Mid-term Research Agenda (2011-2015)

of the chair group

Hydrology and Water Resources
(HWR core)

March 2011

Summary

The Hydrology and Water Resources chair group revisited its research agenda during a full-day core meeting in February 2011 and in several small group discussions. This provided the basis for three priority research themes that will lead the research of the group during the period 2011-2015: (1) hydrological processes near the earth's surface, (2) ecohydrology, and (3) basin hydrology and global changes. The document summarizes the research lines, the on-going research projects as well as the on-going PhD and Post-doctoral research in the different research themes.

UNESCO-IHE
Institute for Water Education

1 Introduction

The chair group Hydrology and Water Resources (see appendix A1 for the composition of the group) at UNESCO-IHE, Delft, The Netherlands, is responsible for teaching and research in the science hydrology. The last research strategy for this chair group was written in 2005, but many things changed since then and the Institute is going through a restructuring process that includes a revision of the composition of the academic departments. The essential building blocks for the academic departments are the chair groups, and it is important that the scope and research objectives of each chair group are well-defined. Therefore, the chair group revisited its research agenda during a full-day core meeting on 18 February 2011 and in several small group discussions that defined the research lines in further detail. Finally, the outcomes of these discussions are summarized in this document.

It has to be noted that the research strategy outlined in this document and the subsequent research projects have significant feedback into the education programme. Staff members of the chair group are responsible for the specialization Hydrology and Water Resources (part of the MSc programme Water Science and Engineering). Additionally, different members of the core group contribute to a number of other MSc programmes/specializations and short courses at UNESCO-IHE and some (Bogaart, Uhlenbrook) are involved in teaching and student supervision at Delft University of Technology. The students are introduced and exposed to recent research findings, and will also contribute themselves to the increase of knowledge through their own projects. Whenever possible, a closer link between MSc research projects and the main research lines is planed.

Furthermore, the core group is involved in a number of projects that support sustainable development in the so-called global South. These are mainly capacity development projects that can have education and research components (e.g. teaching, graduate student supervision) or strengthen the capacity of local/regional organisations (e.g. implementation of monitoring systems, water resources assessments studies etc.). Whenever possible, strong synergies between the capacity development projects and the knowledge and tools developed in the research projects are sought.

The aim of this document is manifold. At the outset it will describe the core's understanding of the science hydrology. It will then briefly review the contemporary ('burning') issues that are influencing the research agenda of the Hydrology and Water Resources chair group (chapter 3). The three priority research themes of the chair group are introduced in the concluding chapter 4. The research themes and all on-going research projects, in which chair group staff is involved, are described in further detail in the appendix.

2 Definition of the Science Hydrology

The International Association of Hydrological Sciences (IAHS) defined hydrology in a very general way as the "*science that deals with the waters of the earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living beings.*" In addition, the IAHS states that Hydrology is the "*science that deals with the processes governing the depletion and replenishment of the water resources of the land areas of the earth, and various phases of the hydrological cycle.*" This makes clear that the science hydrology includes the knowledge of water resources. Understanding and being able to predict future water cycle dynamics at different spatial and temporal scales under different circumstances is key in that respect. The paramount relevance of hydrology to sustainable global welfare and to ensure ecosystem services is also obvious from this definition. Hydrology plays a key role in solving water problems at different scales such as extensive flooding, water scarcity, water quality deterioration, ecosystem decline, and global changes.

The HWR core follows the given definition and recognizes hydrology as a distinct earth system science that deals in particular with all components of the terrestrial water cycle (i.e., atmospheric water, surface water, groundwater, vadose zone, snow and ice, lakes etc.), and addresses both water quantity and quality. Suitable integration entities are either river basins or aquifer systems of different scales.

3 Contemporary Challenges Influencing the Research Agenda

There are several recent documents reviewing the latest achievements of hydrological science and providing prospects for the future of the discipline (e.g. NRC 2001, Maidment et al. 2003, Sivapalan et al. 2003, KNAW 2005, Oki et al. 2006, Wagener et al. 2010). This will not be repeated here. In this chapter an attempt is made to point out a few key issues, which lead to the prioritization of research topics presented below. The current challenges for the science of hydrology range from physical water quantity problems (i.e. water scarcity or extreme floods and flooding) to water quality degradation due to pollution and impacts on the delivery of ecosystem services. These issues are not new, but the magnitude and spatial distribution of many problems have changed in the last decades. This has often led to an aggravation of the water problems in particular in developing countries and in countries in transition.

In almost every basin of the world, human activities disrupt the natural hydrological and ecological regimes. While there are some attempts to improve this situation in developed countries (e.g. river restoration, natural reserves), it appears that the situation is becoming worse in many cases in the less developed countries. This seems to be caused to large extent by environmental changes (e.g. climate change, land use change, political and societal changes etc.). One impact is that the hydrological cycle tends to be accelerated and, consequently, climatic and hydrological extremes appear to increase and/or they become more frequent. Aquatic ecosystems are getting on increasing pressure. The pressure on aquatic ecosystems due to direct human impact continues to increase because of the population pressure, change of hydrological processes and economic development.

