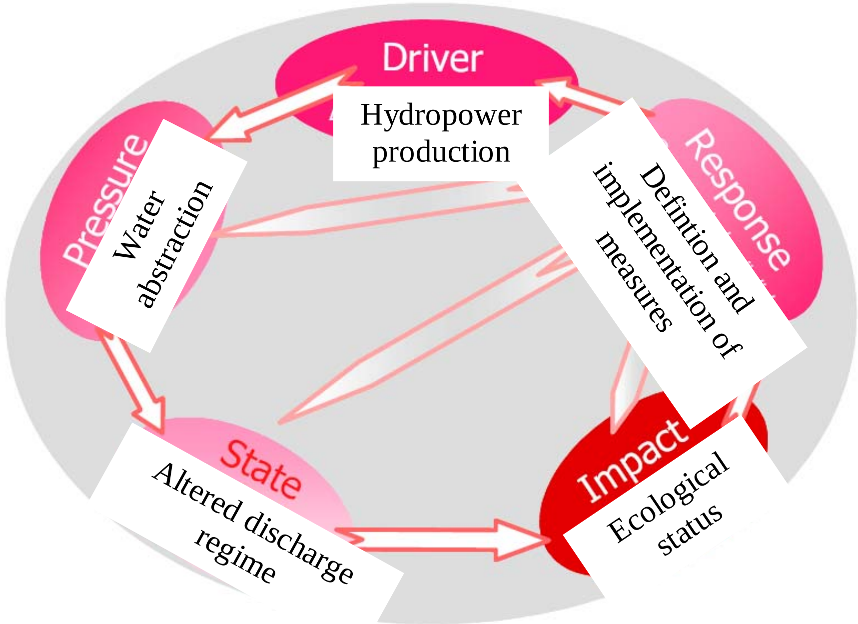

Figure 2: Principle of the DPSIR method with different options of restoration responses: driver=relevant activity, pressure=type of pressure, state=actual ecological integrity, impact=effect on ecological status, response=measure, changed after BMLFUW (2005).

The rivers of Austria drain into the three main river basin districts (RBD) Elbe, Rhine and Danube, with the RBD Danube being most relevant for Austria (Fig. 3). Furthermore for management purposes, Austria was divided into eight national planning areas. As a next step river types were identified following the „CIS Horizontal Guidance on establishing reference conditions and ecological status class boundaries for inland surface waters". Furthermore for the strategic implementation of the EU-WFD so called "Surface water bodies", the spatial main units for management, have been displayed following the „Horizontal Guidance on the Identification of Water Bodies" (BMLFUW 2005). The basic principle for the national preparation of "Surface water bodies" consisted of two essential components: the classification of basic water bodies and their division into differentiated water bodies. The basic classification of the water bodies followed the geographical classification of natural landscapes; a change in typology resulted in a change of water body. In a next step, a differentiated classification of the water bodies has been done based on (1) the status of river stretches with regard to their combinations of significant pressures and (2) on the classification as "Heavily modified water bodies" (when the ecological status and criteria identified them). Within heavily modified water bodies only the "good ecological potential" (GEP) has to be achieved, which is the combination of all possible measures that have no adverse effect on the actual use. All water bodies have been classified with regard of a potential risk having an ecological status worse than "good" and were displayed in a map. All those water bodies at risk are candidates for the monitoring programme. The number of basic water bodies for rivers with > 100 km² catchment area in Austria is 568 (mean length of 20 km with a maximum length of 288 km) and 2596 for rivers with > 10 km² catchment area (mean length of 12 km) (BMLFUW 2005). The number of differentiated water bodies characterised by different combinations of pressures for Austria`s rivers >100 km² catchment area is 940 (mean length of 12,2 km with a maximum length of 135 km), and about 5000 for the river network > 10 km catchment area.

Generally, the aim of the restoration actions is, to reduce the multiple pressures from the individual differentiated water bodies in a way, that a good ecological status of each water boy (with exception of those, that have been classified as heavily modified) is achieved. The environmental objective, to achieve a "good ecological status" or "good ecological potential" for all water bodies has to be met until 2015, with the possibility to extend the management cycle until 2027[3]. From that perspective it becomes clear, that it represents a relatively complex task, to reduce the existing combinations of pressures in a way that the good ecological status of the basic water bodies is achieved in an economically commensurate way decision support, especially from ecological disciplines, is strongly required (Fig. 4).

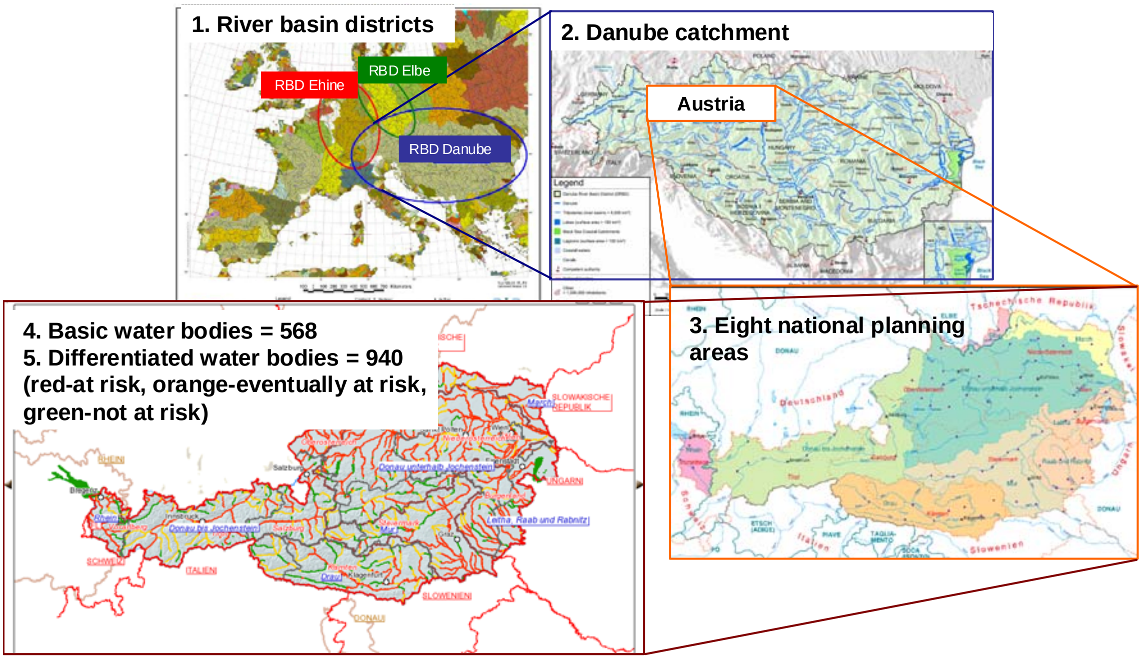

Figure 3: Spatial scales relevant for the implementation of the EU-WFD in Austria: 1. River Basin Districts (RBD), 2. The Danube catchment as the most important RDB, 3. Eight national planning areas, 4. Basic water bodies and 5. Differentiated water bodies, both for the river network > 100 km² catchment area (figure compiled from BLMFUW 2005).

[3] http://ec.europa.eu/environment/water/water-framework/info/timetable_en.htm, 29.12.2008

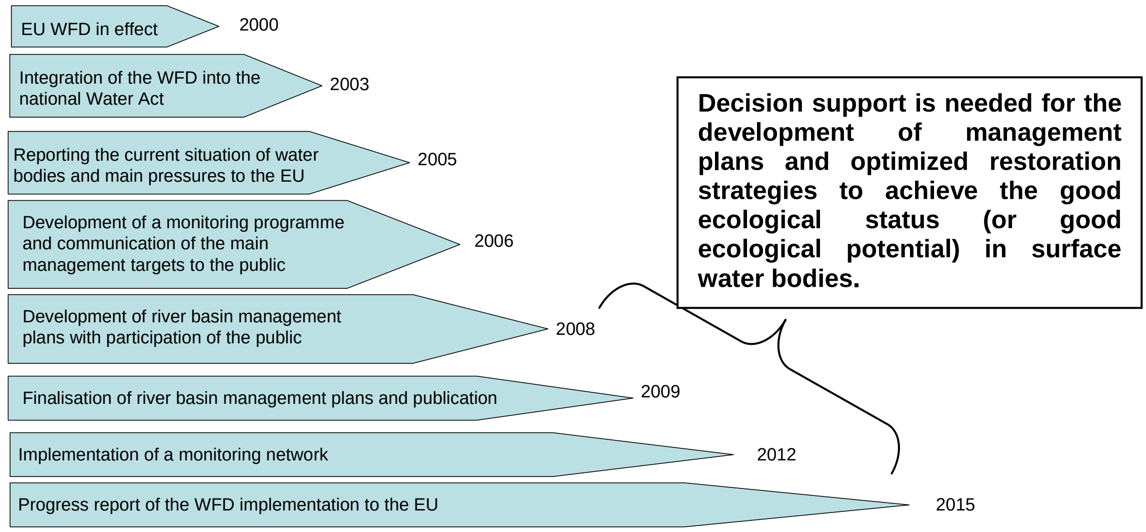

Figure 4: Generalised time frame of the implementation of the EU-WFD (ZITEK et al. 2007) and the need for decision support.

2 Development of a strategy for river restoration in Austria – the MIRR project

As described above, the so called MIRR project, to which this thesis is strongly related to, aimed at the development of a strategic instrument to identify hydro-morphological restoration measures for running waters (SCHMUTZ et al. 2008). Because of their sensitivity for hydro-morphological pressures, especially for connectivity interruptions, fish were considered as indicators within the MIRR project. At the beginning of the MIRR project the following pressures were considered as relevant for probably influencing the ecological status of rivers in Austria (Fig. 5):

- loss of lateral, longitudinal and vertical connectivity
- alteration of the natural morphological character (channelization)
- alteration of the natural flow regime (hydro-peaking, water abstraction)
- impoundment
- land use (indirectly related to many kinds of impacts)
- reservoir flushing (critical short term impact altering water quality and natural morphological character)
- alteration of water quality (pollution)
- shipping
- river bed degradation
- fish eaters, stocking, fishing pressure and alien fish species
- multiple/cumulative impacts.

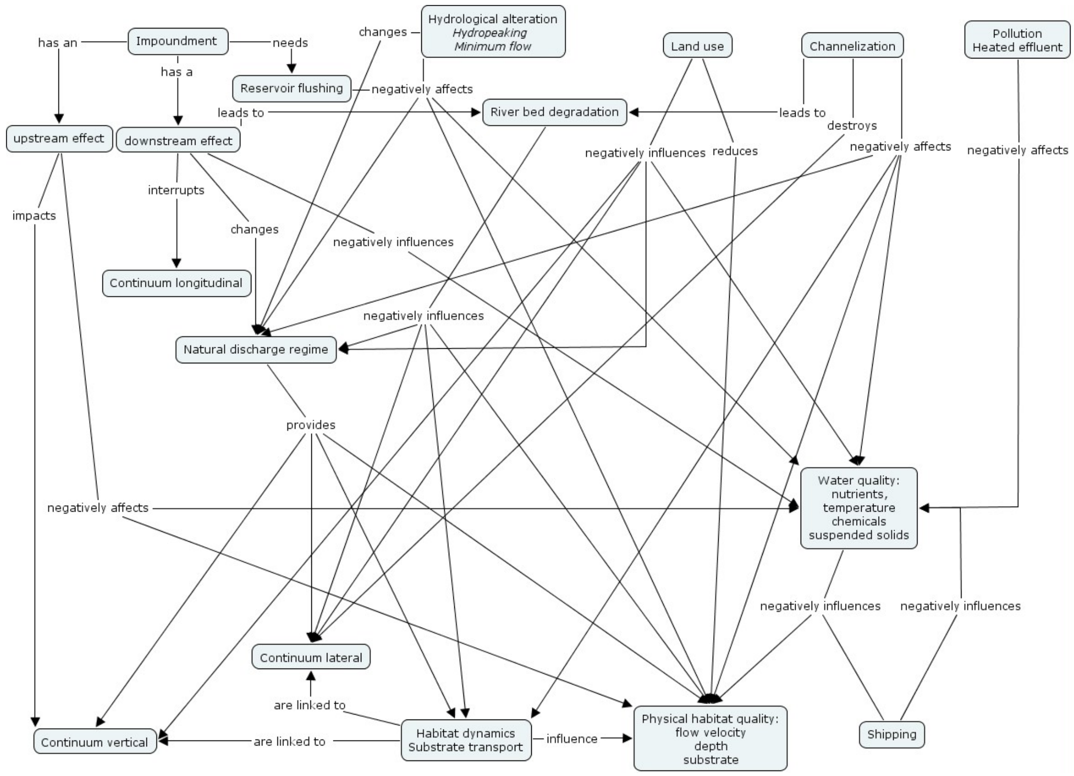

Figure 5: Main human pressures and their interactions within Austrian rivers (ZITEK 2006).

A large set of potentially ecologically relevant abiotic criteria for the pressure types above, mainly focusing on water abstraction, impoundment, land use, channelization, continuum interruptions (lateral, longitudinal) and water quality changes on multiple scales was determined from an extensive literature review (ZITEK 2006).

Based on this list of criteria and the available information and datasets on pressure data in Austria, a comprehensive set of criteria for about 400 fish sampling points in Lower Austria (Fig. 6) was assessed within an extensive GIS analysis matching the results of the literature review with the existence of datasets. Besides the analysis of pressure data, additionally natural environmental parameters that also could influence the fish communities at the fish sampling sites were also assessed (POPPE und ZITEK 2006).

Multivariate analyses of the relationships between different fish metrics and pressure variables on different spatial and temporal scales were conducted, allowing for a quantification of these relationships and an assessment of cumulative effects of pressures (SCHMUTZ et al. 2007).

Finally these modelling results were evaluated within a case study (HOHENSINNER et al. 2008) proving the determined criteria for ecological relevance different spatial scales which led to an adaptation of the initial quantitative fish/pressure relationships. The general structure of the MIRR project is shown in Fig. 7.

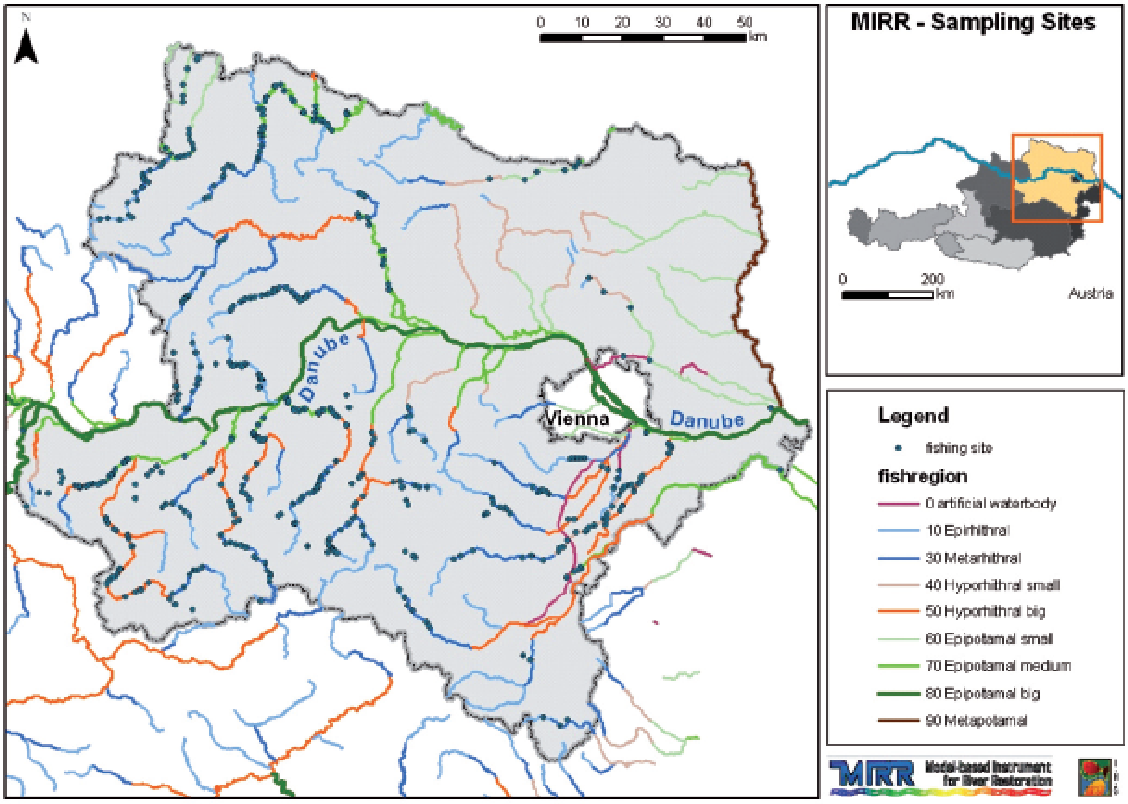

Figure 6: Location of the 400 fish sampling sites within different fish ecological river regions in Lower Austria (SCHMUTZ et al. 2008).

