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The *dewnet* network: JESAT a toolset for environment system assessment, analysis and management

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There is a worldwide demand to improve irrigation systems and water use efficiencies to ensure sustainable agricultural productivity within the framework of sustainable integrated water resources management (IWRM) and environmental system preservation. To address this issue a German and Australian collaborative research cooperation initiative was initiated by the ***dewnet*** network established by the Friedrich-Schiller-University of Jena, Germany, and three German small and medium enterprises (SMEs). The ***dewnet*** initiative is funded by the Federal Ministry of Education and Research (BMBF) of Germany and strives to generate synergy from combining international professional research expertise from Europe and Australia in the field of landscape assessment, analysis and modelling for management and decision support in IWRM and irrigation management. The paper briefly presents the ***dewnet*** concept, discusses the methods and technological components of the Jena Environment System Analysis Toolset (JESAT) and finally presents two JESAT applications from South Africa and Germany.

Keywords: *JESAT, Response Units (RU), holistic landscape assessment, system analysis and modeling, hydrological modelling, Integrated Land Management System (ILMS), JAMS, AIDIS, J2000*

1. INTRODUCTION

Dewnet stands for **D**evelopment for **E**nvironment and **W**atering **NET**work and was established as a BMBF funded project by the Friedrich-Schiller-University of Jena (FSU-Jena), Germany, and three German SMEs in 2008. The main objective of ***dewnet*** is to merge scientific expertise and professional know-how available in Germany and Australia in the fields of environment system assessment, analysis and modelling. As a joint project cooperation ***dewnet*** will enhance the available know-how in this regard. It also contributes to the development of an Integrated Land Management Systems (ILMS) for IWRM and irrigation management. Cooperation projects will apply the Jena Environment System Analysis Toolset (JESAT) as a multifunctional software toolset based on a holistic system approach. JESAT is based on the conceptual landscape model of distributed, process related Response Units (RU) applied as model entities for the J2000 model suite within the Jena Adaptable Modelling System (JAMS). JESAT offers innovative techniques like remote sensing and GIS and uses the Adaptable Integrated Data Information System (AIDIS) as environment knowledge base for system management and decision support. A literature review (EEA, 2008) reveals that integrated toolsets like JESAT or OIKOS (Olazabal et al., 2007) are obviously cutting edge research.

2. JESAT COMPONENTS

JESAT components have been developed since 1994 in many research projects and provide an integrated toolset for comprehensive assessment, analysis, modeling and management support of environment systems applying a multi-scale, holistic approach as described by Flügel (2000) and shown in Figure 1. It considers water quantity and water quality issues in an integrated way by applying remote sensing, GIS analysis, field process data and system modeling techniques. The consistent and scale related application of the JESAT tools is accounting for multi-scale applications. At present the system comprises the following toolset components:

(i) The conceptual Response Units (RU) landscape model applied to delineate process related model entities for process models, i.e. water and solute transport within a river basin and respective GIS tools to delineate RU from digital data layers (Flügel, 1995).

(ii) The Jena Adaptable Modelling System (JAMS) for modular research model development and model application by stakeholders (Kralisch et al., 2007; Kralisch and Krause, 2007).

(iii) The J2000 model suite consisting of the J2000 (Krause, 2002, Krause and Flügel, 2005), the J2000-S (Fink et al., 2007) and the J2000-g (Krause and Hanisch, 2009) hydrological river basin models simulating hydrological dynamics, water and solute transport and are respectively used in hydrological climate change impact assessment.

(iv) The Adaptable Integrated Data Information System (AIDIS) as a web based environmental knowledge and data management platform (Flügel, 2007) with GIS-functionality for information exchange between multidisciplinary research teams.