From the hydrological literature it is clear that in recent years a lot of effort has been directed towards improving the observation of hydrological variables using new ground-based and remote sensing techniques. The latter has an enormous potential in particular for data scarce regions. It is, however, equally important to have sufficient ground truth information to fully utilize remote sensing data for hydrological predictions.

At present, knowledge gaps are apparent in particular in the coupling between hydrological processes and other processes (e.g. atmospheric, biogeochemical or ecological processes). Thus, intensified research should be carried out at the interfaces between hydrology and neighboring disciplines such as ecology, microbiology, atmospheric sciences, geomorphology, soil sciences, etc. A significant knowledge gap is still the spatio-temporal distribution of subsurface hydrological processes. We know that these are characterized by large variabilities and heterogeneities (preferential flows, transient water tables etc.), but good observation techniques are still missing, although many new developments in hydro-geophysics and tracerhydrology are working on that. A better understanding of subsurface processes is crucial, as the base flow of a catchment is generated from groundwater and the contribution of soil water and groundwater during floods is very important in all hydro-climatic regions. In addition, groundwater is often the most important water resource in arid climates.

Hydrological modeling has certainly advanced in the last decades. It is a central component in every hydrological research project and plays a crucial role in integrated water resources management. There exists nowadays a variety of models ranging from widely physically-based, semi-distributed or lumped-conceptual to data-driven models. Each type of model has its strengths and weaknesses for solving given hydrological problems. The focus of further improving hydrological modeling in the chair group's projects is to develop predictive tools, which are able to predict water fluxes and hydrological processes at the relevant spatial and temporal scales in particular under changed circumstances (i.e. global changes). Therefore, the coupling of hydrological models with models from neighboring disciplines is important.

4 Priority Research Themes

Three main research lines will dominate the chair group's research agenda in the coming five years (see below and appendices for further details). The related projects will require undertaking applied and fundamental research. The scale of integration varies significantly from lab-scale experiments to large scale hydrological modeling. In the lines on hydrological process (no. 1) and ecohydrology (no. 2) experimental work will be carried out to improve the understanding of dominating hydrological processes, and with the aim to develop process-oriented models that are able to make predictions for hydrological systems under current and future changed circumstances. All research supports integrated water resources management and sustainable development in particular in the developing world.

4.1 HYDROLOGICAL PROCESSES NEAR THE EARTH'S SURFACE

This research line focuses in particular on improving the understanding of near-surface processes of the land phase of the hydrologic cycle (surface and shallow subsurface processes), in particular the movement of water and associated substances near the earth's land surfaces, the physical and chemical interactions with earth materials accompanying that movement, and the vegetation and biological processes that conduct or affect that movement. The nature of this type of research is experimental and field oriented, and attempts to assess the scales (spatial and temporal) and magnitude of processes in their natural environment, which includes arid to humid climates and cold to temperate and tropical regions, 'soft' and 'hard' rock areas, and natural to human affected habitats. Better understanding of related hydrological processes through experimental research provides the basis for improved process-based modeling - much needed in particular in the developing world to predict the impact of changes (e.g. climate, land use) on hydrological systems.

A main objective is to connect the knowledge of quantitative hydrology, i.e. groundwater dynamics, flow pathways, residence times and mixing of different water compartments etc., with the water quality. The main regional emphasis is on semi-arid conditions. This research is positioned in between the more fundamental sciences (e.g. physics, chemistry, biology), on the one hand, and the applied sciences (e.g. civil engineering, hydraulic engineering) on the other. This research line encompasses:

- Catchment and hillslope hydrology;
- Preferential flow systems (fissures, karstic limestone, and vadose zone);
- Evaporation, interception and transpiration;
- Hydrological systems analysis;
- Water balance evaluation; and
- Transport of pollutants in groundwater.

In order to study water fluxes, the driving forces of these fluxes and their causal relationships, we employ standard field data collection techniques focused on geology (e.g. mapping, auger drilling, electrical resistivity tomography), surface water discharge (e.g. stream discharge, water quality such as temperature, EC and natural isotopes), hydrometeorology, hydrogeology and flow field characteristics (e.g. piezometer installation, automated groundwater monitoring at various temporal scales), tracer methods (multiple artificial and natural tracers incl. DNA, bio-colloids and stable isotopes) and hydrochemistry (major and minor cations and anions). Experiments are carried out under controlled conditions in the lab (column experiments, lysimeters etc.) as well as in the field.

4.2 ECOHYDROLOGY

Ecohydrology is a widely recognized interdisciplinary science integrating hydrological, ecological, and biogeochemical processes. Ecohydrological processes regulate many environmental conditions within aquatic systems, maintaining water quantity and water quality within ranges suitable to native flora/fauna and the services they provide. Human interference in natural ecohydrological processes is the basis for many pressing environmental problems, including the most ubiquitous forms of water pollution (eutrophication, hypoxia, and acidification), related degradation of ecosystem services (loss of soil fertility, declines in fisheries, invasions of exotic species, and outbreaks of pathogens), and accelerating climate change (e.g. non-industrial emissions of greenhouse gases and carbon sequestration). Ecohydrology addresses the underlying physical, chemical, and biological processes that manifest these problems as well as the processes that are the keys to ultimately solve them. In developed areas, knowledge of ecohydrological processes serves to enhance the highly engineered systems already in place, while in less developed areas ecohydrological processes may serve as the primary means for managing water quantity and quality through natural attenuation of contamination and natural regulation of flow levels. The science includes well developed methodologies of field sampling, laboratory analysis, experimentation, and computer modelling.

