Research Résumé

Prof. Dr.-Ing. Erwin Zehe and group

OUR RESEARCH PHILOSOPHY

Fundamental and problem-based research are Ying and Yang of modern hydrology, seemingly oppositional, but inseparable. Fundamental research is deemed to allow for improvement of hydrological models for engineering practice on the long term. On the other hand often practical problems raise fundamental questions. We think that real progress requires a balance between Ying and Yang. Our research is thus located between those two poles, or rather aims to connect them.

From the fundamental perspective we are interested in systems of intermediate complexity, i.e. heterogeneous systems with some degree of organization (Dooge, 1986), ranging from the field/hillslope scale to catchments at the lower mesoscale (10 -100 km^2). We think that especially in those systems the bio-geomorphic architecture exerts crucial controls on the flow and transport of water, mass and energy, because this architecture determines the subsurface storage volumes and the topology of flow paths. It is well known that bio-geomorphological structures allow, depending on the hydrological context (radiation driven, rainfall driven), rapid vertical and lateral flows (Zehe and Sivapalan 2009). These fast processes play a key role during hydrological extremes and environmental hazards such as floods, erosion events or pesticide breakthroughs into ground- or surface waters. However, our understanding of the underlying cause and effect relations is still insufficient to predict fast lateral and vertical preferential flow and transport at scales larger than the field scale. The reason is simply because we can neither observe the underlying structures nor the fast flow processes in situ with current technologies.

From the engineering point of view, our research covers the fields of:

- A) Natural hazards: analysis, prediction and mitigation;
- B) Environmental quality and risk, mainly water and soil quality.

Our research is mainly condensed around the following fundamental themes:

A) Getting an improved understanding of how structure and heterogeneity controls flow- and transport processes within intermediate systems as well as the integral systems response at the next higher scale. This comprises:

- Preferential flow and pesticide transport in the unsaturated zone (Zehe and Flühler 2001 a & b, Klaus and Zehe 2010, Wienhöfer *et al.* 2009)
- Runoff and flood formation in different hydro-climates (Blume *et al.* 2008 a & b, Gräff *et al.* 2008, Zehe *et al.* 2007, Zehe *et al.* 2009)
- Sediment transport and exports (Scherer 2008)

B) Development of improved model concepts to describe flow- and transport processes within intermediate systems, to predict hazards and to reduce predictive uncertainty. This comprises:

- Development of reductionist physically based models (Zehe *et al.* 2001, Zehe and Blöschl, 2004, Zehe *et al.* 2005)

- Treatment of macropores as explicit structures (Klaus and Zehe 2010, Zehe et. al. 2010)
- Development of models based on the REW approach (Lee *et al.* 2007, Zehe *et al.* 2006, Lee *et al.* 2005 a & b)
- Development of innovative model diagnostic tools and alternative objective functions (Reusser *et al.* 2009, Reusser and Zehe 2010, Schaefli and Zehe 2009, Ehret 2009 a & b).

C) Development of improved measurement techniques and strategies for integration of geo-ecological data to characterize hydrological systems and their organization on different scales. This comprises:

- Novel approaches to assess soil moisture dynamics (Zehe *et al.* 2009, Gräff *et al.* 2009 b)
- Use of geophysical data (Graeff *et al.* 2009, Zehe and Tronicke 2010) as well as smart use of tracers (Wienhöfer *et al.* 2009, Blume *et al.* 2009)
- Improved methods to observe and characterize rainfall (Ehret 2003, Heistermann *et al.* 2008, Heistermann and Zehe 2008)

D) Eco hydrology and optimality approaches in hydrology. This comprises:

- Development of generic eco hydrological models for savannah ecosystems (Tietjen *et al.* 2009 a & b, Tietjen *et al.* 2010)
- Description of flow and transport phenomena as dissipative processes within a thermodynamic framework (Zehe *et al.* 2010).

Our approach is in general to combine process modeling with field work. Currently were are active in four research catchments

- The Heumöser Hang, part of the Dornbirner Ach catchment located in Vorarlberg (Lindenmaier *et al.* 2005, research site of the DFG Research Unite FOR 581 “Natural slopes”)
- The Krumbach catchment in Bavaria (research site of the BIOPORE project)
- The Weiherbach catchment in Baden-Württemberg (research site of the BIOPORE project)
- The Weisseritz catchment (research site of the OPAQUE project)

Research Projects

DFG Research Unit FOR 1598 (Germany –Luxembourg).: From Catchments as organised Systems to Models based on Dynamic Functional Units, CAOS. Speaker Dr. Erwin Zehe.

Within CAOS I supervise the following projects:

- Project S: An adaptive process based model framework for water-, energy- and mass cycles in lower mesoscale catchments, (together with Dr. Uwe Ehret (PI)), ZE 533/9-1.
- Project I: From subsurface structures to functions and texture - linking virtual realities and experiments at the plot and hillslope scales. (together with Dr. Theresa Blume (CoPI), Section 5.4 Hydrology, German Research Centre for Geosciences Potsdam), ZE 533/8-1.