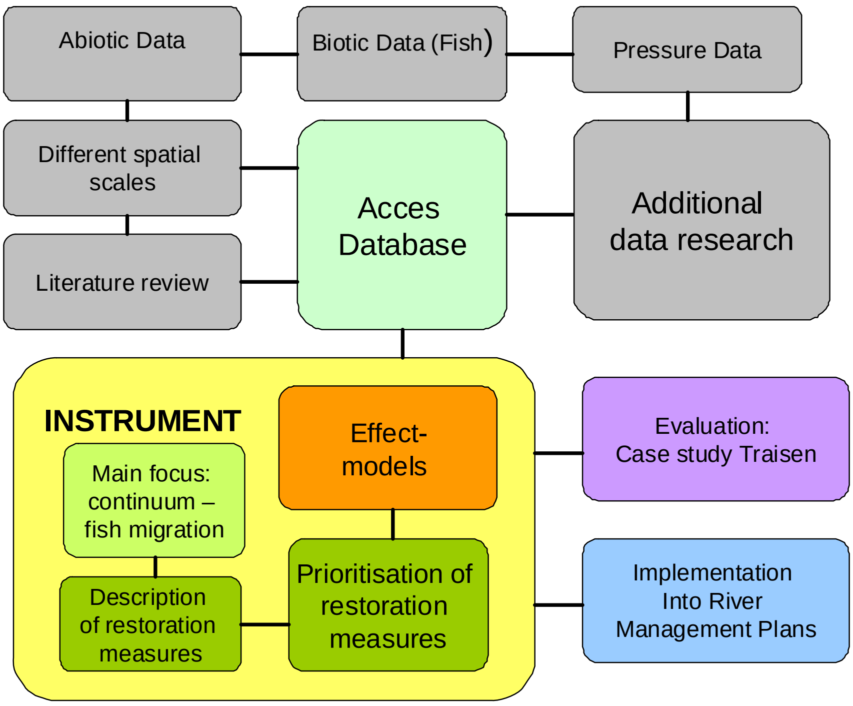

Figure 7: General structure of the MIRR project (POPPE et al. 2008).

2.1 Data research and analysis

Central target of the data research was the assessment of each criterion of the parameter list for each fishing occasion (POPPE und ZITEK 2006). In the following sections the relevant datasets and selected GIS analyses conducted within the MIRR project are described in more detail to demonstrate the complexity of the data collection process under supervision of the author of this thesis.

2.1.1 Relevant datasets

Within the MIRR project both, vector and raster data were processed using ArcGIS 9.0. Vector data were fishing sites (points), rivers (lines), buffer zones around rivers (polygons), whereas land use data (CORINE, SINUS) were processed as raster data.

The dominating type of analyses were spatial requests („spatial join“) and the calculation of attributes (area, length, height, slope) for each fish sampling point on different spatial scales. As a uniform projection Lambert-Conformal-Conic was used, and as geographic coordinate system MGI.

The main underlying datasets analyzed were:

- Digital Terrain Model (DTM) of Austria with a 10 m * 10 m in ESRI GRID format (provided by the Umweltbundesamt – UBA[4])
- Digital ÖK50 maps (provided by the Ministry of Life[5])
- Digital river network used for EU-WFD reporting (provided by the Umweltbundesamt – UBA[6])
- Digital results of a comprehensive river morphological mapping project in Lower Austria – NÖMORPH (provided by the Government of Lower Austria[7]) containing various parameters describing in sum the naturalness of river sinuosity, condition of the river bottom, condition of land-water ecotone, shoreline condition and vegetation of the shoreline and the surrounding landscape; these data were originally mapped in a 7-tiered scheme, and had to be translated in a WFD compliant 5-tiered scheme.
- Digital data of the ANF/KLF project (MUHAR 1996; MUHAR 1998)
    - Potential morphological river type
    - Actual river course

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[4] http://www.umweltbundesamt.at, 27.12.2008

5 http://www.lebensministerium.at, 27.12.2008

[6]http://www.umweltbundesamt.at/umweltschutz/wasser/berichtsgewaessernetz, 27.12.2008

[7]http://www.noe.gv.at/Umwelt/Wasser/Fliessgewaesser/Fliessgewaesser_Situation_in_Niederoesterreich.html, 27.12.2008

- Potential width of the floodplain
- Fish ecological river regions

- Additional data on hydropower plants based on a online documentation („Wasserbuch Niederösterreich“[8]) and ESRI shape files (provided by the Government of Lower Austria[9])
- Discharge data (MAF, MALF, HQ1, HQ1,5 und HQ2,33) at relevant gauges at rivers in Lower Austria (provided by the Government of Lower Austria[10])
- Land use data (see also Fig. 8)
  - CORINE Landcover Projekt 2000 (CLC2000) with (provided by the Umweltbundesamt – UBA[11])

    Based on: Landsat 7 ETM+ data of the year 2000

    Vector based

    Scale 1:100.000

    Spatial resolution: +/- 25 m

    Manually on-screen digitizing by visual interpretation of landscape structures

    Minimum size of polygons 25 ha

    Minimum width of line elements 100 m

    Nomenclature: 3 levels with hierarchical structure (for displaying different spatial scales)

    1. Level: 5 classes
    2. Level: 15 classes(M 1:500.000 bis 1:1.000.000)
    3. Level: 44 classes for Europe

       27 classes for Austria (M 1:100.000)

  - SINUS dataset containing in formation on hemeroby in nine classes describing the degree of human influences on land ecosystems, WRBKA, 2003; provided by the Institute of Surveying, Remote Sensing and Land Information (IVFL) at the BOKU, Vienna[12])

    Based on: Landsat 5-TM of the years1993 – 96 (WRBKA, 2003)

    Raster based

[8] http://www.noe.gv.at/Umwelt/Wasser/Wasserdatenverbund-NOe/wdv_wasserbuch.wai.html, 27.12.2008.
[9] http://www.noe.gv.at/Umwelt/Wasser/Fliessgewaesser/Fliessgewaesser_Situation_in_Niederoesterreich.html, 27.12.2008
[10] http://www.noe.gv.at, 27.12.2008
[11] http://www.umweltbundesamt.at/umwelt/raumordnung/flaechennutzung/corine/, 27.12.2008
[12] http://www.rali.boku.ac.at/ivfl.html, 27.12.2008

Spatial resolution: 30m

Automated segmentation and classification of satellite pictures

Minimum size of spatial elements 0,5 ha

Nomenclature: 2 levels with hierarchical structure allowing the visualisation of information on different aggregation levels

1. Level: 7 classes
2. Level: 18 classes

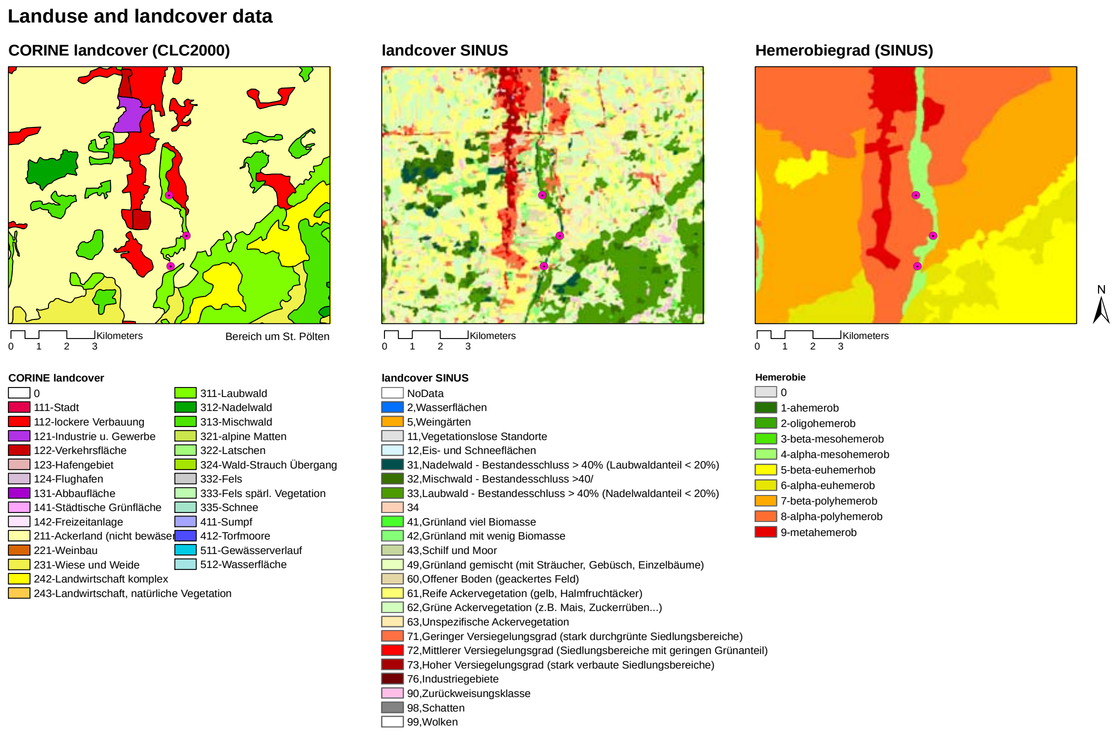

Figure 8: Comparison of the CORINE, SINUS hemeroby datasets around St. Pölten, mind the different spatial resolution of the CORINE and SINUS data set.

- Data on catchment area and water quality (from 1966, 88, 98 und 2001) were taken from the digHAÖ („Digitaler hydrologischer Atlas Österreich, available on CD)
- Population density based on the SINUS data provided by the Institute of Surveying, Remote Sensing and Land Information (IVFL) at the BOKU, Vienna[13])
- Digital data from the Austrian report on the current situation of water bodies and rivers (BMLFUW 2005) (provided by the Umweltbundesamt – UBA[14]) containing information on

[13] http://www.rali.boku.ac.at/ivfl.html, 27.12.2008

- Connectivity interruptions
    - To evaluate and update this dataset additional field mapping was needed and conducted within the frame of the MIRR project
- Water abstraction
    - To complete this dataset
        - Integration of information from the „Wasserbuch Niederösterreich“[15] and ESRI shape files provided by the Government of Lower Austria[16]
        - and additional investigations by personally contacting power plant owners were needed
- Hydro-peaking
    - In Lower Austria there were no data available on hydropeaking, why this pressure type was not further analysed
- Impoundment
    - To complete this dataset, information on the dimensions of impoundments was derived from
        - Calculations, using the height of connectivity interruptions and the local slope to calculate the length of an impoundment and
        - from the „Wasserbuch Niederösterreich“
- River morphology

- Digital information on point sources and sewage treatment plans (provided by the Umweltbundesamt – UBA[17])
- Existing River Managament Plans (“Gewässerbetreuungskonzepte”)
    - Due to the inhomogeneity of these data, only selected information could be selected from those studies
- Fishing sites characterized by biological and environmental data (provided by the Institute of Hydrobiology and Aquatic Ecosystem Management – IHG[18] and by the BAW in Scharfling[19]

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[14] http://www.umweltbundesamt.at/umwelt/raumordnung/flaechennutzung/corine/, 27.12.2008
[15] http://www.noe.gv.at/Umwelt/Wasser/Wasserdatenverbund-NOe/wdv_wasserbuch.wai.html, 27.12.2008.
[16] http://www.noe.gv.at/Umwelt/Wasser/Fliessgewaesser/Fliessgewaesser_Situation_in_Niederoesterreich.html, 27.12.2008
[17] http://www.umweltbundesamt.at/, 27.12.2008
[18] http://www.boku.ac.at/hfa/, 27.12.2008
[19] http://www.baw-igf.at/, 27.12.2008

2.1.2 GIS analyses

Spatial scales

Spatial analyses with regard to river connectivity, morphology and land use were conducted at different spatial scales. Generally buffer circles around the fishing sites with 1 km, 5 km and 10 km were created and spatial information extracted per river; that means that the river length considered was not 1, 5 or 10 km, but resulted in that river segment with the same river name that as cut by the buffer. Furthermore the fish ecological river regions (MUHAR 1996; MUHAR 1998; HAUNSCHMID et al. 2006), the local scale (250 m) (Fig. 10) full and partial catchment areas also represented important longitudinal scales for analysis (Tab. 2). Buffer widths used in the analyses were 30 m, 50 m and 100 m, as well as the so called directly "connected" information. Furthermore the potential floodplain width was used as a lateral buffer; this information was available from MUHAR (1996, 1998) or was estimated by the topography using the digital Austrian Map 3D (1:50 000, available on CD). Although this methodology delivered reliable results at steeper topographies, at lowland rivers no useful results could be achieved with this methodology due to the very flat topography. Most of the buffer dimensions used were determined by the comprehensive literature review (ZITEK 2006).

Table 2: Summary of the scales used for analysis.

Longitudinal buffer	**Lateral buffer**					
	Without lateral buffer	Potential floodplain area	100m	50m	30m	connected
TOTAL catchment	☑	☑	☑	☑	☑	☑
SUB-catchment	☑	☑	☑	☑	☑	☑
Fish ecological river regions	-	☑	☑	☑	☑	☑
10 km	-	☑	☑	☑	☑	☑
5 km	-	☑	☑	☑	☑	☑
1 km	-	☑	☑	☑	☑	☑
LOCAL= (250 m)	-	-	☑	☑	☑	☑

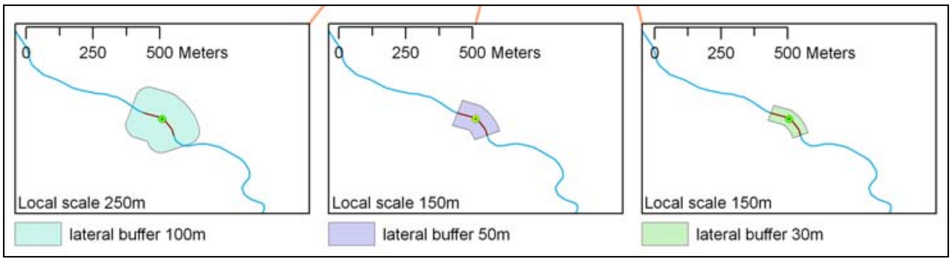

Figure 9: Local scale buffer analysis.

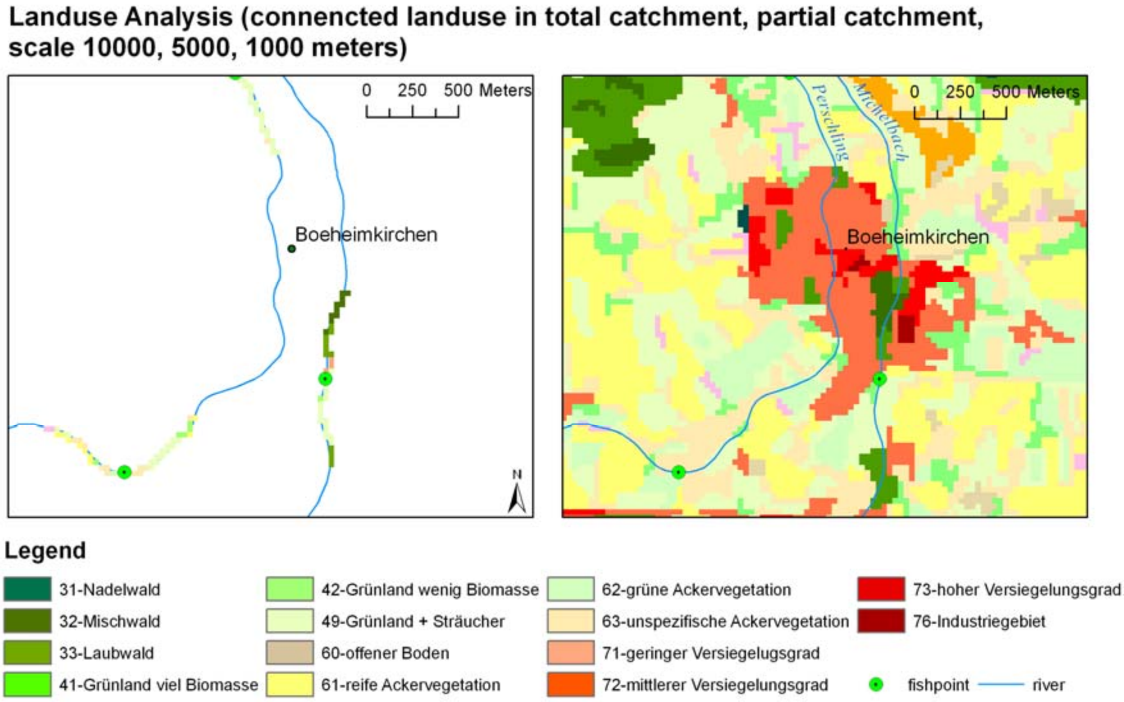

Figure 10: Example of the analysis of connected land use (without any lateral buffer), by extracting raster elements by an overlay with river segments at various longitudinal scales.

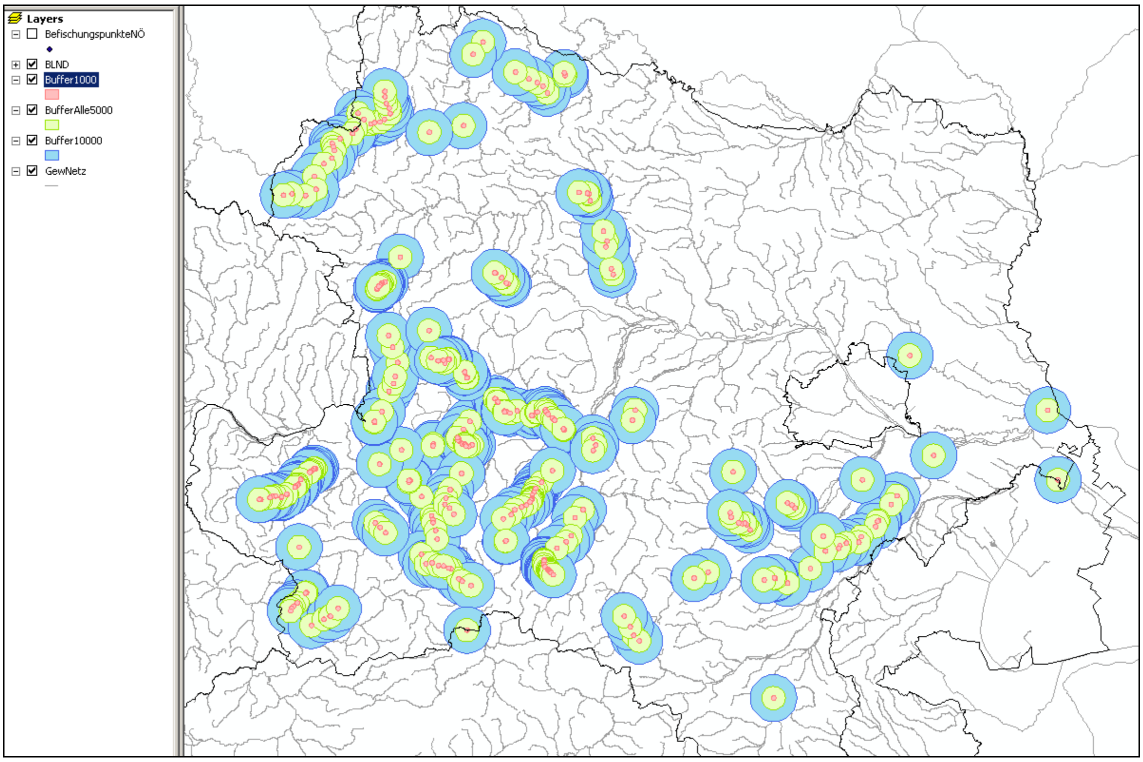

Figure 11: Buffer circles around fishing sites with 1 km, 5 km and 10 km diameter.