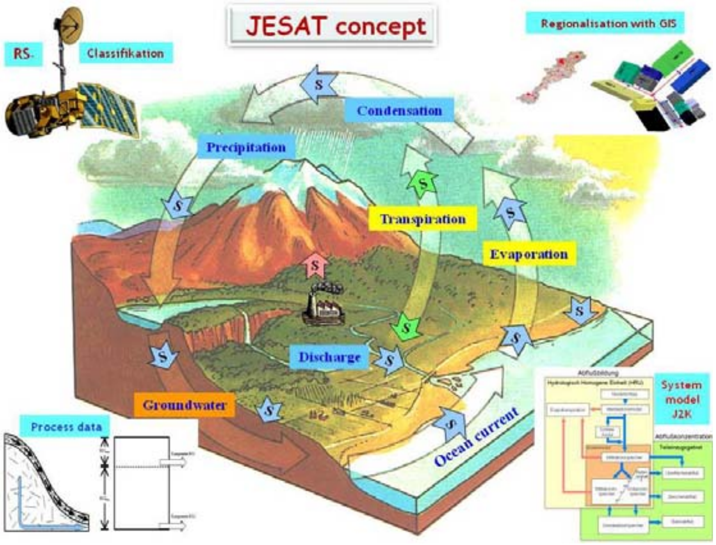

Figure 1. The holistic system approach and its technologies applied by JESAT

2.1. Response Units (RU) conceptual landscape model

The concept of delineating process related response units has been published by Flügel (1995). Since then it has been applied and tested successfully in various applications in Germany and internationally (Bende at al., 1995, Flügel and Märker, 2003; Krause et al., 2006). It is based on a comprehensive system process analysis and understanding and is schematically shown in Figure 2.

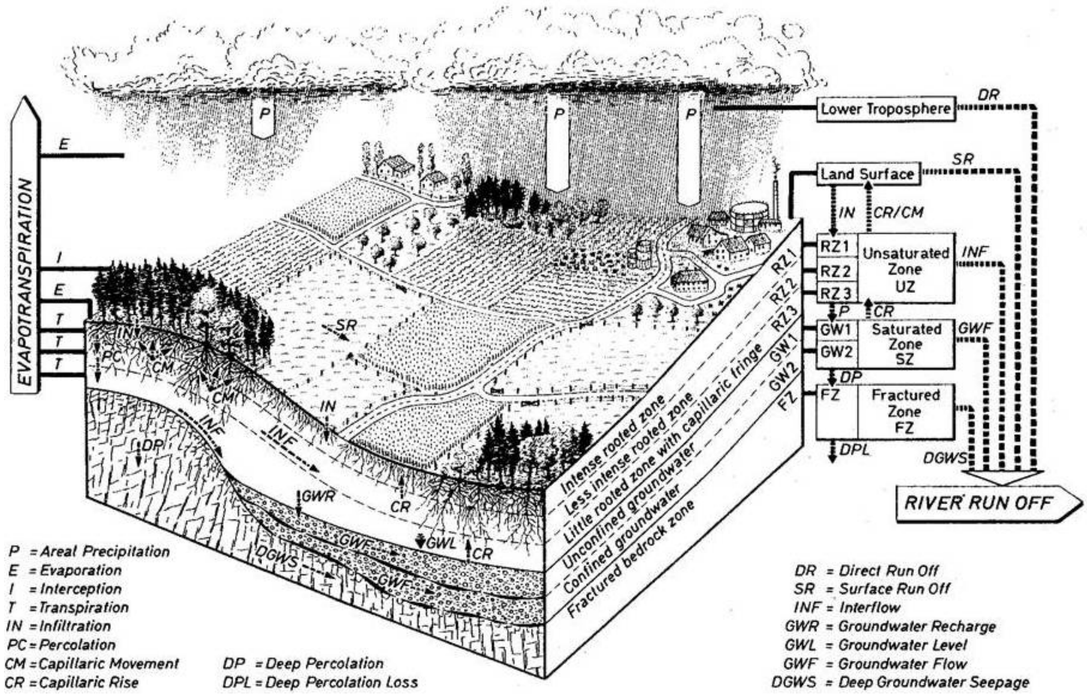

Figure 2. Schematic presentation of the Response Unit (RU) landscape concept

Response Units (RU), i.e. Hydrological Response Units (HRU) are identified as landscape facets that have a specific assembly of landscape features like location within the topography, land use and land cover (LULC),

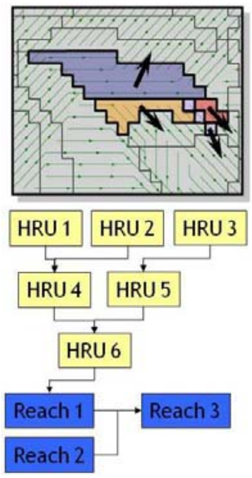

Figure 3. Topological routing of flow and solutes from HRU into the river reaches.

soils and geology. Their specific assembly constitute a process entity that transfers the system input into a site specific system output, i.e. rainfall into actual evapotranspiration and river runoff.