Research in this theme involves multidisciplinary field, laboratory, and modeling techniques. Direct measurements are made of surface water flows and groundwater levels, and chemical and isotopic tools are utilized to trace the spatial and temporal interactions of flowpaths, including uptake by plants (i.e. xylem water). Biogeochemical and ecological methods focus on measurement of flow-related processes such as nutrient and organic matter retention along surface and subsurface flow paths, hypoxia related to high and low flow events, and flow- and wetness-related controls on spatial and temporal patterns of productivity in river and wetland (including GDEs). A wide variety of modeling approaches are applied, including physically based modeling, cellular automata, and fuzzy logic. Emphasis is also placed on model-supported decision making.

4.3 BASIN HYDROLOGY AND GLOBAL CHANGES

With the increasing population, expanding urbanization, modernised lifestyles, climate changes and other global changes the pressure for sustainable planning and management of our finite water resources is more evident than ever. Consequently, the role and importance of hydrological research in river basin of various scales have increased. In particular, we are facing increased challenges in predicting the [future] state of the water resources in view of the impacts from climate and anthropogenic changes to hydrological system dynamics. The key objectives of this research theme contribute to the understanding of hydrological processes at basin scales and modeling of these processes to predict the space-time availability of water resources and water cycle dynamics, including impacts from global changes. We primarily focus our research to the river basin scale typically varying from a few thousand to several hundred thousand square kilometers.

Identification and quantification of the cause and effect relationships and predicting the impacts for the future at the large scale can only be achieved through process-based modeling. Large scale modeling typically encounters data requirements beyond the classical rainfall-runoff simulation. Therefore, representation of hydrological processes at appropriate detail and integration of comprehensive remote sensing and ground observations into the modeling system form the framework for our research methodology. Within this framework, it is also important to acknowledge possible sources of uncertainty, and to provide reasonable assessments of uncertainty in model results.

Delft, March 2011

Chair group Hydrology and Water Resources at UNESCO-IHE, Delft, The Netherlands, in alphabetic order: *Dr. T. Bogaart, Dr. Ann van Griensven, Dr. J. W. Foppen, Dr. S. Maskey, Drs. J. Nonner, Dr. R. Venneker, Prof. Dr. S. Uhlenbrook (head), Dr. J. Wenninger, Dr. Y. Zhou*

References

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Oki T., Valeo C., Heal K. (Eds.): *Hydrology 2020: An Integrating Science to Meet World Water Challenges*. IAHS Publication no. 300, 190 pages.

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Appendices:

A1 - Staff of the Chair Group Hydrology and Water Resources (1 March 2011)

Position	Name	Appointment (fte)	Research input (fte)	Remarks
Professor	Dr. habil. Stefan Uhlenbrook, MSc	0.8	0.3	0.2 FTE at TU Delft and 0.8 FTE at UNESCO-IHE; whereby 0.4 FTE Director of Academic Affairs a.i.
Associate Professors	Jan Nonner, MSc	1.0	0.1	
	Dr. Yangxiao Zhou, MSc	1.0	0.2	
	Dr. Jan Willem Foppen, MSc	1.0	0.5	
	Dr. Michael McClain, MSc	0.5	0.3	Part-time, head of dept.
	Dr. Ann van Griensven, MSc	1.0	0.5	
Senior Lecturers	Dr. Raymond Venneker, MSc	1.0	0.4	
	Dr. Shreedhar Maskey, MSc	1.0	0.4	
	Dr. Thom Bogaard, MSc	0.2	0.1	Staff exchange with TU Delft
Lecturer	Dr. Jochen Wenninger, MSc	1.0	0.4	
TOTAL		8.3	3.2	

A2: Research Line ONE: HYDROLOGICAL PROCESSES NEAR THE EARTH'S SURFACE

Description/Definition of the Field
Hydrology can be broadly defined as the geoscience that describes and predicts the occurrence, circulation and distribution of the water of the earth and its atmosphere (e.g. Eagleson et al., 1991; Dingman, 2002). This research line focuses in particular on the near-surface processes of land phase of the hydrologic cycle (surface and shallow subsurface processes), in particular the movement of water and substance near the earth's land surfaces, the physical and chemical interactions with earth materials accompanying that movement, and the biological processes (i.e. vegetation) that conduct or affect that movement.

Input of the HWR Chair Group
The core focuses on studying water and substance fluxes near the earth's surface, the driving forces of these fluxes, and their causal relationships. The nature of this type of research is experimental and field oriented, and attempts to assess the scales (spatial and temporal) and magnitude of processes in their natural environment. In view of the international background of the institute, this natural environment has a worldwide coverage including arid to humid climates and cold to temperate and tropical regions, 'soft' and 'hard' rock areas, and natural to human affected habitats. The research is not only exact, but also both descriptive and predictive. Within the broad field of sciences, the research is positioned in between the more fundamental sciences (e.g. physics, chemistry, biology), on the one hand, and the applied sciences (e.g. civil engineering, hydraulic engineering) on the other and. It is worth noting that in this particular field of research, the HWR core has a proven track record in:

- Catchment and hillslope hydrology;
- Preferential flow systems (fissures, karstic limestone, and vadose zone);
- Evaporation, interception and transpiration;
- Hydrological systems analysis;
- Water balance evaluation; and
- Transport of pollutants in groundwater.