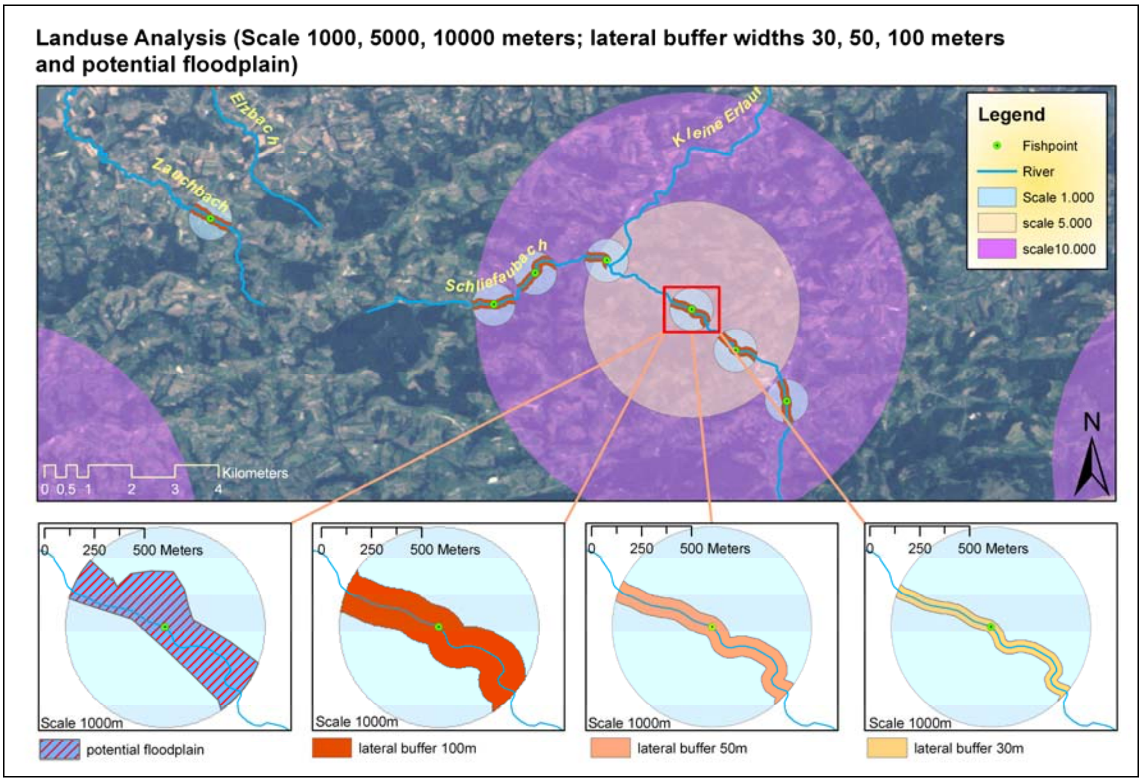

Figure 12: Land use analyses of GIS data on different spatial scales for 1 km, 5 km and 10 km buffers and the potential floodplain area.

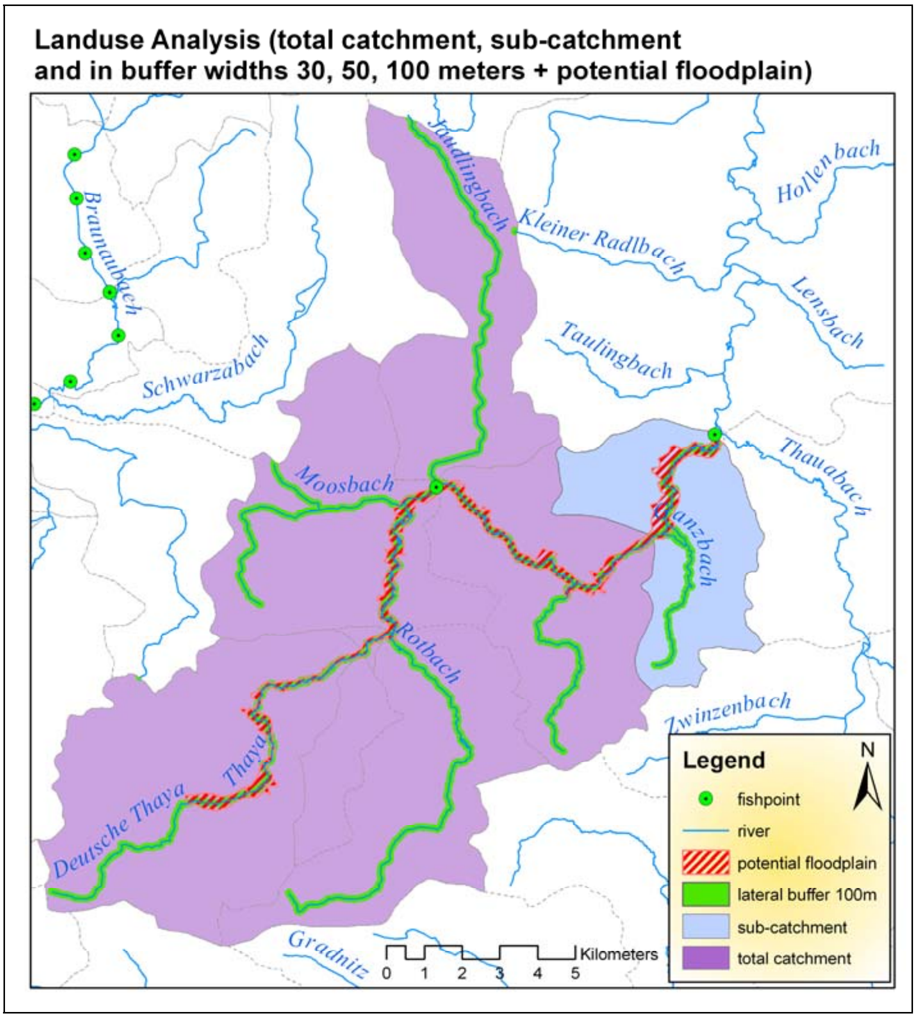

Figure 13: Example of land use analyses on different longitudinal scales (total catchment, sub-catchment) together with lateral buffers (potential flood plain width and 100 m buffer).

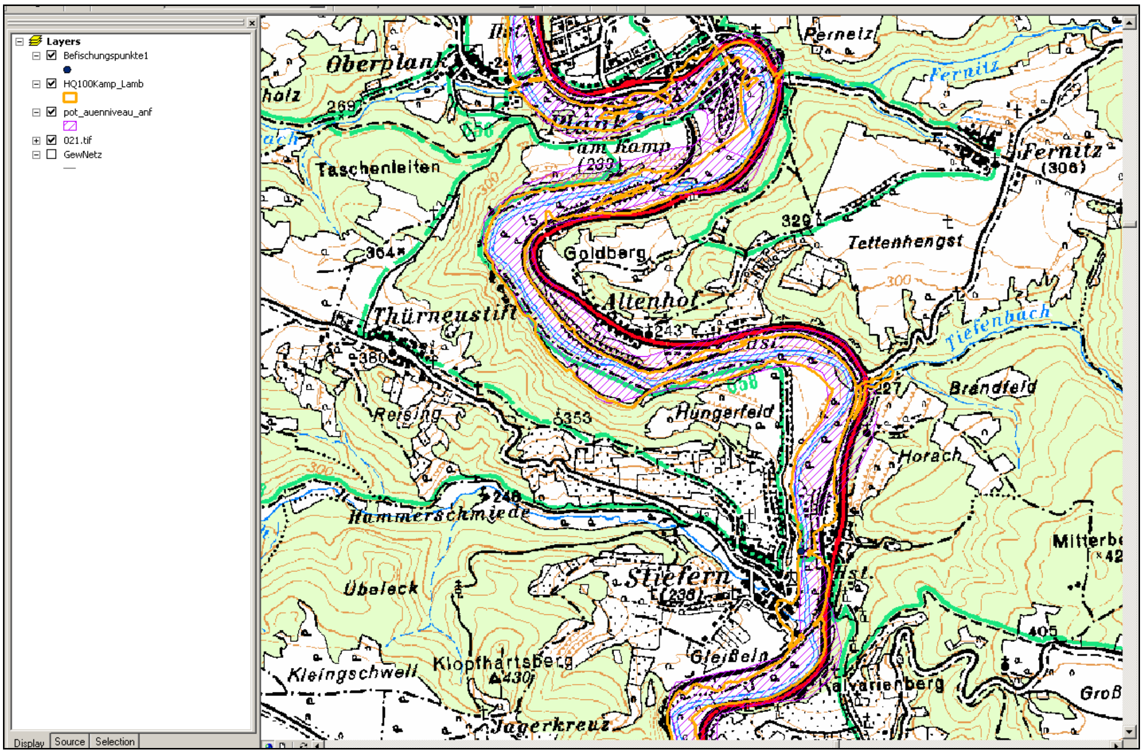

Figure 14: Estimation of the potential floodplain width based on the topography using AMap 3D (BEV) in relation to existing information on the areas flooded by a HQ100 flood (a flood with a 100 year annularity).

Calculation of catchment areas

For each point of interest (fishing site, water gauge, and connectivity interruption) full and partial catchment areas were calculated based on a technology developed within the digHAÖ project allowing selecting the catchment area above each point (Fig. 15).

Calculation of river discharge at point s of interest

For each fishing site, and for each connectivity interruption different statistical discharge values (MAF; MALF, HQ1; HQ1,5; HQ2,33) were calculated starting at the water gauges by linear interpolation based on the catchment area. The values calculated, were compared to information that was already available from another project that has been run in Lower Austria (ILF und LIMNOLOGIE 2004). The difference between the two approaches was that ILF and LIMNOLOGIE (2004) interpolated the discharge for river sections and not for specific locations. Generally the values from the site specific approach applied within the MIRR project were used.

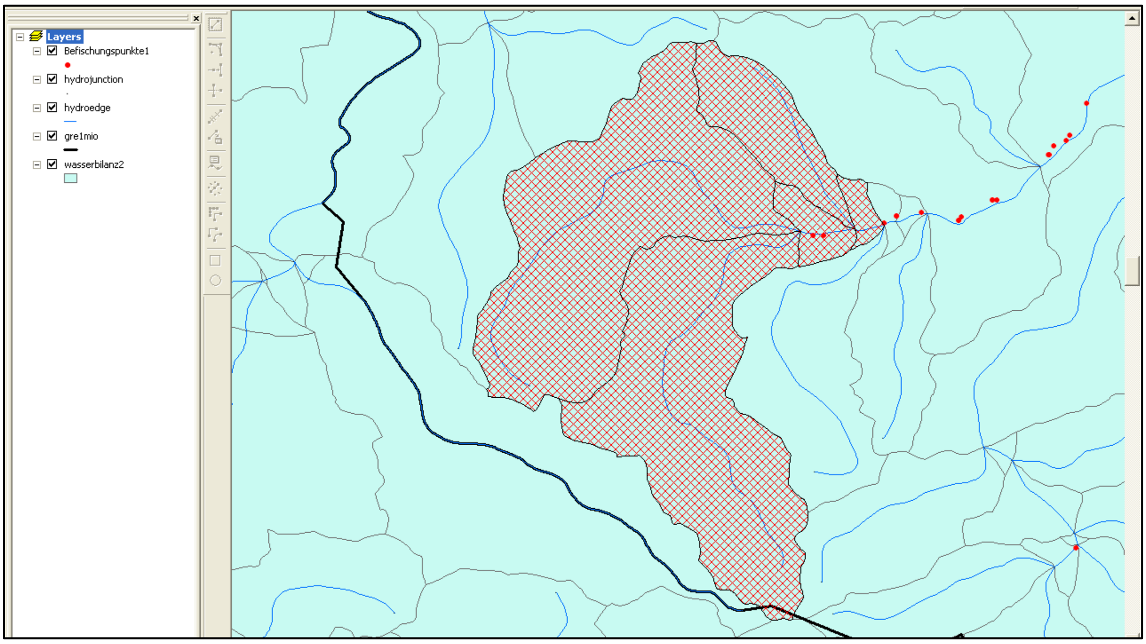

Figure 15: Selection of the catchment area above a fishing site (red dot).

Calculation of slope for river segments

For each river segment the slope was calculated based on the segment length (3dlenght) by overlaying the river network with the DTM (Fig. 16) resulting in height values at the beginning and the end of the line. Together with the segment length it was possible to calculate the slope in %. This value was then assigned to fishing sites and connectivity interruptions within that specific segment. This information was mainly used to calculate the missing lengths of impoundments by relating the height of a connectivity interruption to the slope of the related river segment.

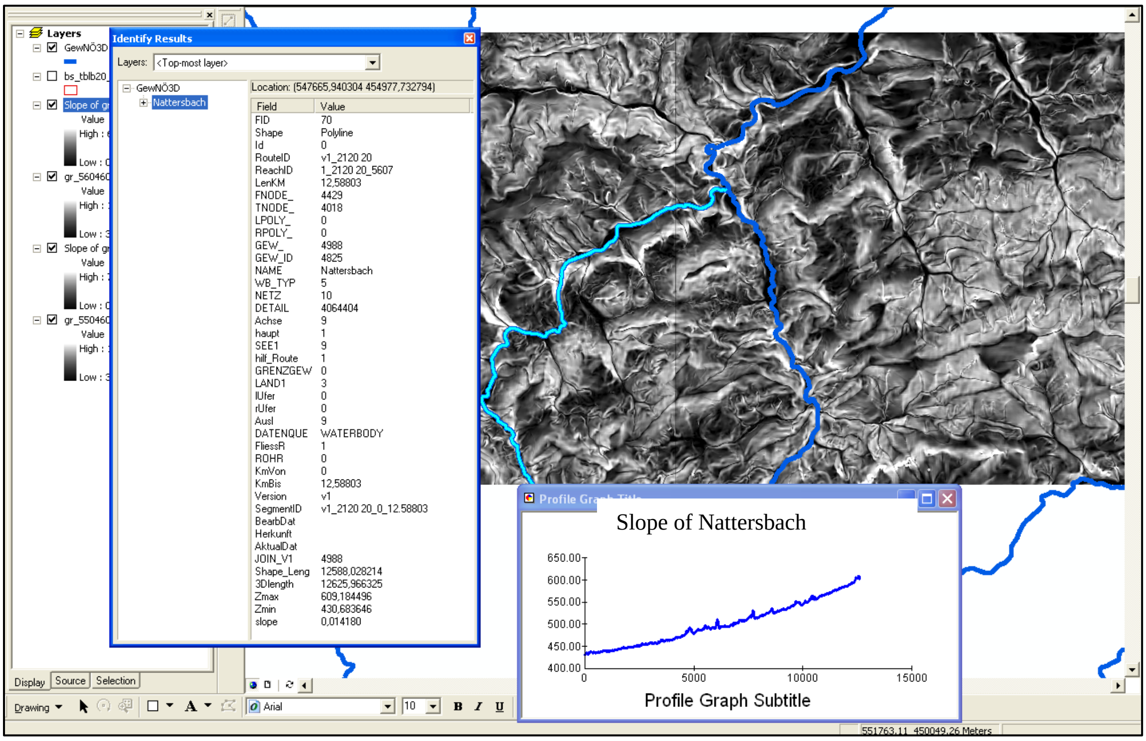

Figure 16: Calculation of river slope for the Nattersbach.

Extraction of the number of connectivity interruptions at different scales

The number of connectivity interruptions was estimated for certain buffers including 1 km, 5 km, 10 km, fish ecological river region as longitudinal buffers. The following parameters were thereby considered:

- Absolute number
- Type of connectivity interruption
- Functionality of existing fish ladders

An automated analysis of the number of connectivity interruptions per buffer within one step was complicated by the excessive overlapping of the circles (Fig. 17). The number of connectivity interruptions per fish region of a river (often containing several fishing sites) was visually counted from the screen.