HRUs are delineated by means of GIS overlay analysis applying the process relevant landscape component assemblies as delineation criteria. In result the river basin is subdivided into process units that represent entities of land component assembly classes (i.e. forest on flat plateau regions growing on hydromorphic soil over sandstone geology). They will have a unique and homogeneous hydrological process dynamics if compared to neighboring HRU entities. GIS software tools for user controlled RU delineation have been developed for ArcInfo©, ArcView© and GRASS©. As shown in Figure 3 the slope gradient between the HRU model entities is generated to route water and solute transport through neighboring HRU into the respective river reach.

2.2. Jena Adaptable Modelling System (JAMS)

JAMS has been designed as a modular model framework system (MFS) to supply researchers with a model development environment providing tools for modular model development and analysis. Practitioners are provided by JAMS with a runtime environment to parameterize and run tested model configurations (Kralisch et al., 2007; Kralisch and Krause, 2007) and to visualize and analyse model output. An example is a multidimensional sensitivity analysis using the HydroNet neural network approach (Kralisch et al., 2005) to evaluate model output. As shown in Figure 4, JAMS comprises three components: **(i)** The system core containing the modular JAMS system library that provides modules for I/O handling and to setup the model runtime environment, **(ii)** the model knowledge component providing process modules to represent the existing understanding of the system dynamics to be modeled, and **(iii)** a GUI for model parameterization and model creation.

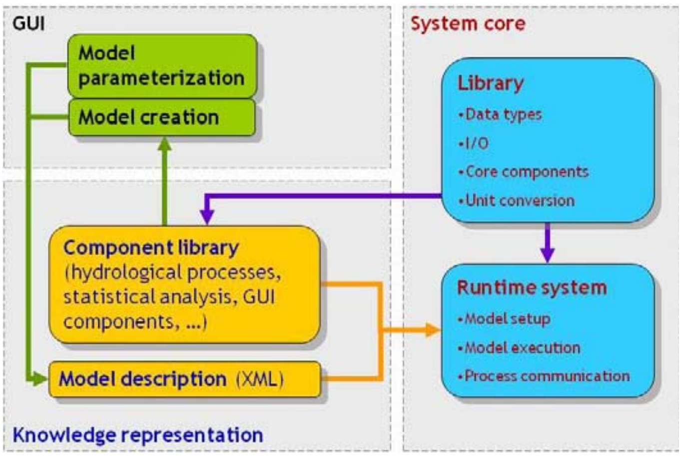

Figure 4. Schematic presentation of the JAMS components

JAMS users can create a model in two different ways. One is by starting from scratch and assembling the system core and component library modules into a new, individual model with the means of the user interface. The second way makes use of existing JAMS models and by exchanging individual model modules that better fit with the existing database or the conceptual understanding of the environment system dynamics a new model can be designed. JAMS provide the user with the ability to integrate new process modules into the component library and to make them available to the user community after successful testing. For example if the user wants to model the generation of irrigation return flow from delineated Irrigation Return Flow Response Units (IRFRU) then he/she can use the J2000-S model structure, develops his/her own irrigation return flow and salinity modules and adds them to the system knowledge component for the ultimate irrigation return flow model.

2.3. J2000 model suite

The J2000 process oriented model suite comprise at present three different hydrological models. They have been developed to provide users with a variety of hydrological tools to carry out hydrological water quality related environment system assessments. All models apply Hydrological Response Units (HRU) as spatially distributed model entities and route the HRU output into the adjacent receiving river reach.

The three hydrological models can be characterized as follows:

(i) The J2000 hydrological system model developed by Krause (2002) has been designed to model the hydrological process dynamics and water balance within river basins as a fundamental instrument for water