Applied Methods and Methodological Developments
In order to study water fluxes, the driving forces of these fluxes and their causal relationships, we employ standard field data collection techniques focused on geology (e.g. mapping, auger drilling, electrical resistivity tomography), surface water discharge (e.g. stream discharge, water quality such as temperature, EC and natural isotopes), hydrometeorology, hydrogeology and flow field characteristics (e.g. piezometer installation, automated groundwater monitoring at various temporal scales), and hydrochemistry (major and minor cations and anions, natural water isotopes). In addition, we have developed a better understanding of and we will continuously improve our understanding of:

- Important contaminant transport processes with a profound and widespread impact. In the recent past we mainly focused on the fate and transport of nitrogen and phosphorus compounds (with regard to eutrophication) in the terrestrial hydrologic cycle;
- Tracer hydrology. More specifically, we have focused and continue to focus on natural water isotopes, multi-tracers like synthetic DNA, and bio-colloids (e.g. fecal indicator bacteria and viruses including pathogens). An important aspect of this type of work is that the core will maintain all laboratory facilities within UNESCO-IHE in order to quantify these parameters;

- Hydrological processes and residence time estimation. Knowledge about hydrological processes and residence times of different water components (e.g. groundwater) is an important aspect in every hydrological study. We have focused and will continue to focus on the application of environmental water isotopes and hydrochemical tracers in different components of the hydrological cycle. The main goal is to improve our understanding of runoff generation processes in small scale experiments and on the catchment scale. Therefore, several meso-scale catchments have been setup in different regions (e.g. Choke Moutains (Blue Nile, Ethiopia), Migina catchment (Kagera, Rwanda), Hailiutu (Yellow River, China), Nyando and Mara catchments (Lake Victoria, Kenya)) with hydrological and meteorological stations and continuous water sampling is carried out.
- Innovative experiments in the lab, plot, and catchment scale (meso-scale). More specifically, we focused on lab scale lysimeters, column experiments with columns ranging in height from a few cm to more than 20 m, and plot scale and catchment scale natural and forced gradient tracer experiments; and
- Groundwater recharge estimation. Based on different types of collected field data groundwater recharge is estimated and verified, usually with the use of groundwater models. The novelty of this research is the proper selection and application of recharge estimation methods in different environments.

Future Developments

- Hydrograph separation. A lot of work has been carried out on hydrograph separation and the origin of runoff components contributing to catchment runoff. The HWR core can distinguish its contribution to this important research area by focusing on two groups of parameters which have not been looked at yet. These are environmental DNA and environmental proteins in addition to environmental isotopes. The general research question is: Is there information contained in DNA and proteins present in high quantities in stream water discharging a catchment, which can assist us in increasing our understanding of the volumes and source areas of different discharge components.
- Separation evaporation – transpiration fluxes. The overall objective of this work is to enhance the application of stable water isotope methods and to develop tools for quantification of evaporation, transpiration and percolation fluxes at the field scale. The general research question is: How can stable isotope methods help to quantify the major fluxes that control the water balance dynamics (e.g. irrigated land, naturally vegetation land etc.), and therefore, can improve the degree of water use efficiency.
- Dynamic soil properties and hydrology. The substratum strongly affects hydrological response to precipitation input. In mountainous areas slopes are under continuous stresses due to gravity movement of material (landslides and soil erosion). In landslide hydrology one important open question is how soil displacement changes the soil hydraulic properties, and how that feedbacks the hydrological behavior of a slope. This strongly links to the questions on the behavior of double porosity (matrix and preferential flow) in hillslopes and, thus, to discharge generation research in headwater catchments.

- Hydrological processes in arid and semi-arid areas. In such areas with scarce and highly variable rainfall and high evaporation rates, runoff and infiltration processes at the land surface as well as groundwater recharge are different from similar processes in temperate regions. Understanding of these processes and making use of innovative field data collection methods and simulation techniques are at the core of this research field.
- Upscaling of lab and plot scale process knowledge to meso- and large scale models. Therefore, ways to delineate areas with similar process behavior as an approach to upscale small scale process understanding are developed.