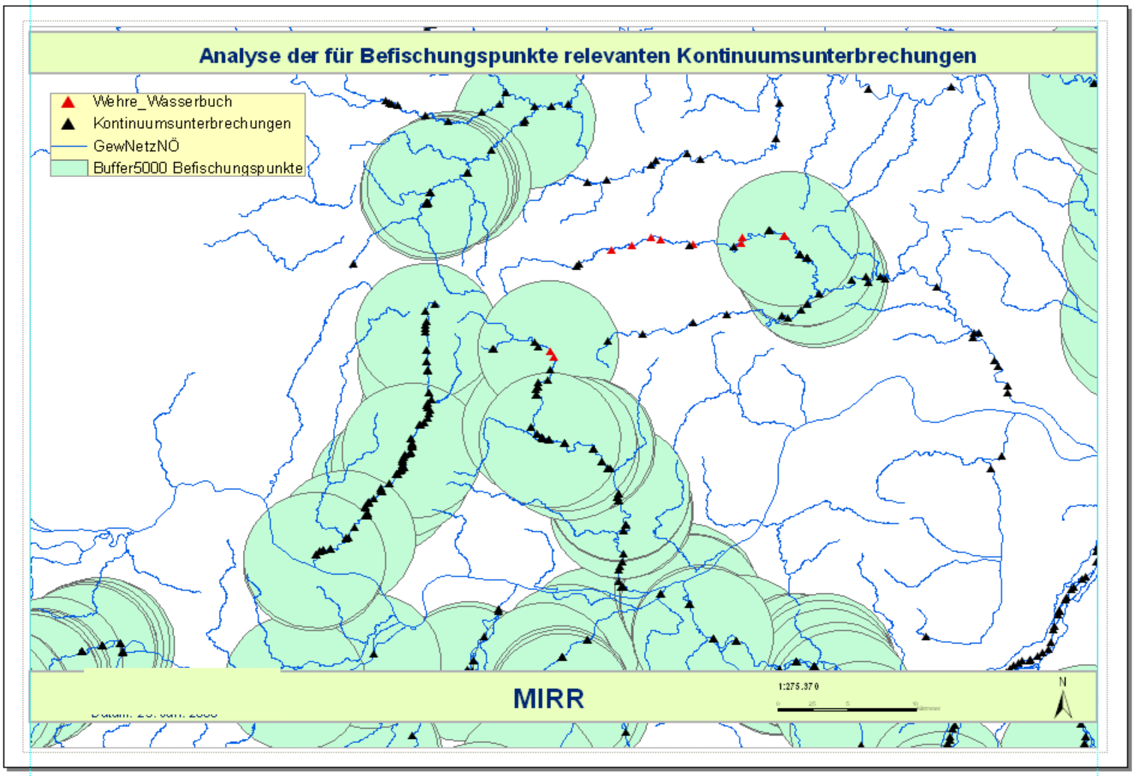

Figure 17: Estimation of the number of connectivity interruptions within a 5 km buffer.

Pressure type water abstraction

As no detailed data spatial on water abstraction were digitally available, these data were assessed within the MIRR project (Fig. 18) taking advantage of another project that was conducted at the IHG at the same time (ZEIRINGER 2006-2008). The following parameters were assessed:

- Residual flow

- o by integrating information from the „Wasserbuch Niederösterreich“[20] and ESRI shape files provided by the Government of Lower Austria[21]
  - o and additional investigations by personally contacting power plant owners
- Dimension of the hydropower turbines to estimate the maximum amount of water that could be abstracted
  - o by integrating information from the „Wasserbuch Niederösterreich“
- River length subjected to water abstraction was measured
  - o by integrating information from the „Wasserbuch Niederösterreich“
  - o measuring the length of residual flow stretches existing within AMap 3D (available on CD, BEV)

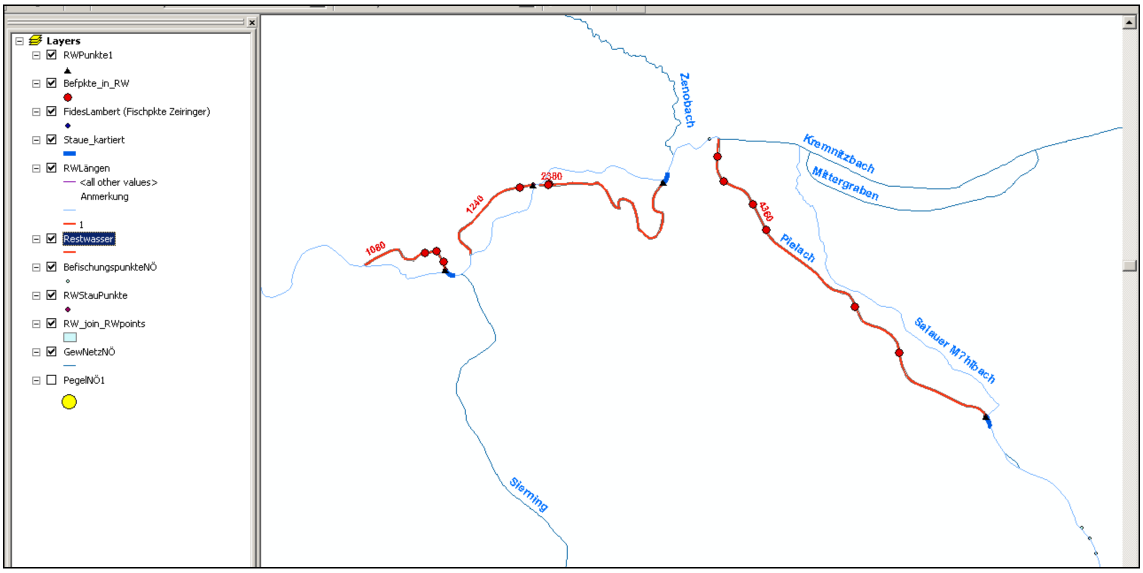

Figure 18: Residual flow stretches (in red) and fishing sites at the river Pielach.

Pressure type impoundment

The following parameters were assessed with regard to the pressure type “impoundment” (Fig. 19):

- Impoundment dimensions
  - o calculations, using the height of connectivity interruptions and the local slope to calculate the length of an impoundment

[20] http://www.noe.gv.at/Umwelt/Wasser/Wasserdatenverbund-NOe/wdv_wasserbuch.wai.html, 27.12.2008.

[21] http://www.noe.gv.at/Umwelt/Wasser/Fliessgewaesser/Fliessgewaesser_Situation_in_Niederoesterreich.html, 27.12.2008

- o the „Wasserbuch Niederösterreich“ and NÖMORPH data being used to determine width and length of impoundments

- Relationship of impoundment and free flowing river sections between two connectivity interruptions
- Water exchange rate of impoundments
    - o Length and depth of impoundments (calculated form the height of the connectivity interruptions) were divided by MAF and MALF

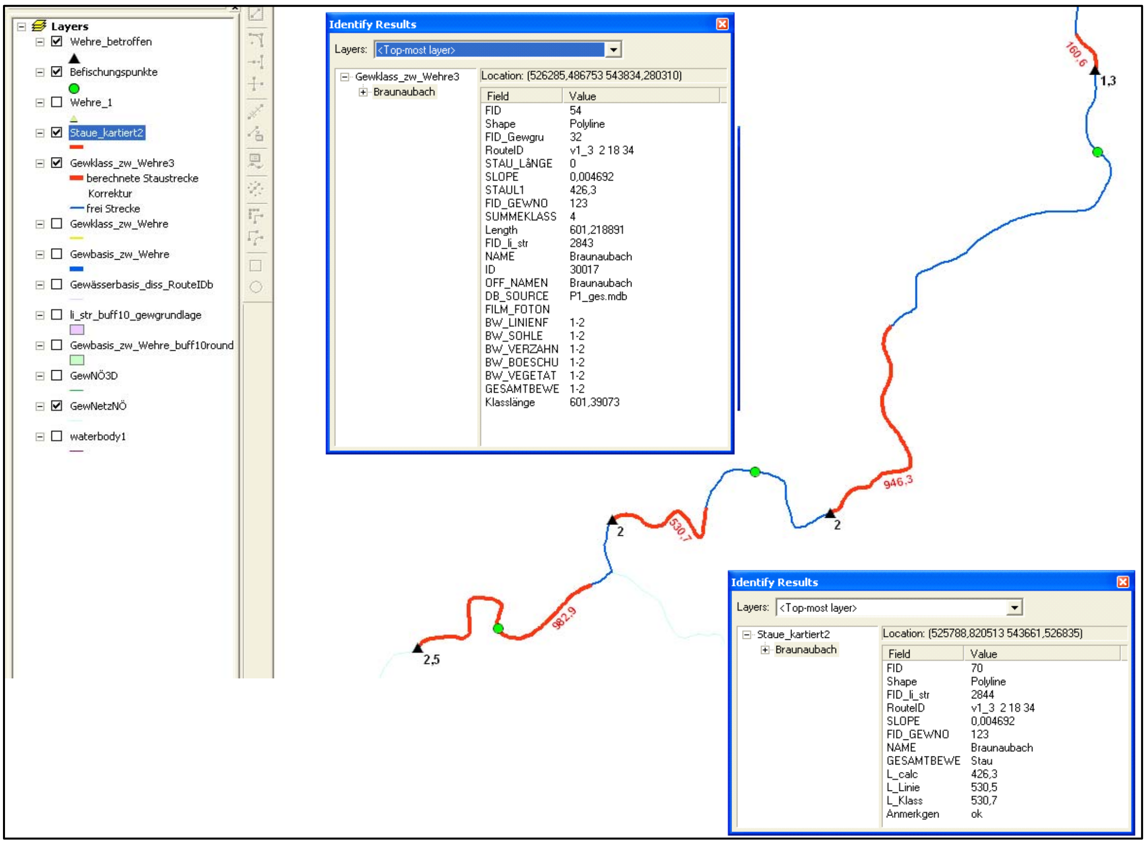

Figure 19: Relationship of impounded sections (red) and free flowing sections between two connectivity interruptions (black triangles).

Pressure type channelization

The analysis of the pressures type “channelization” was mainly based on the NÖMORPH dataset. These data consist of several separate parameters mapped that were finally integrated into a composite parameter to judge the degree of the effect of this pressure type. Originally these data were mapped in a 7-tiered scheme, and had to be translated in a WFD compliant 5-tiered scheme. This analysis had to be run for the left and right shoreline separately. The following parameters were assessed with regard to the pressure type on the defined different spatial scales using (Fig. 20):

- Composite pressure degree
- naturalness of river sinuosity

- condition of the river bottom
- condition of land-water ecotone
- shoreline condition
- vegetation of the shoreline and the surrounding landscape

Additionally data like the

- Potential morphological river type
- Actual river course
- Potential width of the floodplain

were used from ANF/KLF project (MUHAR 1996; MUHAR 1998).

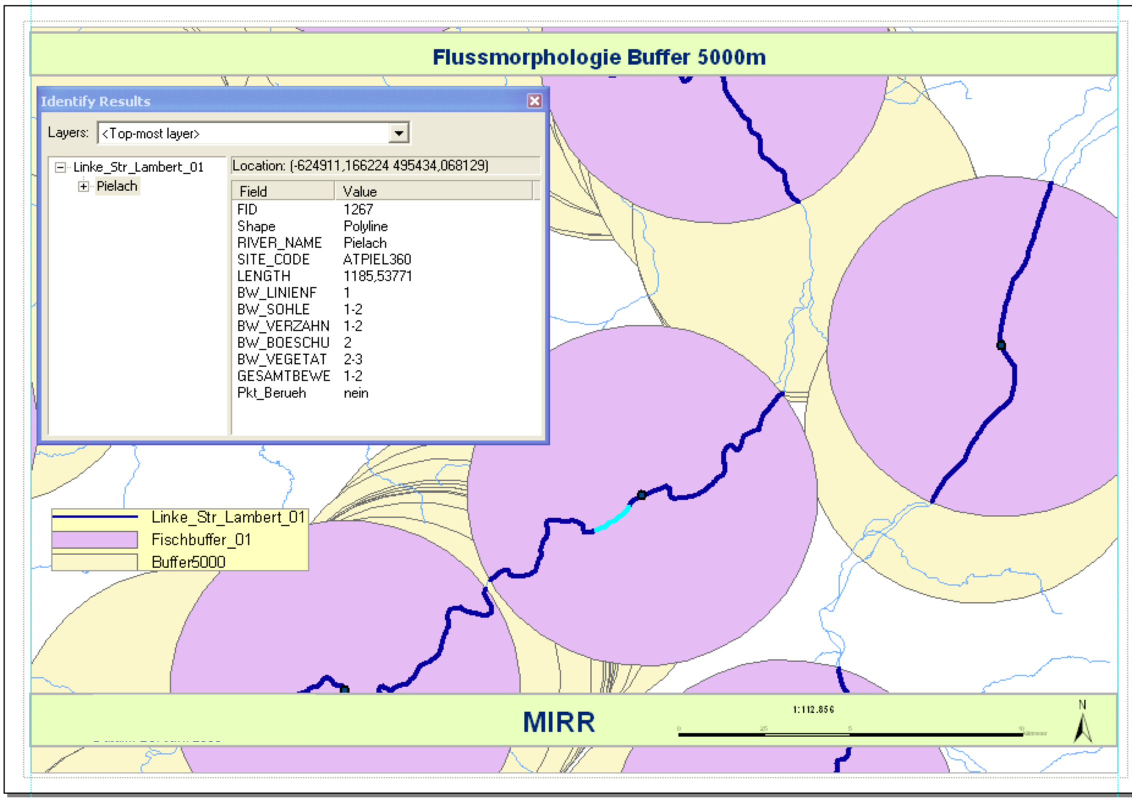

Figure 20: Analysis of the morphological condition of the left shoreline within a 5 km buffer with results for each parameter.

Pressure type land use

Land use data on different spatial scales were derived from the SINUS dataset due to its better spatial resolution (WRBKA 2003) (see the ***"Spatial scales"*** section at the beginning of this chapter). Results of this analysis were the percentage of each land use type and each hemeroby class in the selected buffers.

Pressure type water quality

Criteria derived from that dataset provided by the UBA were

- Distance of a fishing site to point sources and sewage treatment plants
- Upstream number of point sources and sewage treatment plants

- Capacity of the sewage treatment pant upstream(expressed in number of inhabitants connected to this sewage treatment plant)
- Summed capacity of the upstream sewage treatment plants (expressed in number of inhabitants connected to this sewage treatment plant)

Pressure type population density

The population density analyses were based on the SINUS data provided by the Institute of Surveying, Remote Sensing and Land Information (IVFL) at the BOKU, Vienna and were calculated as “number of inhabitants per pixel”.

Natural characteristics

Finally natural characteristics describing the fishing sites that were integrated into the analyses incorporate:

- Meters above sea levels
- Catchment area
- Slope
- Distance to source
- Distance to river mouth
- Mean monthly air temperature
- Discharge
- Geology
- Potential floodplain width
- Natural river type

2.1.3 Relevant spatial (pressure) criteria and their quantitative relationship to fish

Out of about 550 pressure criteria (summarized in a table in the appendix of SCHMUTZ et al., 2007), most of them assessed using GIS technology (POPPE und ZITEK 2006), and managed in a large relational ACCESS database (Fig. 21), only a few were identified to be significantly related to fish variables (SCHMUTZ et al. 2007; HOHENSINNER et al. 2008).

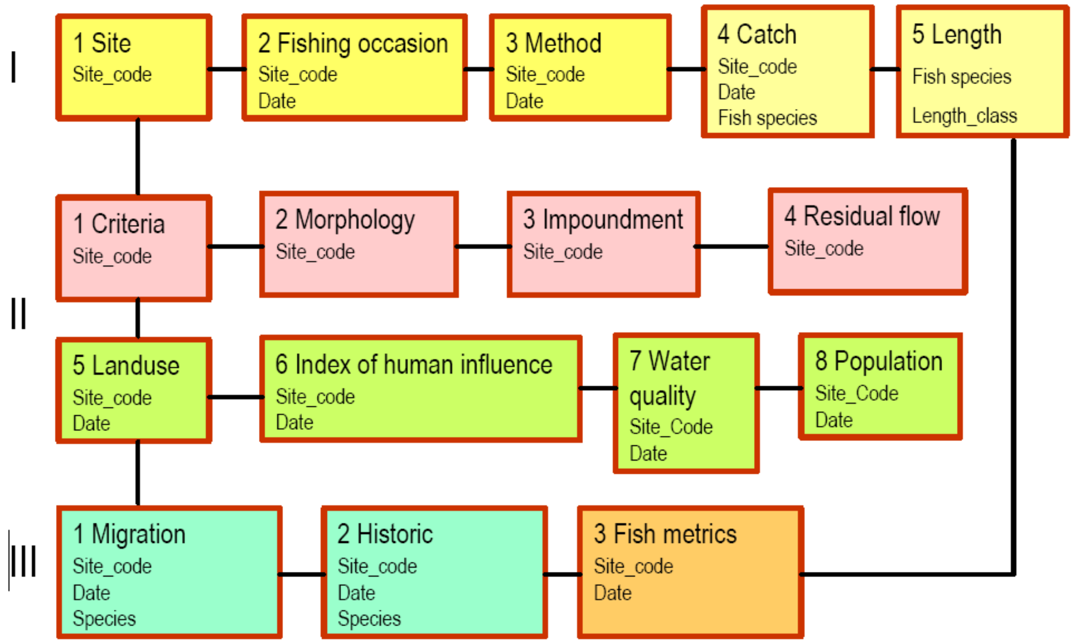

Figure 21: General structure of the MIRR database (SCHMUTZ et al. 2007).

The most important criteria, also forming the basic input for developing the WSDSS framework, that were identified by multivariate analysis (SCHMUTZ et al. 2007) and adapted within a case study (HOHENSINNER et al. 2008) were (Fig. 22):

- Proportion of forest in the catchment (> 54 % yielded a significant better fish ecological situation)
    - Proportion of forest in 100 m x 10 km buffer (if the proportion of forest in a catchment is below 54 %, the proportion of forest in the described buffer becomes an important criterion; more than 24 % leads to a significant better fish ecological situation).
- Number of connectivity interruptions within the ecological fish region (less than 10 connectivity interruptions yield a significant better fish ecological situation)
- Morphology index of the river bottom (within a five-tiered scheme, the morphological status of the river bottom within a 10 km buffer was found to

significantly influence the fish ecological situation negatively when it was above 2,1).