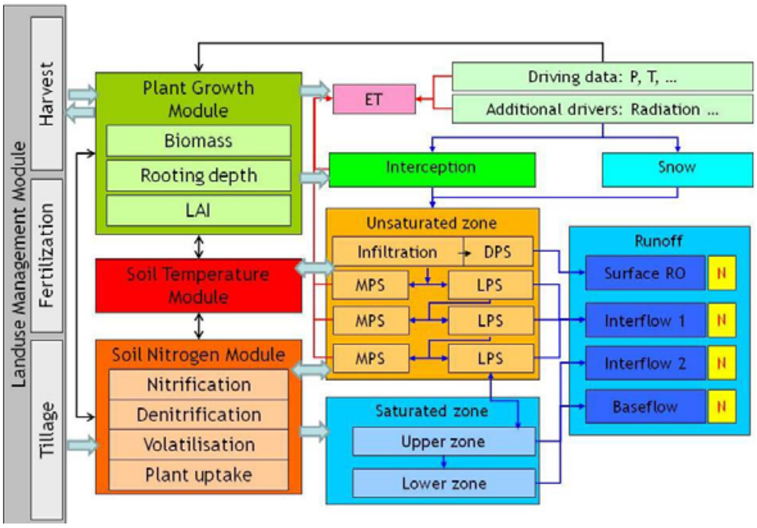

Figure 5. Component structure of the J2000-S model integrating management and nutrient processes (left side) into the hydrological dynamics (right side).

resource assessment and IWRM. The model has intensively been tested since its release and provides the core of the J2000 model suite.

(ii) The J2000-S hydrological and nutrient transport model (Fink et al., 2007) was developed to simulate diffuse Nitrogen leaching from agricultural areas into river reaches. As shown in Figure 5 the J2000 hydrological model structure is used to link land use management, plant growth and nitrate dynamics components. In result J2000-S is producing the discharge components generating river runoff and their associated nitrogen loads.

(iii) The J2000-g model (Krause and Hanisch, 2009) is a simplified version of the J2000 hydrological process model and has been designed for two purposes. The first aim was to carry out a basic hydrological system assessments to identify 'hot-spots' where more intensive research work is required. The second aim was to assess impacts of likely "what-if?" climate change scenarios on temporal and spatial distributed water resources in macro-scale river systems and management domains. The J2000-g model has been successfully tested and applied for these purposes in the state of Thuringia, Germany and in the EU-Project BRAHMATWINN (http://www.brahmatwinn.uni-jena.de).

2.4. Adaptable Integrated Data Information System (AIDIS)

AIDIS is a web-based object-relational data, information and knowledge base with GIS functionality that fully implements the ISO 19115 standard. The system is based on the following open source software (OSS) components:

(i) PostgreSQL (Worsley and Drake, 2002) is used as the object-relational data base management system ORDBMS). It is highly extensible, and permits the use of the procedural Standard Query Language (SQL).

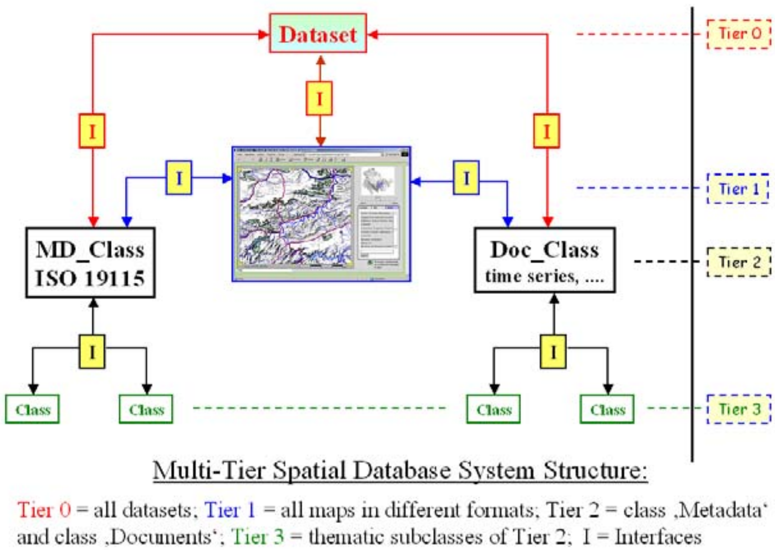

Figure 6. Multi-tier relational information strategy of AIDIS.

(ii) PostGIS is implemented as the geo-spatial extension. It provides import and export of Arc-View© shape files and OpenGIS Simple Feature Specification for SQL. The GIS functionality is implemented by the JANUS extension linked to the metadata component.

(iii) A APACHE Web Server is used for the client to server communication, and the visualization of maps is done by the Minnesota Map Server (MMS).