Key Partner Institutions

- Makerere University, Kampala, Uganda
- Birzeit University, Palestina
- University of Dar es Salaam, Tanzania
- An-Najah University, Palestina
- National University Rwanda, Rwanda
- Addis Ababa University, Ethiopia
- China University of Geosciences, Beijing, China
- Xi'an Centre of China Geological Survey, China
- University of KwaZulu Natal, Pietermaritzburg, South Africa
- Water Resources Management Agency, Kisumu, Kenya
- Delft University of Technology, The Netherlands

Projects in Hydrological Process Research (see A5 for project definition)

EXACT and UWIRA (Palestine, West-Bank), SCUSA (Kampala, Uganda), ERODO (Yellow River, NE Plateau, China), SSI-2 (Pangani catchment, Tanzania, and Thukela catchment, South Africa),Hydrosolidarity Blue Nile (Ethiopia, Sudan), KultuRisk (Italy),PhD studies in catchment hydrology in Nicaragua, Rwanda and Luxemburg, IsoWUE IAEA (Swaziland and Netherlands), ECOLIVE (Nyando wetland, Kenya), MARAFLOWS (Mara River Kenya-Tanzania).

PhD or Post-doc Studies in Hydrological Process Research

PhD fellow, country	Promotor(s)	Supervisor(s)	Title research project	Start year	End year
G. Lutterodt, Ghana	S. Uhlenbrook	J.W. Foppen	Effects of surface characteristics of Escherichia coli on transport in saturated porous media	2007	2011
O. Munyaneza, Rwanda	S. Uhlenbrook	J. Wenninger,. S. Maskey, Wali	Water resources assessment and prediction in the Rwandan catchments	2008	2012
S. Tekleab, Ethiopia	S. Uhlenbrook, H. H.G. Savenije	Y. Mohammed, J. Wenninger	Hydrological processes and modelling in the Blue Nile river basin	2008	2012

P. Nyenje, Uganda	S. Uhlenbrook,	J.W. Foppen	Hydrological Implications of improved sanitation in slum areas, Kampala, Uganda	2008	2012
H. Calderon, Nicaragua	S. Uhlenbrook	J.W. Foppen	Development of innovative tracer methods to observe surface water-groundwater interactions in seasonal rivers	2009	2014
C. Orup, Uganda	S. Uhlenbrook	JW Foppen, M. Mul, S. Maskey	Surface water-groundwater interactions in dryland rivers, Pangani catchment, Tanzania	2009	2014
Yang Zhi, China	S. Uhlenbrook, Wan Li	Y. Zhou J. Wenninger	Surface water-groundwater interactions in Erdos Plateau, China	2009	2014

Post-doc Researchers

- Dr. Melesse Temesgen: Impact of agricultural practices on hydrologica processes and erosion in Upper Blue Nile River basin, Ethiopia, supervisors: Prof. Stefan Uhlenbrook, Dr. Jochen Wenninger, Dr. Yasir Mohammed, Prof. Pieter van der Zaag, Prof. Huub Savenije

Key Staff Members from HWR Chair Group Active in this Theme

Dr. Jan Willem Foppen, Dr. Jochen Wenninger, Dr. Thom Bogaart, Drs. Jan Nonner, Dr. Michael McClain, Dr Yangxiao Zhou, Prof. Dr. Stefan Uhlenbrook

A3: Research Line TWO: ECOHYDROLOGY

Description/Definition of the Field

Ecohydrology is a widely recognized interdisciplinary science integrating hydrological, ecological, and biogeochemical processes. Ecohydrological processes regulate many environmental conditions within aquatic systems, maintaining water quantity and water quality within ranges suitable to native flora/fauna and the services they provide. Human interference in natural ecohydrological processes is the basis for many pressing environmental problems, including the most ubiquitous forms of water pollution (eutrophication, hypoxia, and acidification), related degradation of ecosystem services (loss of soil fertility, declines in fisheries, invasions of exotic species, and outbreaks of pathogens), and accelerating climate change (e.g. non-industrial emissions of greenhouse gases and carbon sequestration). Ecohydrology addresses the underlying physical, chemical, and biological processes that manifest these problems as well as the processes that are the keys to ultimately solve them. In developed areas, knowledge of ecohydrological processes serves to enhance the highly engineered systems already in place, while in less developed areas ecohydrological processes may serve as the primary means for managing water quantity and quality through natural attenuation of contamination and natural regulation of flow levels. The science includes well developed methodologies of field sampling, laboratory analysis, experimentation, and computer modelling.

Main Research Questions

1) *How do fluxes of nutrients in river systems vary as a function of land-use and climate?* Land-use change is the most immediate form of global change, especially in large parts of the developing world, and climate change poses serious future challenges. Ecohydrological research seeks to understand the relationships between land use change/climate change and runoff components and to identify land management practices that help reduce negative impacts. Research related to this question is underway in the ECOLIVE, Mara*Flows*, WETwin, ACCION, RISKOMAN and PROACC projects.

2) *How do aquatic ecosystem processes and related services in river systems vary as a function of changes in hydrological flow regime?* Ecohydrological processes in river, wetland, and aquifer systems provide services like the natural attenuation of water contamination and the productivity of useful plants (fibre) and animals (e.g. commercial fisheries). Research related to this question examines these processes in the context of environmental flows and is currently being carried out in the Mara*Flows* and ECOLIVE (in Aquatic Ecosystems Chair Group) project.

3) *What is the degree of dependency of phreatophytic vegetation and wetland ecosystems on groundwater attributes (levels, fluxes, and quality)? What are the safe limits to changes in groundwater regimes that do not cause the unacceptable change in the functions and services of groundwater-dependent ecosystmes (GDEs)? How much groundwater can be abstracted for water supply while maintaining the health of GDEs?* Ecohydrological research examines these questions with in-situ measurements and model simulations. Research related to these questions is underway in the China ERDOS Project.