- Additionally the number of tributaries within the fish region positively influenced the fish ecological status (this could not be tested with regression tree).

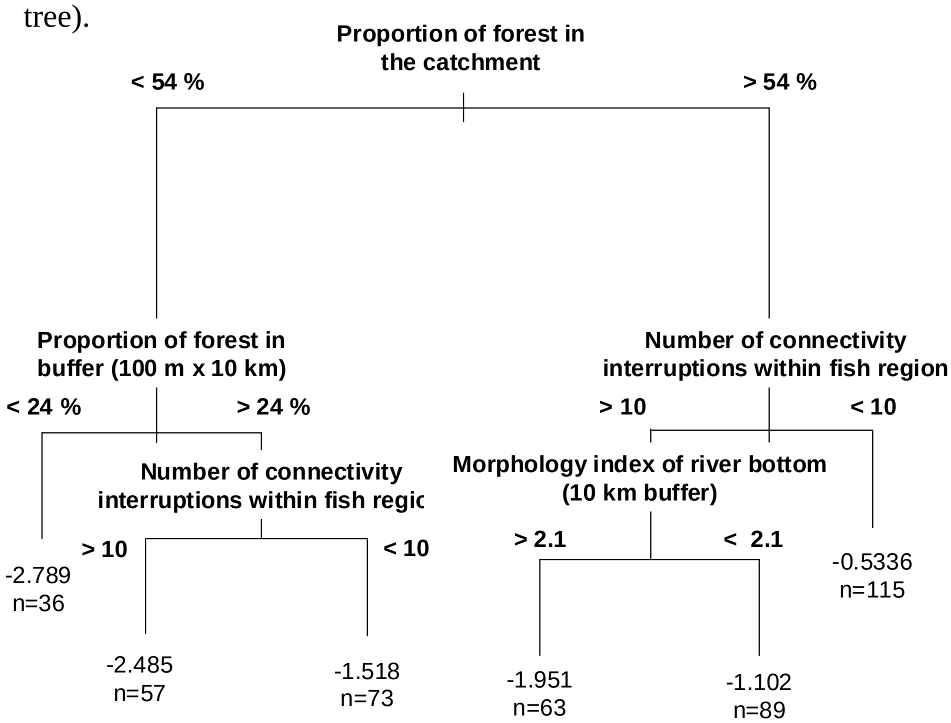

Figure 22: Final regression tree yielded by a validation of the original model based on a case study, redrawn from HOHENSINNER et al. (2008).

For the pressure type *water abstraction*, which could not be identified within the regression tree analysis, generally an ecologically acceptable minimum flow of 40 % of Mean Annual Low Flow (MALF) was identified as a target value, although due to the significant influence of site specific factors, each case is recommended to be treated individually (SCHMUTZ et al. 2008). The pressure type *impoundment* was generally found to degrade the fish ecological integrity, with smaller impoundments (< 300 m) having a limited impact; therefore a reduction of the impoundment length could be seen as an important type of measure, but being impracticable in reality. Relatively seen, each river segment (also each water body) should consist of about 80 % of intact river stretches (without any significant pressures) to guarantee a good ecological status, minimum connected river lengths are 5 km for small rhithral (highland) sites and 10 km for all other river types (SCHMUTZ et al. 2008). For each pressure type, to aid the application of these results for management purposes, flow charts based on the results of the multivariate analysis were developed (SCHMUTZ et al. 2007); Fig. 23 shows a flow chart related to land use and river morphology as relevant pressure types. Finally, a general scheme for restoring rivers in Austria has been developed (Fig. 24). Another important prioritization scheme as dealing with the prioritization of connectivity measures on a catchment level, and was published within a separate document (ZITEK et al. 2007).

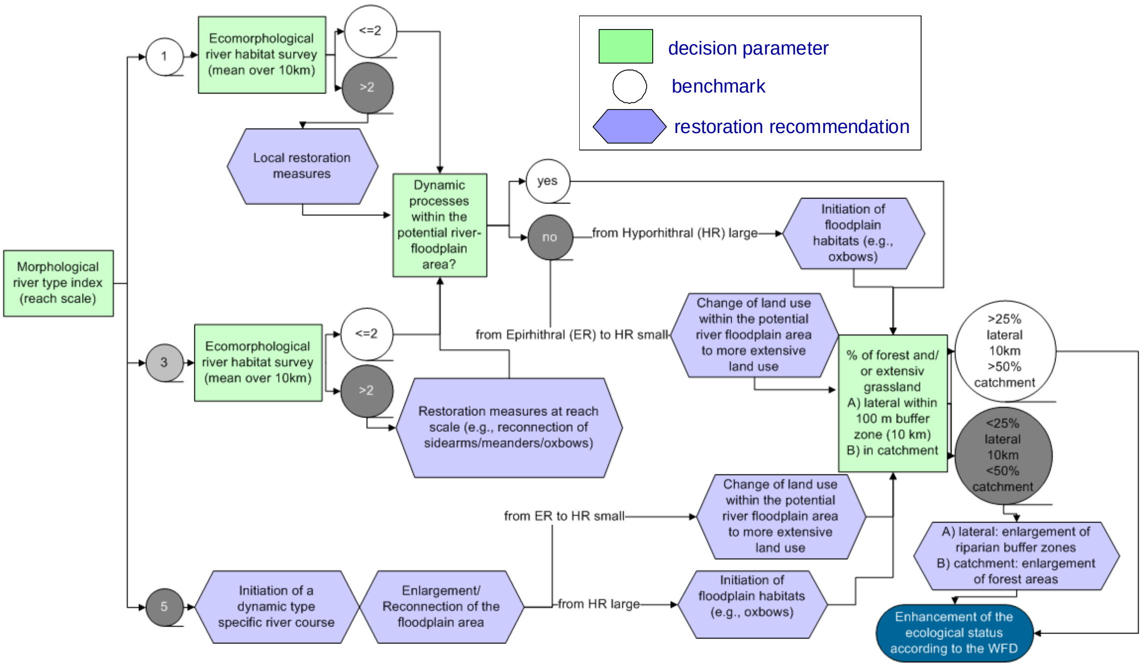

Figure 23: Flow chart for identifying measures fort he pressure types "land use" and channelization (POPPE et al. 2008).

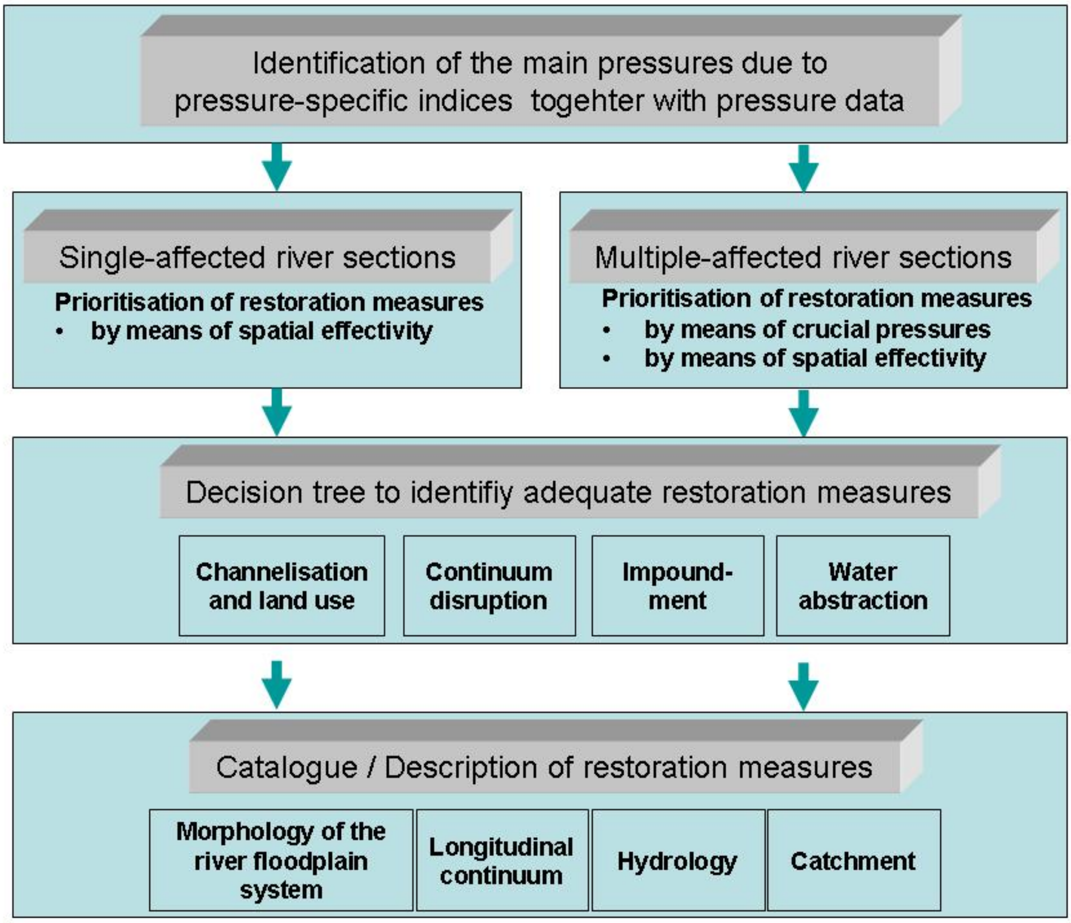

Figure 24: General scheme for restoring rivers in Austria (SCHMUTZ et al. 2008), without hydropeaking as a pressure type, that was not treated within the MIRR project.

General recommendations that were drawn from the results of the MIRR project for river restoration are (SCHMUTZ et al. 2008):

- Development of strategies from a catchment perspective to the local scale
- Relatively low degraded catchments should be restored first, as here restoration measures are expected to be most effective
- Prioritizing potamal (lowland) rivers, as measures are expected to yield the most effective results
- Measures with an effect at larger spatial scales should be prioritized, for example the restoration of connectivity at river mouths
- At sites with multiple pressures, reduction of all pressures starting with the most intense ones
- Overall aim of the restoration effort is the creation of morphologically intact river reaches with full connectivity with minimum lengths of 5 km (small rhithral – highland - rivers) and 10 km (all other rivers).

The restoration approach used in the MIRR project is based on a reduction of the pressure along a gradient (Fig. 25). Knowing that it takes time for fish to recover habitats (NIEMI et al. 1990; DETENBECK et al. 1992; RABORN und SCHRAMM 2003), which besides natural variability will influence the efficiency of measures, this approach is being considered as a pragmatic way to reduce the hydro-morphological pressures at Austrian rivers.

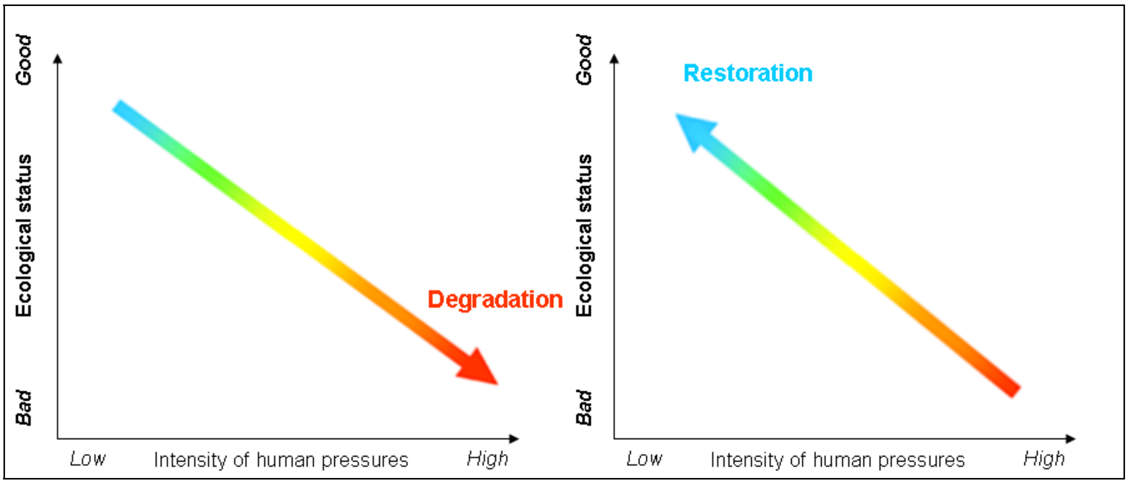

Figure 25: Conceptual approach of the MIRR project, where restoration is treated as a reciprocal action to degradation processes; in this simplified approach restoration is seen as a reduction of the pressures (SCHMUTZ et al. 2008).

3 Background information on decision making, web based spatial decision support and open source/free GIS products

3.1 Decisions and decision making

Decision making is traditionally regarded as being a choice about the course of an action, the choice of a strategy for action or a choice leading to a certain desired objective, whereas knowledge could be seen as the stuff from which and of which decisions are made (HOLSAPPLE 2008). Knowledge can be structured along a gradient of usability and relevance for a decision making process, and in a knowledge-based conception of decision making presented by HOLSAPPLE (2008), the decision forms the highest state of knowledge resulting from processing the other knowledge; new knowledge is created by making a decision (Fig. 26). Another accepted structure of the decision making process includes three major phases: the intelligence phase, design phase, and the choice phase (MALCZEWSKI 1999), that could also be extended to five phases including implementation and monitoring (TURBAN et al. 2004), that might feedback to the start of the decision making process representing an adaptive management cycle, if the decision did not lead to the desired results. In all decisions a first step is the acquisition and identification of the specific knowledge that is needed for the decisions to be made. This knowledge has to be made consequently available for the decision making process and has to be offered to potential decision makers in a way that enables the decision maker to interact with this knowledge; furthermore validation of this knowledge is needed to create confidence in the decision making basis. Taking a decision can be seen as a knowledge intensive activity (HOLSAPPLE 2008).

"**Knowledge** is defined (Oxford English Dictionary) variously as (i) expertise, and skills acquired by a person through experience or education; the theoretical or practical understanding of a subject, (ii) what is known in a particular field or in total; facts and information or (iii) awareness or familiarity gained by experience of a fact or situation". "Philosophical debates in general start with Plato's formulation of knowledge as 'justified true belief'. There is however no single agreed definition of knowledge presently, nor any prospect of one, and there remain numerous competing theories".

"Knowledge acquisition involves complex cognitive processes: perception, learning, communication, association and reasoning. The term *knowledge* is also used to mean the confident understanding of a subject with the ability to use it for a specific purpose if appropriate".[22]

[22] WIKIPEDIA (2008). Knowledge. *Wikipedia, The Free Encyclopedia,* *<http://en.wikipedia.org/w/index.php?title=Knowledge&oldid=248228467(accessed November 1, 2008).* .

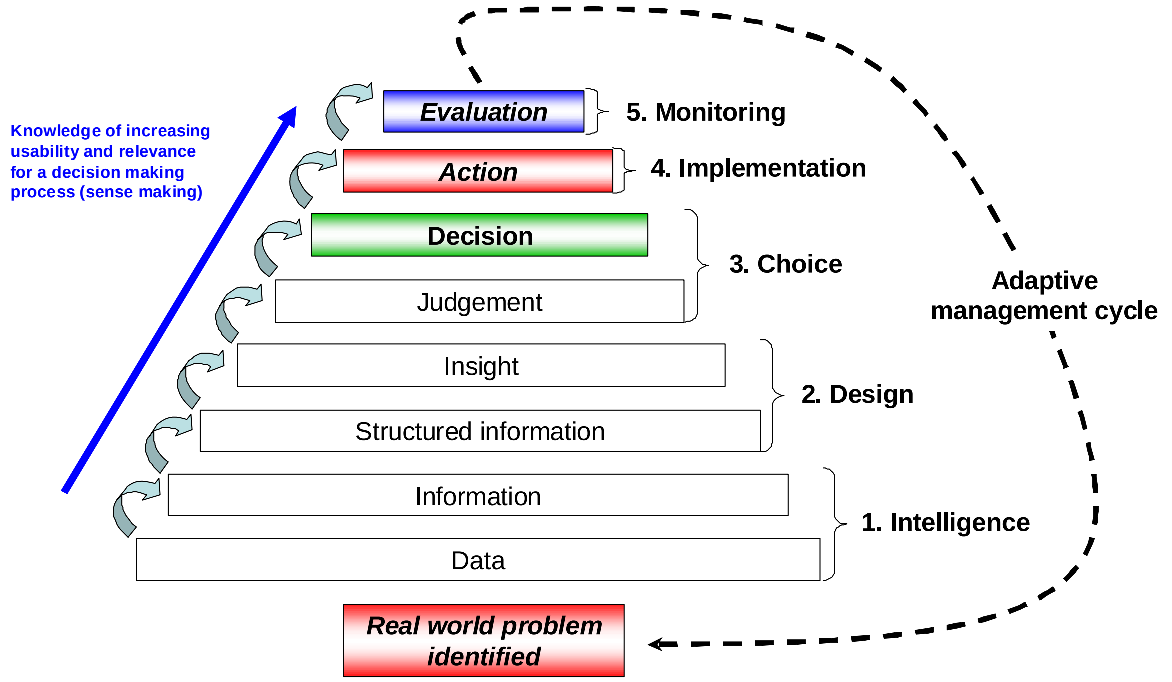

Figure 26: Knowledge as a procession of states, adopted from HOLSAPPLE (2008) and TURBAN et al. (2004).

3.2 Decision support systems

A decision support system (DSS) is usually a computer based system, that represents and processes knowledge in ways to allow decision making to be more productive, agile, innovative and/or reputable (HOLSAPPLE 2008). In a more general view a DSS represents a toolbox which provides, operates and maintains a range of tools (techniques, protocols, models, procedures) for servicing the interactive management process representing the technological interface between management and research (ROGERS und BIGGS 1999).