Coupling of flow and deformation projects to model large mass movements (DFG Research Unit 581 "GROSSHANG")

Joined research within the DFG Research Unite "Natural Slopes" aims thus on an improved understanding which structures, process interactions and boundary conditions trigger slow mass movements as well as on development of a hierarchical model of appropriate complexity to predict such a phenomenon. Speakers are Dr. Reinhard Hinkelmann (TU Berlin) Dr. Erwin Zehe (KIT). Research site is the "Heumöser Hang" in Voralberg. Total funding volume is 3 300 000 € for six years, funding period is 2006 – 2011.

Within GROSSHANG I supervise the following projects:

- *Dominant hydrological structures, processes and parameters: from active seismic exploration to modelling of appropriate complexity*. PI Erwin Zehe; Funding volume is 360 000€; Funding period is January 2009 – December 2012, (ZE 533/3-3).
- *Process identification and numerical modelling of surface runoff at a creeping slope in the Alps*. PI Erwin Zehe; Funding volume was 300 000 €; funding period was October 2005 – September 2008 (ZE 533/3-2), completed.

Additional information is provided at the project homepage: http://www.grosshang.de/

Completed Research projects

Operational flood forecasting in headwater catchments (OPAQUE)

The overall goal of the OPAQUE project was to improve operational flood forecasts and flood management through:

- Long term warning of flood prone weather situations by means of statistical downscaling and critical systems states based on innovative soil moisture monitoring
- Improved quantification of the space-time pattern of rainfall and rainfall nowcasting by merging rain gauge data and weather radar
- Improved operational rainfall-runoff models (LARSIM and WASIM ETH I)
- Improved reservoir operation and flood management.

The project consortium consisted of the Potsdam University (Dr. Axel Bronstert, lead contractor), Munich Technical University TUM (**Dr. Erwin Zehe, lead contractor**) Stuttgart University (Dr. András Bárdossy), the GFZ German Research Centre for Geosciences (Dr. Bruno Merz) and the operational flood forecasting services in Baden-Württemberg (Dr. Manfred Bremicker), Bavaria (Stefan Laurent) and Saxony (Dr. David Kneis). **Funding volume was 1 040 000 €**, funded period was June 2007 – May 2010. Additional information is provided at the project homepage:

http://www.uni-potsdam.de/u/Geooekologie/forschung/hydrologie/projekt_opaque.html

BIOPORE: Linking spatial patterns of anecic earthworm populations, preferential pathways and agrochemical transport in rural catchments: An ecohydrological modelling approach

Earthworms play a pivotal role in agro-ecosystem functioning by modulating soil structure that significantly influences soil hydraulic properties, organic matter dynamics, and plant growth. The project focuses on anecic earthworms like Lumbricus terrestris which create vertical, semi-permanent burrows that function as preferential flow pathways. Preferential flow in macropores is a key process which strongly affects infiltration and may cause rapid transport of pesticides into depths of 80 to 150 cm where they are subject to much slower degradation. Therefore, preferential transport is an environmental problem because the topsoil is bypassed and with it its ability to act as

a filter to protect the subsoil and shallow groundwater. The overall goal of BIOPORE is to assess the environmental risk of pesticide transport in earthworm burrows and feedbacks of human management by developing an integrated eco-hydrological model. This model shall allow for predictions of

- The spatiotemporal distribution and population dynamics of anecic earthworms,
- The related pattern of connective preferential flow pathways (i.e. earthworm burrows),
- The space-time pattern of infiltration and travel depth distribution of solutes, ideally pesticides.

The project consortium consisted of Munich Technical University TUM (**Dr. Erwin Zehe, PI**), Potsdam University (Dr. Boris Schröder, Ecological Modelling, PI). **Funding volume is 500 000 €** for three years; funding period is Nov. 2007 –May 2011 (SCHR 100/3-1, ZE 533/5-1).

Key cooperations

We have the honour and pleasure to co-operate with some of the most creative and visible scientists in the world and additionally with a number of excellent scientists:

- Prof. Dr. M. Sivapalan, University of Illinois at Urbana-Champaign, USA. We do joined research on the development of physically based hydrological models based on the REW approach.
- Prof. Dr. G. Blöschl, Vienna University of Technology, Austria. We do joined research on predictability and thermodynamic treatment of soil water flows.
- Prof. Dr. A. Bárdossy, University of Stuttgart. We do joined research on model uncertainty and precipitation downscaling and structure generation.
- Prof. Dr. Hubert Savenije, Delft University of Technology, The Netherlands. We do joined research on the development of physically based hydrological models based on the REW approach.
- Prof. Dr. Boris Schröder and Prof. Dr. Florian Jeltsch, Potsdam University. We do joined research in the field of eco-hydrology.
- Dr. Axel Kleidon, Dr. Stan Schymanski, Max-Planck-Institute for Biogeochemistry, Jena. We do joined research on thermodynamic treatment of the water cycle.

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