AIDIS uses a table model that is generic in its design structure and therefore can be adapted to account for data, information, and indicator requirements of river basins in all climates. This design structure permits the extension of data, information and knowledge from other scientific disciplines that join a multidisciplinary research team. The object oriented design of AIDIS permits an adaptation by its multi-tier class layer structure (Figure 6). This adaptation can be done by adding additional class hierarchies or modifying existing ones. The structural analysis of AIDIS reveals the following characteristics:

- AIDIS has an easy to understand class oriented hierarchical structure using the Unified Modelling Language (UML)
- Classes are linked by interfaces (I) which store the organization of relationships.
- A central role is given to the 'map-class' on Tier 1, which is used not only for the visualization of results but also for spatial queries that refer to metadata and the document-class hierarchy.
- All data stored in AIDIS are described by the ISO 19115 metadata model. Extensions are realized by extended lookup tables (LUT).

Due to its adaptable design, AIDIS provides a multidisciplinary data and information exchange platform for multidisciplinary research projects. By means of its comprehensive metadata structure AIDIS is able to preserve knowledge obtained from the functioning of environmental systems. This is a prerequisite for the design of an Integrated Land Management System (ILMS) to implement sustainable land and water management.

3. JESAT APPLICATIONS

JESAT has been applied successfully in various collaborative projects concerning IWRM and environment system research in Europe, Africa and Asia. Two examples from these studies are given below.

3.1. Impact of large scale afforestation in the Eastern Cape Province (ECP), South Africa

Since 1990 the Mooi headwater river of the Tsitsa River in the Eastern Cape of South Africa has seen a drastic change of land use by afforestation of about 60,000 ha of former range land farms with pines and eucalypt industrial forests. It was expected that the significant change of land use will impact the hydrological dynamics of the Mooi river system and the functioning of wetlands as unique environmental features of the former cultural landscape. In cooperation with colleagues from the University of Kwazulu-Natal, South Africa the JESAT toolset was applied as follows:

Figure 7. Large scale afforestation of former range land impacts unique wetland features and base flow support during dry summer periods.

(i) A comprehensive system assessment was done by means of intensive field campaigns and landscape system analysis. In result three different types of wetlands with specific hydrological dynamics and adapted vegetation were distinguished: (1) wetlands formed at the rim of the sandstone escarpments fed by seeping groundwater with seasonal dynamics, (2) wetlands on slopes fed by interflow and rainfall and (3) wetlands in broad valley floors fed by rainfall and groundwater seepage with perennial water courses meandering in the flat and broad valleys.

(ii) Hydrological Response Units (HRU) were delineated by means of GIS analysis using digital data layers of a terrain model, LULC obtained from Landsat remote sensing image classification, soils from the South Africa soil survey and geology from a respective geological survey.

(iii) The HRU model entities were parameterized and the hydrological dynamics of the Weatherly test creek and the Mooi river catchment were modeled using the J2000 model. The hydro-meteorological input data was consisting of rainfall, air temperature, radiation and relative humidity.

Year	Wetland type	ΔQ_{SR} [%]	ΔQ_{SSR} [%]	ΔQ_{GW} [%]	ΔSum [%]	$\Delta Total$ [%]
1999-2001	Plateau	- 83,6	- 55,8	- 10,2	**- 34,1**	- 17,3
	Slope	- 14,5	- 19,5	- 3,0	**- 14,9**	
	Valley bottom	-5,4	- 7,2	- 0,3	**- 6,9**	

ΔQ_{SR} … changes of surface runoff; ΔQ_{SSR} … changes of subsurface runoff; ΔQ_{GW} … changes of groundwater flow, ΔSum … changes of total runoff for each wetland type; $\Delta Total$ … changes of averaged runoff from all wetlands

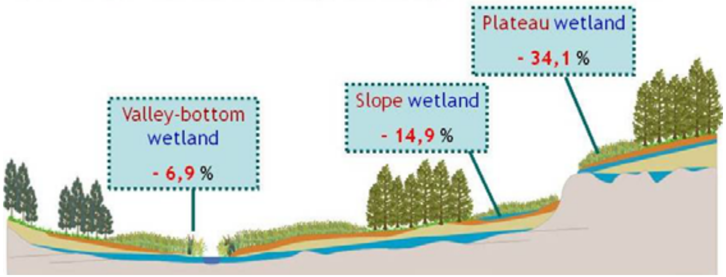

Figure 8. Large scale afforestation of former range land impacts unique wetland features and base flow support during dry summer periods.