After LAL et al. (2001) a DSS generally consists of (see also Fig. 27):

- a set of biophysical, social, and economic data;
- a set of integrated analytical, simulation, and/or optimization models derived from individual disciplines;
- an output module for the spatial and/or non-spatial depiction of expected future outcomes; and
- a user-friendly interface that enables relevant stakeholders to perform "what if" scenario analyses.

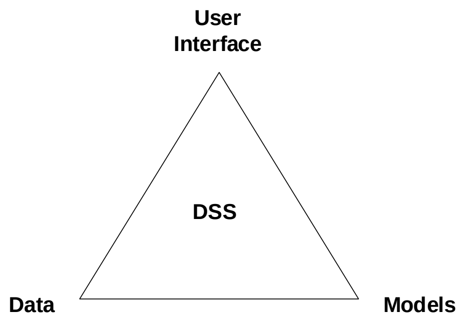

Figure 27: Representation of major parts of a decision support system redrawn from REGMI (2002).

3.2.1 Spatial decision support systems

Decision support systems are frequently build within the framework of a Geographical Information Systems (GIS), which provide a convenient platform for handling, compiling and presenting large amounts of spatial data essential to river basin management; and since GIS technology is often linked to information and knowledge management systems and is readily available to most governmental entities, a high degree of transparency in decision-making for stakeholders can be achieved (MALCZEWSKI 1999; KJELDS et al. 2007). Spatial decision support systems (SDSS) combine GIS and DSS technologies to aid spatially based decision-making. A SDSS is designed to solve complex spatial problems with the main focus of design oriented towards decision-makers (REGMI 2002). Usually GIS tools do not allow for a direct interaction with the data for decision making, but an accordingly formatted integrated system containing only relevant pre-processed information using web based and GIS enabled graphical user interfaces with relational databases, visualization techniques, analysis tools and decision logic strongly enables managers and decision makers to obtain answers to critical questions and to interactively explore the outcomes of different strategies (KJELDS et al. 2007). Existing applications of Decision Support Tools demonstrate the benefits of Decision support systems (DSS) for cost-effective information management and have proven to be reliable and effective tools in the integrated management enabling professional communication between scientists, managers, decision makers, major stake holders and the public and also in the communication of conditions and decisions (KJELDS et al. 2007). After KJELDS et al. (2007) typical DSS interactive and integrated components are:

- *Data and information management:* The data and information component is key and central in developing a DSS. The focus is integrating database and connecting data islands into a dynamic framework with advanced display, mapping, query and presentation capabilities.

- *Analysis and modelling:* The data framework provides the basis for further analysis and interpretation of data and information. Depending on stage and scope of the DSS the analysis can range from simple to complex including statistical and numerical models, economic and cost/benefit as well as User Defined and Custom tools
- *Scenario management and alternative formulation:* The DSS framework is capable of supporting and providing information (costing and prioritization) for project feasibility and planning projects as well as design and implementation. Upon implementation the project may have an operations component that requires real time and online decision making.
- *Decision making:* Customizable GIS and Web based interfaces are tailored to meet specific needs and requirements. Advanced graphics, on-line access, custom rules and interpretations can be embedded into the DSS to support and provide the basis for decision makers to make timely, reproducible and well informed decisions.

3.2.2 Web based spatial decision support

Due to the rapid growth of the internet and the related technologies, increasingly, web-based approaches to GIS and web based spatial decision support have gained in importance. This enables strongly the ability of researchers, regulatory agencies, planners, and consultants to share data, models, tools, and other information with potential users (DYMOND et al. 2004). The benefits of using the internet for SDSS has been documented by many researchers, and the major advantages of a WSDSS after DYMOND et al. (2004) include the following:

1. C*ommunication* between and among field experts, decision makers, and stakeholders can be greatly improved,

2. *Model accessibility* is improved as the user only needs a browser—no GIS tools or databases,

3. *Updated models* are always available on the web server so that distribution is not a problem and administration issues of the software and hardware are centralized,

4. As a web-based model, there is inherent *cross-platform flexibility*

5. *Data input* into the model can be verified at the server level by experts, data pre-processing needed is done by experts; and

6. *Models* that require intensive CPU operations can optimally be run on high level servers.

3.3 Open Source and free Web-GIS Software

Open source means, that the source code is open to the user allowing them "to use, change, and improve the software, and to redistribute it in modified or unmodified form".[23] **"**Free software is software that can be used, studied, and modified without restriction, and which can be copied and redistributed in modified or unmodified form either without restriction".[24]

Open source/free GIS web products and services become increasingly popular (DICKMANN 2001; KROPLA 2005; DAVIS 2007; MITCHELL et al. 2008; STROBL will be published in 2009) widely applied (see for example the references on the homepage of the Where Group[25]) and might serve as important social catalysers (see the homepage of the Open Planning Project-TOPP, a non-profit incubator for projects and technology to catalyze large scale social change[26] and the free book "Open source democracy"[27] by RUSHKOFF, 2003) For example on the Open plans platform[28], an explicit platform for social activism, a project called "Geoserver for freshwater Conservation" has been started that should be mainly based on open source tools[25]. "With open technologies, governments everywhere could become radically more effective" and save a lot of money[25]; free openly accessible and interoperable information systems open the way for collaborative and integrative decision-making and for a large scale re-use of already implemented ideas and systems. At http://opensourcegis.org/ a comprehensive and updated list of available open source/free GIS products for a variety of purposes could be found. Generally the demand for web-based GIS is increasing at the mainstream market, although up to now web GIS products only offer limited ability for data analysis (BRAUNER 2008).

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[23] http://en.wikipedia.org/wiki/Open_source_software, 29.12.2008
[24] http://en.wikipedia.org/wiki/Free_software, 29.12.2008
[25] http://www.wheregroup.com/, 29.12.2008
[26], http://topp.openplans.org/, 29.12.2008
[27] http://www.demos.co.uk/publications/opensourcedemocracy2, 29.12.2008
[28] http://www.openplans.org/, 29.12.2008

4 Conceptual development of the WSDSS

4.1 Translating the MIRR project into a DSS framework

In its responsibility for implementing the EU-WFD in Austria, and especially for the development of a river restoration strategy and a catalogue of measures needed for the so called “National river basin management plans” (Tab. 3), the Ministry of Life needed decision support, and charged the IHG at the BOKU with the MIRR project. Within the *Intelligence phase* of the project, the problem was further specified, the objectives were determined, a comprehensive literature review to determine known ecologically relevant pressure parameters on different scales was conducted (ZITEK 2006), the availability of relevant datasets in Austria was assessed, and finally a large set of parameters for 400 fishing sites in Lower Austria was collected (POPPE und ZITEK 2006). In the *Design phase* of the project, the models were formulated and strategies developed, the relevant criteria were identified, alternatives were discussed, and a program of measures developed (SCHMUTZ et al. 2007; SCHMUTZ et al. 2008). Finally, the results of the intelligence phase were validated within a case study (HOHENSINNER et al. 2008).

This master thesis generates a framework for supporting the *Choice phase* of the project for generating spatial explicit solutions to the model, for a sensitivity analysis of different strategies, for the selection of best alternatives, and for developing a plan for implementation (Fig. 28). Finally, restoration measures will be implemented, and will lead to the good ecological status. In the case of a failure adaptations related to one of the prior decision support phases will be needed, for example testing and integrating different parameters.

Table 3: Instruments relevant for the implementation of the WFD at surface water bodies with main responsibilities and activities.

Implementation	Responsibility	Activity
WFD	EU	Setting the legal framework and controlling the implementation of the WFD.
National river basin management plans	Government of Austria (Ministry of Life)	Development of a river restoration strategy and a catalogue of measures for national planning areas, assessment of the ecological and economic efficiency of these measures; reporting the status of Austria`s water bodies to the EU.
Regional implementation of river basin management plans	Federal State Governments	Implementation of the proposed types of measures within their national river basin districts, integrating the local spatial conditions with the aim to reach the good ecological status of water bodies, monitoring and reporting of the ecological status of water bodies to the Austrian Government.

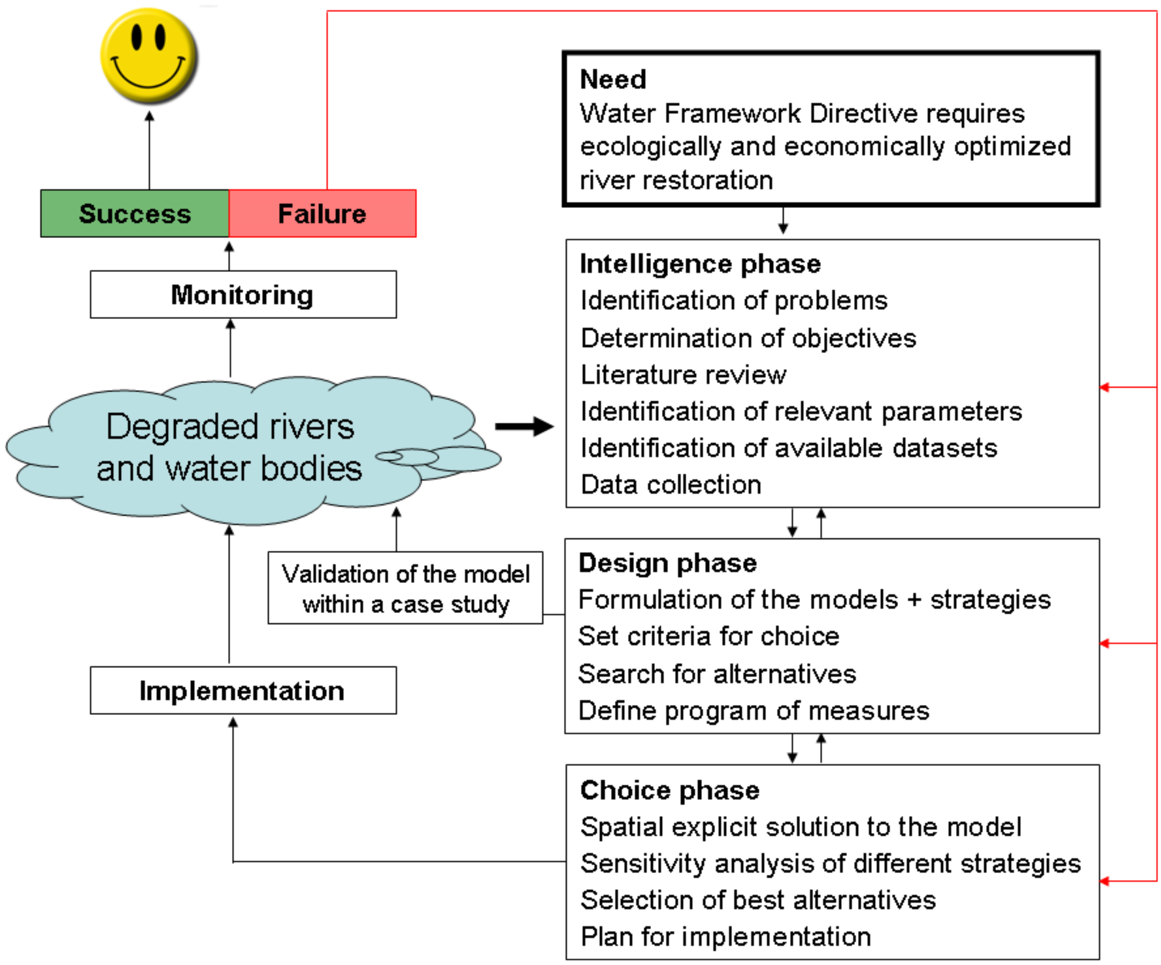

Figure 28: The MIRR project translated into a DSS framework containing the typical phases (intelligence, design, choice, implementation, monitoring); changed after TURBAN et al. (2004).

4.2 *Pre-processing of existing datasets*

The parameters identified within the MIRR project form the basis of the WSDSS. Therefore, if one would like to implement the WSDSS for the whole Austrian river network, data pre-processing is needed. The aim of this pre-processing is the extraction of the parameters identified by the MIRR project for each 500 m section in the Austrian river network, and their subsequent translation in a 5-tiered scheme allowing to directly model the ecological status based on the intensity of each pressure type. Data that have to be pre-processed and parameters that have to be extracted are:

- SINUS data set
  - Proportion of forest in the catchment above
  - Proportion of forest in 100 m x 10 km buffer
- Digital data from the Austrian report on the current situation of water bodies and rivers soon available in a database
  - Number of connectivity interruptions within the ecological fish region of the
  - Mean morphology index of the river bottom within a 10 km buffer.
  - Impoundment lengths per 500 m section
  - Water abstraction intensity

For the last two parameters (impoundment lengths per 500 m section, water abstraction intensity) probably further more detailed investigations might be needed, as data might be incomplete. For the land use parameters, it might be useful, to use the centre of each 500 m section for the required spatial queries. For the integration of the economic aspect of each restoration effort, data on the costs of reducing a specific type of pressure (per degree pressure reduction on a 5-tiered scheme) have to be added. Here an existing report containing detailed catalogue of measures together with estimation of costs and ecological efficiency could be used as a basis (BLMFUW 2007).

Finally all information should be related to 500 m sections of the river network. Subsequently, after adding other required information to the database, the data could be imported into PostgreSQL/PostGIS database. The algorithm for calculating the ecological status of each 500 m segment has also to be defined and implemented based on the specific combination of pressures taking into account the pressure type specific influence on the overall ecological status of each 500 m segment. Finally the access to the content of the database has to be established by the implementing the client/server interface (Fig. 29).

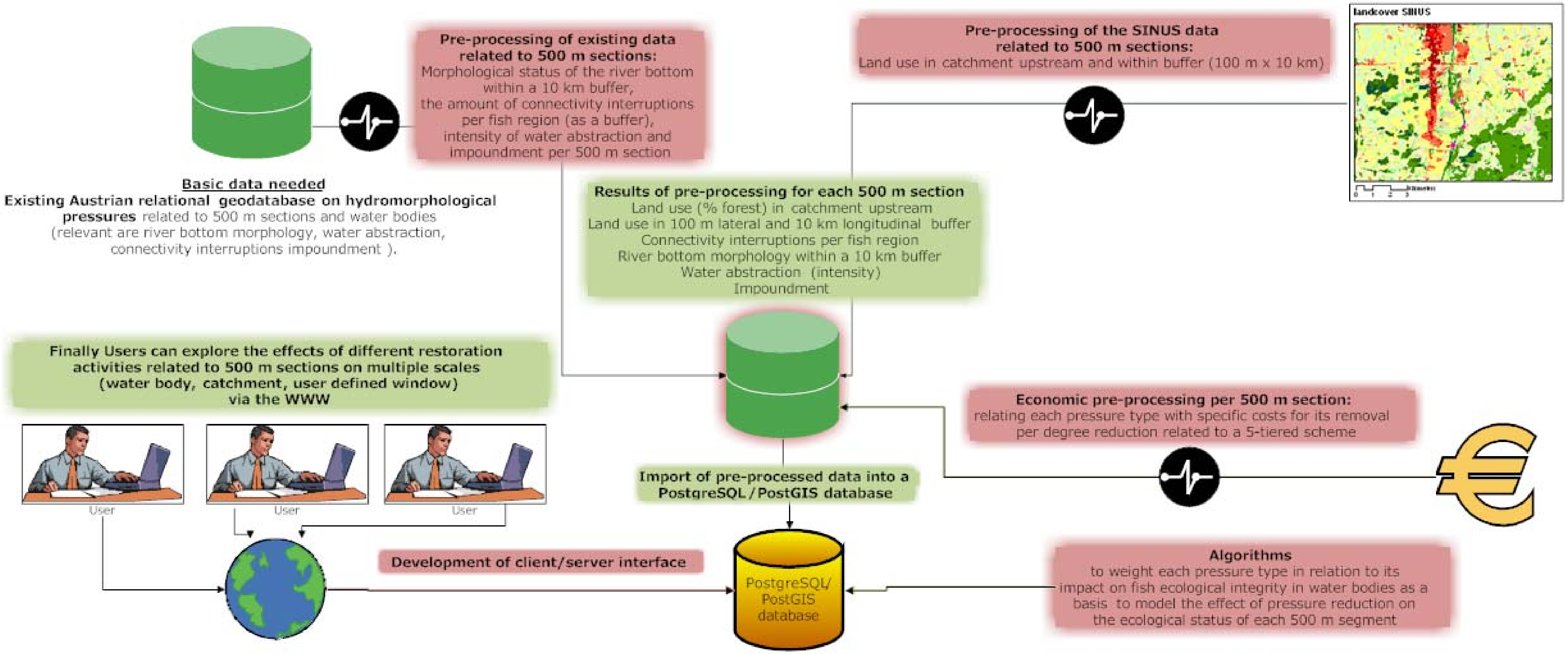

Figure 29: Schematic representation of pre-processing needed to translate the results of the MIRR project into the proposed WSDSS.