4) *How can ecohydrological models be improved to better simulate the accumulated effects of pollutants on the ecology of the receiving waters and the human aspects related to the decision making process?* New holistic and participatory policies for water management (e.g. Water Framework Directive in Europe or TMDL in USA) have posed new challenges to model-supported decision making, replacing

simple emission based approaches with ‘immission’ based approaches. Research related to this question is underway in AQUAREHAB, EnviroGRIDS, and AFROMAISON projects.

Applied Methods and Planned Methodological Developments

Research in this theme involves multidisciplinary field, laboratory, and modeling techniques. Direct measurements are made of surface water flows and groundwater levels, and chemical and isotopic tools are utilized to trace the spatial and temporal interactions of flowpaths, including uptake by plants (i.e. xylum water). Biogeochemical and ecological methods focus on measurement of flow-related processes such as nutrient and organic matter retention along surface and subsurface flow paths, hypoxia related to high and low flow events, and flow- and wetness-related controls on spatial and temporal patterns of productivity in river and wetland (including GDEs). A wide variety of modeling approaches are applied, including physically based modelling, cellular automata, and fuzzy logic. Emphasis is also placed on model-supported decision making.

Key Collaborators and Partner Institutions

China University of Geosciences, Beijing, China
Hohai University, Nanjing, China
Xi'an Centre of China Geological Survey, China
Egerton University, Kenya
University of Dar es Salaam, Tanzania
Univesity of Makerere, Uganda
Meking river commission, Asia
ESPOL, Ecuador
Water Res. Mngt. Agency, Kenya
Vrije Universiteit Brussel, Belgium
Universite Laval (Quebec, Canada), Canada
Texas A&M University, USA
PIK, Germany
IGB, Germany
VITUKI, Hungary
CNRS, France
Florida International University, USA
University of KwaZulu Natal, South Africa

Projects in Ecohydrology (see A5 for project definition)

MARAFLOWS (Mara River Kenya-Tanzania), ERODOS (Yellow River, China), ECOLIVE (Nyando wetland, Kenya), AQUAREHAB ENVIROGRIDS)(Odense river basin, Denmark and Scheldt river basin, Belgium) WETwin (Guayas river basin, Ecuador).

PhD or Post-doc Studies in Ecohydrology Research

PhD fellow, country	Promotor(s)	Supervisor(s)	Title research project	Start year	End year
P. Khizza, Kenya	S. Uhlenbrook,	J. Wenninger, A. van Griensven	Hydrology of Nyando wetland, Kenya (ECOLIVE project)	2009	2013
E. Teferi, Ethiopia	S. Uhlenbrook	Belay Simane, J. Wenninger	Past-present-future land use in the Blue Nile and impacts on hydrology	2008	2012
E. Natumanya	S. Uhlenbrook	M. McClain M. Mul	Spatial-Temporal Dynamics of Flow Regime and Water Resources in the Mara Basin, Kenya	2010	2014
G. Alvarez, Ecuador	A. Mynett (RBD core)	A. van Griensven	Ecological modeling in tropical rivers and wetlands	2010	2014
Linh Hoang, China	A. Mynett	A. van	The effectiveness of wetlands to remove	2009	2013

	(RBD core)	Griensven	pollution at river basin scale		
F. Kilonzo, Tanzania	P. Lens (PPCcore)	A. van Griensven, M. McClain	Assessing impacts of climate change on the hydrology and water quality of the Mara river basin	2010	2014
F. Masese, Kenya	tbd	M. McClain	Spatio-temporal dynamics in organic matter and its influence on food web architecture in the tropical Mara River	2010	2014
G. Yimer, Ethiopia	A. Mynett (RBD core)	A. van Griensven	Modelling groundwater – surface flow interactions in relation to contaminant transport	2008	2012

Post-doc Researchers

- Dr. Yin Lihe: Study on groundwater dependent ecosystems in the Erdos Plateau, China; ERODO project, supervisors: Dr. Yangxiao Zhou, Dr. Jochen Wenninger

Key staff member from HWR Chair Group active in this Theme

Dr. Michael McClain, Dr. Ann van Griensven, Dr. Yangxiao Zhou, Dr. Jochen Wenninger, Prof. Dr. Stefan Uhlenbrook

A4: Research Line Three: BASIN HYDROLOGY AND GLOBAL CHANGES

Description/Definition of the Field

With the increasing population, incessant urbanization, modernized lifestyles, climate changes and other global changes the pressure for sustainable water resources planning and management of our finite water resources is more evident than ever. Consequently, the role and importance of hydrological research in river basin of various scales have increased. In particular, we are facing increased challenges in predicting the [future] state of the water resources in view of the impacts from climate and anthropogenic changes to hydrological system dynamics. The key objectives of this research theme contribute to the understanding of hydrological processes at basin scales and modeling of these processes to predict the space-time availability of water resources and water cycle dynamics, including impacts from global changes. We primarily focus our research to the river basin scale typically varying from a few thousand to several hundred thousand square kilometers.