The obtained results are shown in Figure 8 and reveal that the three wetland types are affected in different ways and magnitude from the afforestation activities:

- The small and only seasonal active wetlands on the rims of the sandstone plateaus will be reduced in their runoff contribution by about 34 % as the forest on the plateau increases evapotranspiration due to higher interception and water consumption.
- Wetlands on the slopes suffer by losing in average about 15 % of their discharge contribution as less groundwater will percolate through the sandstone into the slopes and less interflow will be generated.
- The wetlands in the broad valley floor will experience the least loss of only 7 % discharge contribution as they mainly get recharged by rainfall in the broad valley floor and are less depending on inflow from the slopes and plateaus.

3.2. Reduction of nutrient seepage into a water reservoirs in Thuringia, Germany

The Weida-Zeulenroda water reservoirs supplying potable water to the population of East Thuringia are impacted by high loads of nitrate input by the Weida River. Nitrate seeps into the river from adjacent agricultural lands. JESAT was applied in a research project with the following main objectives: **(1)** Identify the distributed areas of nitrate input and model distributed N-output **(2)** provide recommendations to optimize N-reducing measures like payments to farmers to compensate for harvest losses when using less N-fertilizers. JESAT was applied to this catchment as follows:

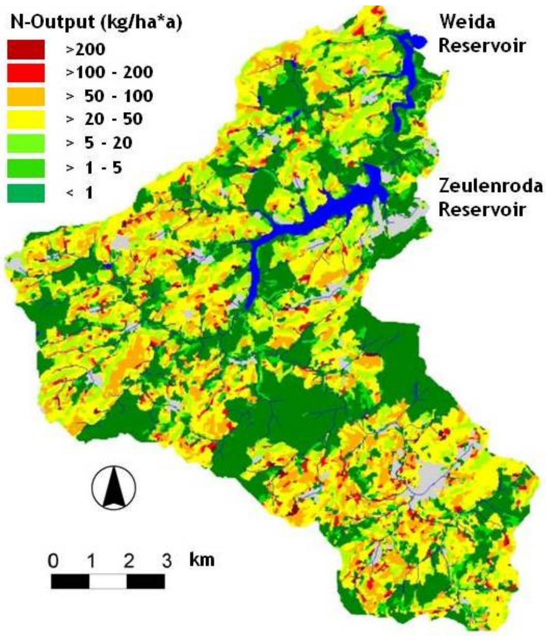

Figure 9. Modelled distributed N-output from a HRU network within the Weida river catchment.

(i) Based on digital data layers of terrain, soils, LULC and geology the HRU were delineated.

(ii) Hydro-meteorological station data and fertilizer input data on a field scale were collected.

(iii) J2000-S was applied to model the N-dynamics of the HRU and results were presented as distributed N-output within the catchment (Figure 9).

(iv) To elaborate the efficiencies of nitrate reduction measures a multidimensional sensitivity analysis was carried out by applying the HydroNet neural network tool of JAMS to the topologically fixed HRU network.

(v) Threshold values for manageable N-inputs into the reservoir were identified and referred to the HRU network by means of backward propagation to identify those HRU where the reduction of N-fertilization i.e. by compensation payments to farmers were most effective. Results in Figure 10 indicate that HRU in valley floors are most effective target areas.

4. CONCLUSIONS

The Jena Environment System Analysis Toolset (JESAT) is based on a conceptual, process related landscape model that subdivides the river basin in Response Units (RU). JESAT components are the result of an ongoing development process at the Department of Geoinformatics, Hydrology and Modelling since its

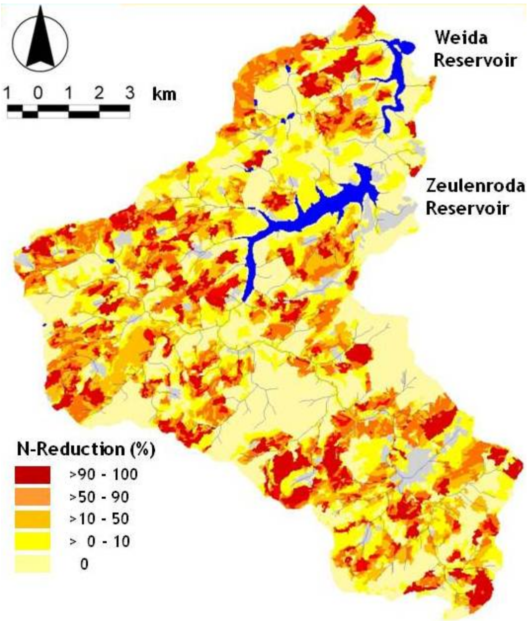

Figure 10. Effectivity of compensation payments to reduce N-input from fertilization into the Weida River and the Zeulenroda reservoir.

establishment in 1994 at the Friedrich-Schiller University of Jena (FSU-Jena). RU are delineated by means of GIS analysis applying knowledge based delineation criteria that refer to the landscape components, i.e. topography, LULC, soils and geology and their impacts on processes within the landscape, i.e. water and solute transport. All JESAT components are OSS based and have been applied successfully in many international research projects on scales ranging from 10^2 till $5*10^5$ km^2 in Europe, Africa and Asia. Enhancements and improvements of JESAT are expected to be developed within close project cooperation with Australian and international research institutions.