4.3 *Important components of the WSDSS architecture*

PostgreSQL

"PostgreSQL is a powerful, open source object-relational database management system. It has more than 15 years of active development and a proven architecture that has earned it a strong reputation for reliability, data integrity, and correctness."[29]

PostGIS

"PostGIS adds support for geographic objects to the PostgreSQL object-relational database. In effect, PostGIS 'spatially enables' the PostgreSQL server, allowing it to be used as a backend spatial database for geographic information systems (GIS), much like ESRI's SDE or Oracle's Spatial extension. PostGIS follows the OpenGIS 'Simple Features Specification for SQL' and has been certified as compliant with the 'Types and Functions' profile."[30]

Apache HTTP server

"The Apache HTTP Server Project is an effort to develop and maintain an open-source HTTP server for modern operating systems including UNIX and Windows NT. The goal of this project is to provide a secure, efficient and extensible server that provides HTTP services in sync with the current HTTP standards. Apache has been the most popular web server on the Internet since April 1996. The Apache HTTP Server is a project of the Apache Software Foundation."[31]

Mapbender

"Mapbender is an Open Source Geospatial Foundation project and the software and portal site for geodata management of OGC OWS architectures. The software provides web technology for managing spatial data services implemented in PHP, JavaScript and XML and licensed under the GNU GPL. It provides a data model and interfaces for displaying, navigating and querying OGC compliant map services. The Mapbender framework furthermore provides authentication and

[29] http://www.postgresql.org, 25.12.2008
[30] http://postgis.refractions.net, 25.12.2008
[31] http://httpd.apache.org, 25.12.2008

authorization services, OWS proxy functionality, management interfaces for user, group and service administration in WebGIS projects."[32]

A selection of Mapbender applications can be found at the Mapbender gallery[33]. An important feature of Mapbender is its ability to implement a user management, which other frameworks like for example OpenLayers[34] lack, although the Mapbender user management can be extended to support OpenLayers map interfaces combining the advantages of both packages.

UMN MapServer

"MapServer is an Open Source development environment for building spatially-enabled internet applications. MapServer is not a full-featured GIS system. Instead, MapServer excels at rendering spatial data (maps, images, and vector data) for the web.

Features

- Advanced cartographic output
    - Scale dependent feature drawing and application execution
    - Feature labelling including label collision mediation
    - Fully customizable, template driven output
    - TrueType fonts
    - Map element automation (scale bar, reference map, and legend)
    - Thematic mapping using logical- or regular expression-based classes
- Support for popular scripting and development environments
- PHP, Python, Perl, Ruby, Java, and C#
- Cross-platform support
    - Linux, Windows, Mac OS X, Solaris, and more
- A multitude of raster and vector data formats
    - TIFF/GeoTIFF, EPPL7, and many others via GDAL
    - ESRI shape files, PostGIS, ESRI ArcSDE, Oracle Spatial, MySQL and many others via OGR
    - Open Geospatial Consortium (OGC) web specifications

[32] http://www.mapbender.org/Main_Page, 25.12.2008
[33] http://www.mapbender.org/Mapbender_Gallery, 25.12.2008
[34] http://openlayers.org/, 25.12.2008

- WMS (client/server), non-transactional WFS (client/server), WMC, WCS, Filter Encoding, SLD, GML, SOS
- Map projection support
    - On-the-fly map projection with 1000s of projections through the Proj.4 library."[35]

CGI

"The CGI (Common Gateway Interface) defines a way for a web server to interact with external content-generating programs, which are often referred to as CGI programs or CGI scripts. It is the simplest, and most common, way to put dynamic content on your web site."[36]

"The Common Gateway Interface (CGI) is a standard protocol for interfacing external application software with an information server, commonly a (HTTP) web server. The task of such an information server is to respond to requests (in the case of web servers, requests from client web browsers) by returning output. Each time a request is received; the server analyzes what the request asks for, and returns the appropriate output. The two simplest ways for the server to do this, are the following:

- if the request identifies a file stored on disk, return the contents of that file;
- if the request identifies an executable command and possibly arguments, run the command and return its output

CGI defines a standard way of doing the second. It defines how information about the server and the request is passed to the command in the form of arguments and environment variables, and how the command can pass back extra information about the output (such as the type) in the form of headers."[37]

GML

"The Geography Markup Language (GML) is the XML grammar defined by the Open Geospatial Consortium (OGC) to express geographical features. GML serves as a modelling language for geographic systems as well as an open interchange format for geographic transactions on the Internet. Note that the concept of feature in GML is a very general one and includes not only conventional "vector" or discrete objects, but also coverages (see also GMLJP2)

[35] http://ms.gis.umn.edu, accessed 25.12.2008
[36] http://httpd.apache.org/docs/2.0/howto/cgi.html, accessed 25.12.2008
[37] http://en.wikipedia.org/wiki/Common_Gateway_Interface, accessed 25.12.2008

and sensor data. The ability to integrate all forms of geographic information is key to the utility of GML."[38]

HTML

"HTML, the acronym of HyperText Markup Language, is the predominant markup language for Web pages. It provides a means to describe the structure of text-based information in a document — by denoting certain text as links, headings, paragraphs, lists, and so on — and to supplement that text with interactive forms, embedded images, and other objects. HTML is written in the form of tags, surrounded by angle brackets. HTML can also describe, to some degree, the appearance and semantics of a document, and can include embedded scripting language code (such as JavaScript) which can affect the behavior of Web browsers and other HTML processors. Files and URLs containing HTML often have a .html or .htm filename extension."[39]

PHP

"PHP is a widely-used general-purpose scripting language that is especially suited for Web development and can be embedded into HTML."40 It "is a scripting language originally designed for producing dynamic web pages. It has evolved to include a command line interface capability and can be used in standalone graphical applications. While PHP was originally created by Rasmus Lerdorf in 1995, the main implementation of PHP is now produced by The PHP Group and serves as the de facto standard for PHP as there is no formal specification. PHP is free software released under the PHP License, however it is incompatible with the GPL due to restrictions on the usage of the term PHP. PHP is a widely-used general-purpose scripting language that is especially suited for web development and can be embedded into HTML. It generally runs on a web server, taking PHP code as its input and creating web pages as output. It can be deployed on most web servers and on almost every operating system and platform free of charge. PHP is installed on more than 20 million websites and 1 million web servers."[41]

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[38] http://en.wikipedia.org/wiki/Geography_Markup_Language, 25.12.2008
[39] http://en.wikipedia.org/wiki/Hypertext_Markup_Language, 25.12.2008
[40] http://www.php.net/, 25.12.2008
[41] http://en.wikipedia.org/wiki/PHP, 25.12.2008

4.3.1 Entity relationship model (ERM) of the WSDSS database

The entity relationship model (ERM) displays the structure of the tables existing in the SDSS database (Fig. 30, Tab. 4). The central table is the 500_m_segments table, with the related parameter_values table. The parameter_values table contains the degree of intensity for each pressure parameter (from 1 to 5 with five being the highest impact), which is equivalent to the ecological status; removing pressures by one degree, changes also the ecological status by one degree. This directly allows for modelling the ecological status of each 500 m segment by changing the degree of pressure criteria. One of the most important parts of the WSDSS is the algorithm used to calculate the ecological status for each 500 m segment, as here the relative importance of each pressure is taken into account, which directly influences the efficiency and the costs of a specific scenario. Costs in the parameter_values table are expressed as costs per degree reduction of a specific pressure along the 5-tiered scheme. This allows for a calculation of the total costs for each model by multiplying the costs per degree pressure reduction with the pressure degrees removed at all 500 m segments. The 500 m segments are directly linked to four spatial scales: the water body scale (water_bodies table), the catchment scale (catchment table) and the national planning area scale (national_planning_area table). It is also possible, to directly select water bodies within catchments or NPA`s. The user table contains the information on the users added during the operation of the WSDSS and is linked to a full set of parameters in the parameter_values table by the User_ID.

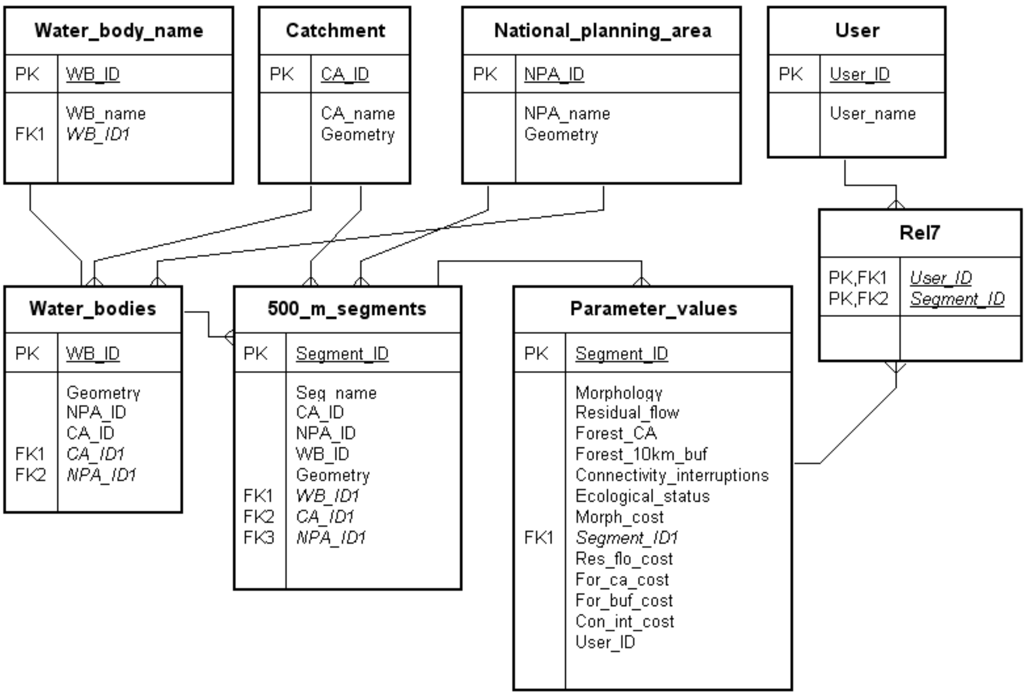

Figure 30: Entity-relationship model of the SDSS database.

Table 4: Entity relationship diagram information.

Entity Relationship Diagram Information SDDS Project Andreas Zitek December 30, 2008			
Column	**Datatype**	**Nullable**	**Comment**
Water_body_name			
WB_ID	numeric(10,0)	0	
WB_name	char(50)	0	
Water_bodies			
Column	Datatype	Nullable	Comment
WB_ID	numeric(10,0)	0	
Geometry	line	0	
NPA_ID	numeric(10,0)	0	
CA_ID	numeric(10,0)	0	
500_m_segments			
Column	Datatype	Nullable	Comment
Segment_ID	numeric(10,0)	0	
Seg_name	char(50)	0	
CA_ID	numeric(10,0)	0	
NPA_ID	numeric(10,0)	0	
WB_ID	numeric(10,0)	0	
Geometry	line	0	
Parameter_values			
Column	Datatype	Nullable	Comment
Segment_ID	numeric(10,0)	0	
Morphology	decimal(10,0)	0	
Residual_flow	decimal(10,0)	0	
Forest_CA	decimal(10,0)	0	
Forest_10km_buf	decimal(10,0)	0	
Connectivity_interruptions	decimal(10,0)	0	
Ecological_status	decimal(10,0)	0	
Morph_cost	decimal(10,0)	0	
Res_flo_cost	decimal(10,0)	0	
For_ca_cost	decimal(10,0)	0	
For_buf_cost	decimal(10,0)	0	
Con_int_cost	decimal(10,0)	0	
User_ID	numeric(10,0)	0	
User			
Column	Datatype	Nullable	Comment
User_ID	numeric(10,0)	0	
User_name	char(50)	0	
Catchment			
Column	Datatype	Nullable	Comment
CA_ID	numeric(10,0)	0	
CA_name	char(50)	0	
Geometry	polygon	0	
National_planning_area			
Column	Datatype	Nullable	Comment
NPA_ID	numeric(10,0)	0	
NPA_name	char(50)	0	
Geometry	polygon	0	
Rel7			
Column	Datatype	Nullable	Comment

4.3.2 General description of the data processing within the WSDSS

The user approaches the DSS environment via the WWW using an HTML interface implemented in Mapbender (Fig. 31). This application provides all functionality that is accessible through the web front end:

- creating new users
- selection of areas (polygons) with 500 m segments returning their corresponding values per segment
- selection of areas (polygons) with water bodies returning the contained 500 m segments with their corresponding values in a HTML spreadsheet
- select all 500 m segments that are part of a catchment or national planning area with their corresponding values in a HTML spreadsheet
- select singular water bodies with the corresponding values of the 500 segments in a HTML spreadsheet (shown as example in Fig. 31)

Additionally, the user is introduced into the main results of the MIRR project, especially to the recommended restoration strategy. Furthermore the functionality and aim of the WSDSS is shortly explained.

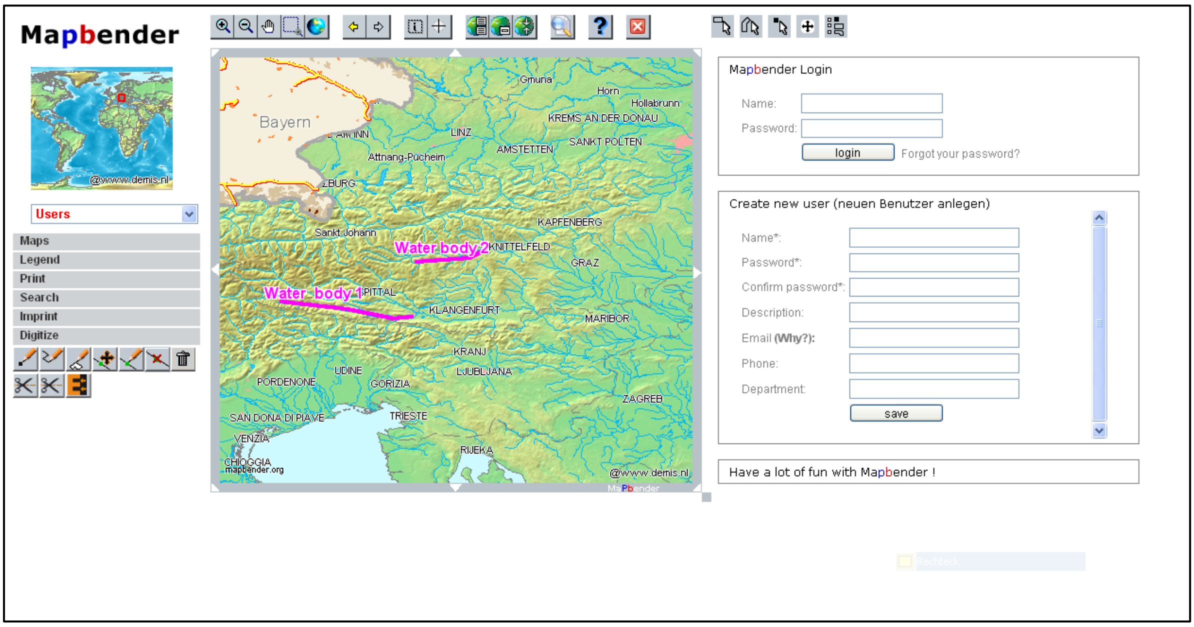

Figure 31: Concept of the HTML interface implemented in Mapbender, containing the functionality to create users and view the pressure values and the ecological status for each 500 m segment.

All data is stored within a PostgreSQL/PostGIS database. Map images are generated by a web map service (UMN MapServer) and returned to the calling application, here a client interface implemented with Mapbender. Interactive selection of segments queries a web feature service (also UMN MapServer) and the returned information can be displayed again as a map by the web map service and additionally as a HTML spreadsheet (Fig. 32).

WWW Browser (HTML, JavaScript)

↕

OGC OWS Client Environment (Mapbender, PHP, SQL)

↕

OGC WMS MapServer (CGI, SQL)

↕

Data Store PostgreSQL/PostGIS (SQL)

Figure 32: General structure of the Web Based Spatial Decision Support System based on open source software.

The general process of viewing the original values for the 500 m river segments works as follows:

- The user opens the web site and in turn receives a dynamically generated web application.
- The application includes a map, navigation and selection buttons.
- The map shows the water bodies, catchments or national planning areas coloured corresponding to their ecological status, but also the 500 m segments could be directly shown instead.
- All metadata required to display the OGC WMS map is managed by the OGC orchestration framework Mapbender.
- The data is stored in a central database and rendered as a map by the OGC WMS software MapServer.
- Each water body, catchment, national planning area or 500 m segment can be selected individually to show the corresponding alphanumerical values (Fig. 33).

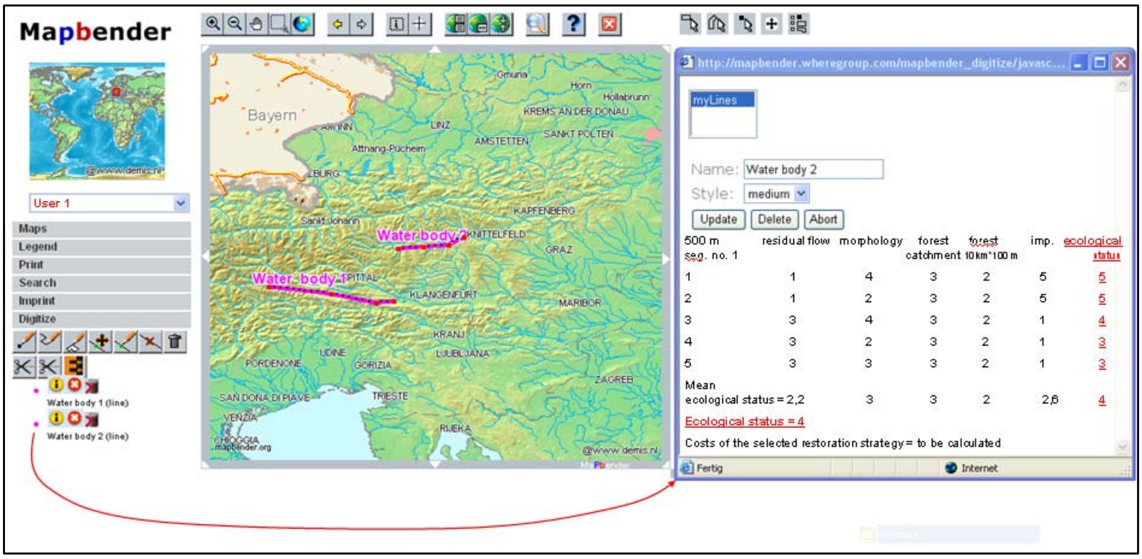

Figure 33: Concept of the HTML interface implemented in Mapbender, showing two selected water bodies (left side) and the information on the magnitude of different pressures for each 500 m segment, the ecological status of each 500 m segment and the overall ecological status of water body 2 returned by a HTML spreadsheet; the ecological status per 500 m segment is NOT the mean value, but is calculated by a defined algorithm, that might be driven by the worst ecological status in a row, but has to be specified as one of the most important components of the WSDSS.