Main Research Questions

- How do hydrological processes act and interact differently with respect to space and time scales?
- How do hydrological processes act, interact and connect at a basin scale?
- How do human interference and water use impact basin water cycle dynamics?
- How does climate change impact basin hydrology?
- Do global changes exacerbate hydrological extremes, such as floods and droughts?
- How do global change adaptation measures impact hydrological processes?

Applied Methods and Planned Methodological Developments

Identification and quantification of the cause and effect relationships and predicting the impacts for the future at the large scale can only be achieved through process-based modeling. Large scale modeling typically encounters data requirements beyond the classical rainfall-runoff simulation. Therefore, representation of hydrological processes at appropriate detail and integration of comprehensive remote sensing and ground observations into the modeling system form the framework for our research methodology. Within this framework, it is also important to acknowledge possible sources of uncertainty, and to provide reasonable assessments of uncertainty in model results.

The link that the hydrological process understanding can support and inform integrated water resources management is vital. We strive to make a visible impact through our research to the water sector development in countries we work in, particularly the developing countries and countries in transition. We reach out and collaborate with water sector partners that have a mandate in water resources policy making and management implementation. Such organizations include relevant government ministries and agencies, universities and research institutes, basin water authorities and NGOs.

Projects in Basin Hydrology and Global Changes (see A5 for project definition)

AGloCAP (Koshi basin, Nepal), ProACC (Mekong river basin, SE Asia), DEWFORA (Africa), PhD Yurong Hu (Upper Yellow River, China), PhD Ilyas Masih (Karheh River Basin, Iran), PhD Wong Chee Long (Peninsula

Malaysia), RISKOMAN (Incomati catchment, South Africa, Swaziland and Mosambique), ACCION (Nile basin, East Africa), Hydrosolidarity Blue Nile (Ethiopia, Sudan), ENVIROGRIDS (Black Sea).

Key Collaborators and Partner Institutions

- AIT, Bangkok, Thailand
- Addis Ababa University, Ethiopia
- Khartoum University and HRS, Sudan,
- Yellow River Commission, China
- Mekong River Commission, SE Asia
- Cantho University, Vietnam
- Chinese Academy of Sciences, Beijing, China
- Department of Irrigation, Kathmandu, Nepal
- Department for Irrigation and Drainage (DID), Kuala Lumpur, Malaysia
- International Water Management Institute (IWMI), Colombo, Sri Lanka
- University of KwaZulu Natal, Pietermaritzburg, South Africa
- Texas A&M University
- Potsdam Institute for Climate Impact Research (PIK), Germany

PhD or Post-doc Studies in Basin Hydrology and Global Changes Research

PhD fellow, country	Promotor(s)	Supervisor(s)	Title research project	Start year	End year
D. Love, Zimbabwe and UK	P. van der Zaag, S. Uhlenbrook	R. Owen, S. Twomlow	Integrated modelling of water resources in the Mwenezi and Mzingwane subcatchments, Limpopo river basin	2005	2011
K. Kittiwet, Thailand	B. Schulz (LWD core), S. Uhlenbrook	S. Suriyadi	Flood management and land use in the Chi River basin, Thailand	2005	2011
I. Masih, Pakistan	S. Uhlenbrook	A. Mobin, V. Smaktin, S. Maskey,	Hydrology and water balance analysis for sustaining food security and environmental services in Karkheh River Basin, Iran	2006	2011
C.L. Wong, Malaysia	S. Uhlenbrook	R. Venneker	Assessment and modelling of large-scale hydrological variability in Peninsular Malaysia	2006	2011?
Yurong Hu, China	S. Uhlenbrook,	S. Maskey	Climate Change Impacts in the Upper Yellow River	2009	2013
A. Saraiwa, Mozambique	S. Uhlenbrook, P. van der Zaag	-	Hydrological predictions for risk-based operational water management for the Incomati River Basin	2010	2014
D. Bhatt, Nepal	S. Uhlenbrook	S. Maskey	An integrated approach for adapting agriculture and water management to global changes - with a case study of a Himalaya river basin in Nepal	2010	2014

S. Yalew, Ethiopia	S. Uhlenbrook, P. van der Zaag	A. van Griensven	A spatially explicit tool to support the integration of land use and natural resources management at river basin scale	2010	2014

Post-doc Researchers

- Dr. Max Kigobe: Climate change impact on the water resources of the Kyoga river basin (Uganda); ACCION project, supervisors: Dr. Ann van Griensven, Prof. Dimitri Solomatine (Hydroinformatics)
- Dr. Jun Li: Climate-vegetation interactions in Lancang River Basin, China (Upper Mekong River Basin); PRoACC project, supervisors: Dr. Raymond Venneker, Prof. Stefan Uhlenbrook
- Bikesh Shrestha (post-MSc researcher): Impacts on Sediment Due to Climate Change and Human Activities in the Mekong River Basin; PRoACC project, supervisors: Dr. Ann van Griensven, Dr. Shreedhar Maskey, Prof. Stefan Uhlenbrook
- Dr. Tri Van (post-doc): Vulnerabilities and hazards mapping under climate change scenarios for the coastal area in the Mekong Delta, Vietnam supervisors: Dr. Ann van Griensven, Dr. Ioana Popescu (Hydroinformatics), Prof. Dimitri Solomatine (Hydroinformatics).
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Key staff member from HWR Chair Group active in this Theme