REFERENCES

Bende, U., Flügel, W.-A., and Kern, T. J. (1995), Using GIS to delineate Chemical Response Units (CHRU's) for hydrochemical modelling in a mesoscale catchment in Germany. *IAHS-Publ.*, No. 226, 133-139.

EEA (2008), Modelling environmental change in Europe: towards a model inventory (SEIS/Forward). *EEA Technical Report*, No. 11, 69 p.

Fink, M., Krause, P., Kralisch, S., Bende-Michl, U., and Flügel, W.-A. (2007), Development and application of the modelling system J2000-S for the EU-water framework directive. *Advances in Geosciences*, 11, 123-130

Flügel, W.-A. (1995), Delineating Hydrological Response Units (HRU's) by GIS analysis for regional hydrological modelling using PRMS/MMS in the drainage basin of the River Bröl, Germany. *Hydrological Processes*, Vol. 9, 423-436.

Flügel, W.-A.. (2000), Systembezogene Entwicklung regionaler hydrologischer Modellsysteme. *Wasser & Boden*, 52. Jg., H. 3, 14-17.

Flügel, W.-A. (2007), The Adaptive Integrated Data Information System (AIDIS) for global water research. *Water Resources Management (WARM) Journal*, 21, 199-210.

Flügel, W.-A., and Märker, M. (2003), The Response Units Concept and Its Application for the Assessment of Hydrologically Related Erosion Processes in Catchments of Southern Africa. *ASTM STP 1420*, 163-177.

Kralisch, S., M. Fink & C. Beckstein (2005), Neural Network Based Sensitivity Analysis of Natural Resource Models. Zerger, A., and Argent, R.M. (eds.): *Proc. MODSIM 2005, December 2005*, 2498–2504

Kralisch, S., Krause, P., Fink, M., Fischer, C., and Flügel, W.-A. (2007), Component based environmental modelling using the JAMS framework. Kulasiri, D. and Oxley, L. (eds.): *MODSIM 2007 International Congress on Modelling and Simulation*. Modelling and Simulation Society of Australia and New Zealand, December 2007.

Kralisch, S., and Krause, P. (2007), - JAMS - A Framework for Natural Resource Model Development and Application. Voinov, A., Jakeman, A., and Rizzoli, A.E. (eds.): *Proceedings of the iEMSs Third Biannual Meeting "Summit on Environmental Modelling and Software"*, Burlington, USA, July 2006

Krause, P. (2002), Quantifying the impact of land use changes on the water balance of large catchments using the J2000 model. *Physics and Chemistry of the Earth*, 27, 663-673

Krause, P., and Flügel, W.-A. (2005). Model Integration and Development of Modular Modelling Systems. *Advances in Geosciences*, 4, 1-2

Krause, P., and Hanisch, S. (2009). Simulation and analysis of the impact of projected climate change on the spatially distributed water balance in Thuringia, Germany. *Advances in Geosciences*, (in print)

Krause, P., Bende-Michl, U., Bäse, F., Fink, M., Flügel, W.-A., and Pfennig, B. (2006), Investigations in a Mesoscale Catchment – Hydrological Modelling in the Gera Catchment. *Advances in Geosciences*, Vol. 9, 53-61.

Olazabal, M., Urzelai, A., García, G., Herranz, K., Abajo, B., Feliú, E., Santa Coloma, O., and Aspuru, I. (2007), OIKOS: An integrated approach towards sustainable spatial planning and management. Horner, M., Hardcastle, C., Price, A., and Bebbington, J. (eds), *Proc. Int. Conf. on Whole Life Urban Sustainability and its Assessment*, Glasgow, 2007, 1 – 15

Worsley JC, and Drake D (2002) Practical PostgreSQL, *O'Reilly and Associates*