4.3.3 Detailed description of the data processing within the WSDSS

The data stored in the PostgreSQL/PostGIS table “parameter_values” can be modelled (edited) online. To do this it is required to first create a new user on the system and log in with that account. By creating a new user the system automatically creates a copy of all data (within the same table, added at the bottom) and adds the corresponding user name (technically the "user_id") to each dataset. This way the user can now edit and change all values in the “parameter_values” table. The original data is not changed, it is identified by a fixed system user named "root". Any other value in the field “user_id” of the table “parameter_values” identifies the corresponding datasets as part of that model. All data can be queried by selecting a user name. Internally this adds an SQL WHERE Parameter with the user_id to the database query. This way the user can interact with the data by selecting water bodies, catchments or national planning areas and change all relevant values in the HTML spreadsheet that shows the alphanumeric data for each 500 m segment. Changing a value in the spreadsheet display of the data triggers a JavaScript function that recalculates the new ecological status of each 500 m segment (by a specific algorithm) and the ecological status of the water body (mean value of the 500 m segments) and sums up the costs (by multiplying the degrees changed with the costs per degree change per pressure type and summarizing the pressure type specific calculation results) for each restoration scenario (“*model*”, Fig. 34).

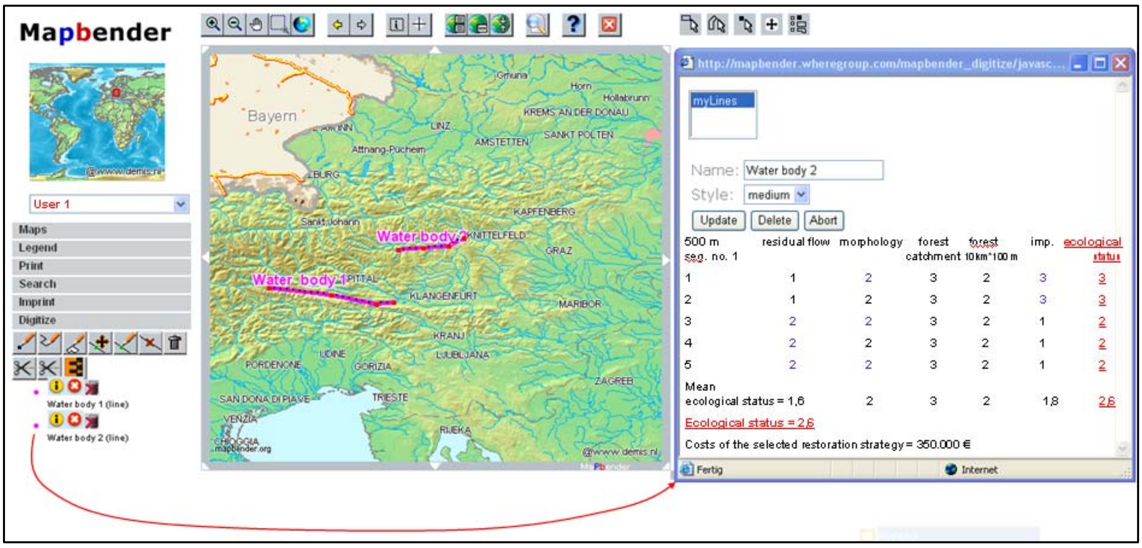

Figure 34: Concept of the HTML interface implemented in Mapbender, showing the changed values of the magnitude of different pressures (in blue) and the recalculated ecological status for each 500 m and the overall ecological status of water body 2 returned by a HTML spreadsheet; the ecological status is still 2,6 (moderate), as 40 % (two 500 m segments) are still impounded, although some restoration measures enhanced the ecological status of the impoundments, and the forest in catchment is still less than 54 %.

After editing the spreadsheet, the results can be stored and made accessible by adding the user name to a selection box. At the end each user represents a service that can be activated showing the modelling results. This setup allows for a collaborative modelling a decision support based on the Web.

Summarizing, the creation of a new model requires the following steps:

- To change a parameter the user has to first log into the system.
- All requests to the MapServer are then processed with that user's ID as a parameter to the SQL script.
- Authenticated users can change data and store them back to the database
- All subsequent map and data requests from the web browser will display the modified data.

In more detail, the process of creating a new model allowing removing pressures from 500 m river segments works as follows (Fig. 35):

- The user opens the web site and in turn receives a dynamically generated web application including a map, navigation and selection buttons with the original data.
    - The OGC WMS request to the database that displays the original data is SELECT * FROM parameter_values WHERE user_id = "root";
- The user creates a new account on the system or authenticates with a previously created account
    - The OGC WMS that displays the dynamic user models requires and additional "Vendor Specific Parameter" identifying the model. The database query is SELECT * FROM parameter_values WHERE user_id = "[user_id]". The value in square brackets is replaced dynamically by the “user_id” which is added by the web mapping environment Mapbender.
- Maps are generated by a web map service (UMN MapServer) and displayed in the client interface generated by Mapbender. Interactive selection of segments uses a web feature service (also UMN MapServer) and the returned information can be displayed again as a map by the web map service and/or as an HTML spreadsheet.
    - Only two MapServer configuration files (Mapfiles) need to be maintained:
        - one for the user “root” with a static SQL query
        - one, where the user is dynamically changed by a dynamically modified SQL query.
- Authenticated users can edit their personal copy of all values of all 500 m segments and store changes back to the database. The edited values are stored with the user's

account number in order to distinguish them from the original values which are owned by the user "root".

- The new ecological status for each 500 m segment (by a specific algorithm), of the water body (as a mean value of the ecological status of all 500 m segments per water body) and the costs of each restoration scenario (by multiplying the degrees changed with the costs per degree change per pressure type and summarizing the pressure type specific calculation results) is calculated and displayed.

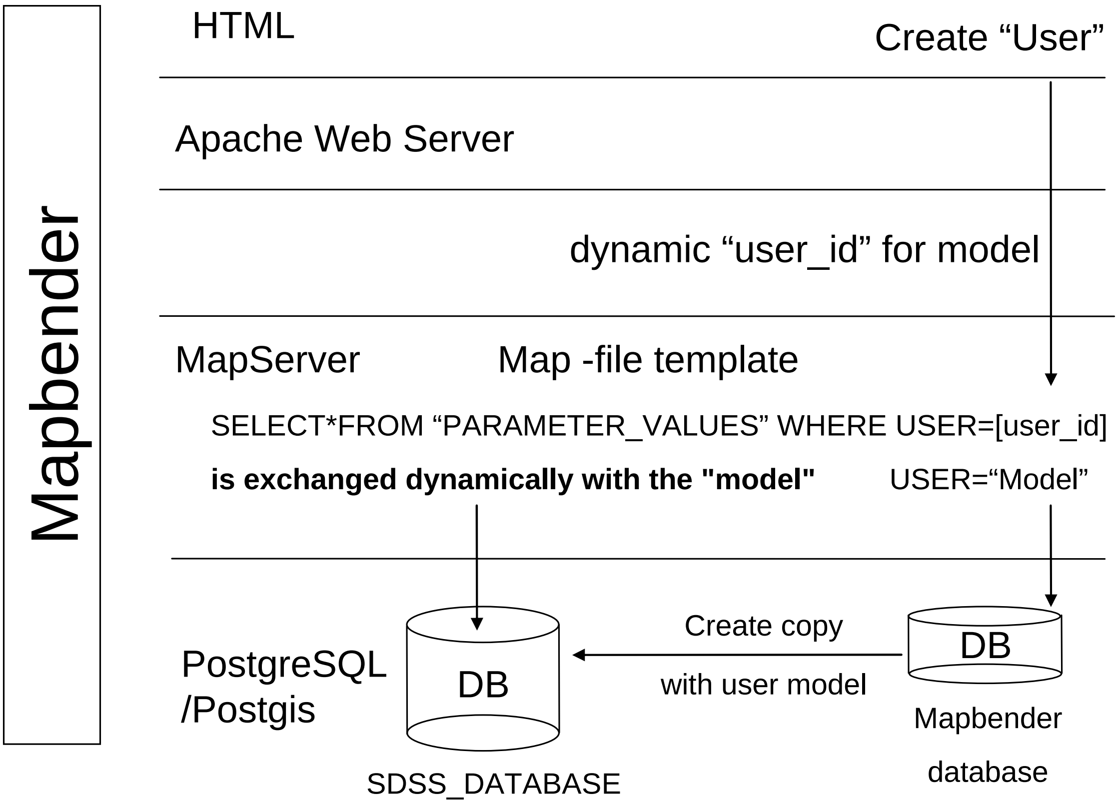

Figure 35: Components needed to establish a communication between the user and the database; the newly created user is added to the SQL statement of the Map-file with his user number. This will only select the content that was newly created and added to the existing table with the user ID. Another, separate OGC WMS only queries for the data of the user root. This map service shows the original, unaltered data. It cannot be changed.

The general process of viewing an existing model works as follows:

- The original values are always available by selecting the "root" user
- To see another model the user selects the corresponding user name from the selection box.
- The user name is added as a Vendor Specific Parameter to the standard OGC WMS request as "user_id".
- MapServer uses the Vendor Specific Parameter "user_id" in the SQL request to the database. This allows to specifically select the data of the corresponding user.

- The database PostgreSQL/PostGIS processes the SQL-2 query and returns the data to MapServer
- MapServer renders a map with the received data and creates a PNG image that is returned to the web browser where it is displayed

Roles of the components (Fig. 36):

- The PostgreSQL database "mapbender" stores the user information. This is required to allow users to authenticate; the user “root” is the first user that is automatically created by the system.
- The PostgreSQL database "SDSS_database" stores all geometric and alphanumeric data including the "user_id" in the table "parameter_values".
- The Mapbender framework stores meta-information of OGC web map services, the application interface and manages users.
- The Apache webserver receives all requests from the browser, relays them to the Mapbender PHP Scripts or UMN MapServer and returns their results to the browser.
- UMN MapServer returns maps for OGC WMS GetMap requests and result-sets for OGC WMS GetFeatureInfo requests to the Apache web server which relays them to the browser.

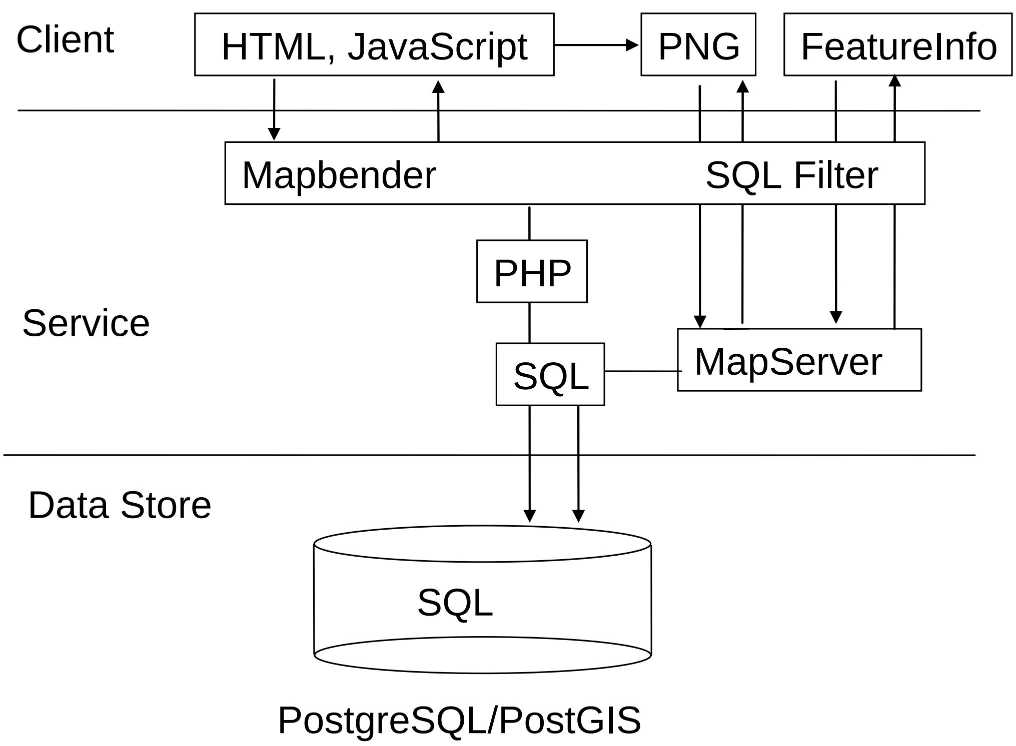

Figure 36: Roles of the components within the Web based Spatial Decision Support System.

5 Conclusions

Taking decisions can be seen as a knowledge intensive task. Besides that, the existing knowledge has to be made available in an adequate manner to support decision makers, politicians, planners and other potential user groups in directing their actions. The comprehensive analysis results of the MIRR project allow for the development of a WSDSS framework supporting the development of spatially explicit river restoration strategies making the existing knowledge accessible for a broader use. As a main finding of the MIRR project was the additive influence of different types of pressures on fish, the algorithm that is used to calculate the ecological status of each 500 m segment is one of the most important parts of the WSDSS. Generally, river segments with multiple pressures usually were more degraded that river segments subjected only to single pressures. Therefore the restoration should start at river sites with only single pressures, successively implementing the most effective measures at from multiply affected sites. The most important factors influencing fish identified were land use, morphology and connectivity, why a first approach should focus on these pressure types. Land use was recognized as a surrogate parameter, integrating several other pressure types (channelization, loss of shoreline vegetation…), why the removal of morphological changes and connectivity interruptions, together with residual flow stretches should be targeted first. Finally a comprehensive reduction of different pressure types will be needed, as for example only focusing only on the restoration of connectivity will not lead to a significant change in ecological integrity, when morphology remains degraded. Generally the algorithm that determines the ecological status of a 500 m segment subjected to multiple pressures can be seen as one the most important components of the WSDSS, determining the success and costs of different strategies of removing different combinations of pressures.

The proposed framework directly allows for a modelling of the effects of removing single and multiple pressures on various spatial levels. Based on the direct interaction with 500 m segments, users could aggregate the results on multiple spatial levels in accordance to the needs of the EU-WFD: the water body, the catchment, the national planning areas and areas directly selected by the users. This allows for the first time an estimation of actions and costs needed in different catchments and different regions of Austria. The WDSS framework described therefore could be seen as an innovative step towards a broader use of web based open source GIS technology in combination with up to date ecological knowledge for a collaborative, ecologically and economically optimized decision support and integration of the public, both important requirement of the EU-WFD. The proposed WSDSS framework allows for going directly into the next phase of the development of a MSS, the implementation of a prototype. As it was recognized during the development of the presented WSDSS, much interaction between users, scientists and technicians will be needed again, to really produce something that is really useful containing all the functions that are needed for decision support. This could be also seen as one of the main conclusions of this thesis. Generally it was recognized, that the development of a decision support system is not a linear process, and might require intense back and forward movements between the *Intelligence-Design-Choice-Implementation-Monitoring* phases of a DSS development process. Summarizing the advantages and disadvantages of the proposed approach are:

Advantages

- First approach to make the results of the MIRR project directly available to a broader community for a spatially explicit decision support
- Visualisation and analysis of the degree of degradation of rivers on different spatial scales
- Decision support on a all spatial scales relevant for the WFD (water bodies, catchments, national planning areas) allowing to model multiple restoration measures on relatively small spatial scale (500 m segments)
- Different restoration strategies concerning different spatial scales can be modelled, as it is possible to accumulate the values of the 500 m segments on water bodies, catchments and national planning areas
- Costs of different restoration strategies can be estimated at different spatial scales
- Effects of removing single and multiple pressures can be modelled
- Parameters can be easily added or removed in the case of an adaptation of the model
- The algorithm for calculating the ecological status for each 500 m segment could be changed accordingly monitoring results
- Updated models are always available on the web server, administration issues of the software and hardware are centralized
- Data pre-processing is done by experts
- Easy to understand approach

- The user only needs a browser and no extra GIS tool
- Exchange of different strategies via the www allow for a collaborative decision support and communication between different user groups
- At the same time the public is informed and also is able to contribute to the discussion and decision process
- Cheap, customizable software packages
- Once the system is properly working, the architecture and know how could be used to produce cheap WSDSS for similar decision support problems.

Disadvantages

- The fish/pressure relationships identified within the MIRR project may not be valid in other (more alpine) parts of Austria, as the analyses were based on a dataset limited to lower Austria
- Some pressure types (especially hydro-peaking) were not covered within the MIRR project
- On an Austrian scale, the required data sets might be incomplete (especially with regard to impoundment, and water abstraction), that might cause much work to establish the criteria needed
- Data pre-processing might be a labour intensive task
- The implementation of a more complicated and sophisticated decision support approach will require a change of the software architecture
- It might be complicated to adequately model the spatial effects of restoration measures across water bodies,
    - e.g. the upstream effects of the removal of connectivity interruptions (e.g. if only the connectivity interruptions within a fish region are removed, but the connectivity interruption(s) at the river mouth is (are) remaining, the ecological effect is limited, as fish migration is still blocked at the most sensitive position in the river network); this problem could be solved by integrating a factor into the algorithm, that weights the efficiency of connectivity measures based on the location of the water body within a river system, taking into account the existence of downstream connectivity interruptions.

6 Literature

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