Dr. Shreedhar Maskey, Dr. Raymond Venneker, Dr. Ann van Griensven, Prof. Dr. Stefan Uhlenbrook

A5: Overview Current Research Projects

The following gives an overview over the research projects in which the chair group is involved (alphabetic order according to the acronym; only names of staff members from the chair group involved are given in brackets):

- AGLOCAP - Adaptation to Global Change in Agricultural Practices, with a case study in a Himalayan River Basin in Nepal, in collaboration with Asian Institute of Technology, Thailand, and Depart of Irrigation, Nepal. Two PhD students (Mr. D. Bhatt at UNESCO-IHE and Mr. Agarwal at AIT) and one MSc student (Mr. Pradhan) joined the project in 2010. (Maskey, Uhlenbrook)
- BLUE NILE HYDROSOLIDARITY project - In Search of Sustainable Catchments and Basin-wide Solidarities; Transboundary Water Management of the Blue Nile River Basin; funded by NWO-WOTRO and DUPC (led by Prof P van der Zaag, MAI department), co-supervision of PhD students Ermias Terefi and Sirak Terlak and post-doc Dr. Melesse Temesgen (Uhlenbrook, Wenninger)
- CHE - Conserving Hydrological and Ecological functions through payment for watershed services, with special reference to South-Central Bolivia. 1 PhD student or post-doc and several MSc students areinvolved. Co-operation with Vrije Universiteit Amsterdam, Universidad Mayor de San Simón and Fundación Natura Bolivia. Inception workshop was held in March 2010. (Uhlenbrook, McClain)
- DEWFORA - Improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in Africa; an EU FP7 research project. The project officially started in January 2011. UNESCO-IHE's team is led by Shreedhar Maskey. The main contribution of UNESCO-IHE is in the development of a hydrological model (coupled with meteorological forecasts by ECMWF) for drought forecasting in selected river basins in Africa. Patricia Trambauer, a HWR graduate (2010), joined the project as a full time PhD researcher. (Maskey, Trambauer, Uhlenbrook)
- ECOHYDROLOGY ERDOS CHINA - Project funded by the Netherlands Asian Facility for China programme and the Chinese government. A research catchment has been instrumented to monitor the complete hydrological cycle and its interactions with ecosystems. One sandwich PhD student (Mr Yang Zhi) and one post-doc (Mr Yin Lihe) with China University of Geosciences are carrying out major their research activities in this project. The results will provide scientific bases for sustainable water resources management and ecosystem projection in the cold semi-arid Erdos plateau of China (Zhou, Wenninger).
- ECOLIVE - Ecology of Livelihoods, Nyando wetland, Kenya, funded by DUPC (led by Dr A van Dam, ER department), supervision of PhD student r Patrick Khiza (Wenninger, van Griensven, Uhlenbrook)
- EXACT - Small scale water treatment and artificial recharge project. Total budget: 2.3 million Euro (DUPC funded). Principal partners are the Ministry of Water and Irrigation of Jordan, the Palestinian Water Authority and the Israeli Water Authority (Nonner).
- ISOWUE - Experimental investigations of water fluxes within the soil-vegetation system using isotopes to improve water use efficiency, part of the IAEA’s Coordinated Research Project (CRP): Quantification of Hydrological Fluxes in Irrigated Lands Using Isotopes for Improved Water Use Efficiency. Supervision of MSc students (Wenninger).
- MARAFLOWS - Environmental Flows for People and Ecosystems in the Mara River Basin, Kenya/Tanzania, funded by DUPC and USAID at total level of €638,338 over four years. The project is led by Michael McClain and we are involved in the co-supervision of 2 PhD students

(McClain, Uhlenbrook); partnering with University of Dar Es Salaam (Tanzania) and Egerton University (Kenya). The inception workshop was held in May 2010.

- PRoACC - Post-doctoral programme for research on Climate Change Adaptation with special emphasis on the Mekong River basin. 8 post-docs from different disciplines started in April 2010 their research projects for a duration of 18 months; the total project budget amounts to 700 kEuros. Cooperation with many partners in the Mekong countries including, MRC, CRC, AIT Bangkok, Hanoi WRU, Chinese Academy of Sciences, etc. (Uhlenbrook (project director), Venneker, Maskey, van Griensven)
- RISKOMAN - Risk-based operational water management for the Incomati River Basin (RISKOMAN), funded by DUPC and led by Prof P. van der Zaag (MAI department); collaboration with Eduardo Mondlane University in Mozambique and Komati Basin Water Authority in Swaziland; co-supervision of PhD student Aline Saraiwa (Uhlenbrook)
- UWIRA - Impact of untreated wastewater on natural water bodies: Integrated risk assessment. With the Institute of Environmental and Water Studies at Birzeit University (Birzeit, Palestine), Water and Environmental Studies Institute at An-Najah National University (Nablus, Palestine) and the Palestinian Water Authority (Al-Bireh, Palestine) (Wenninger, Uhlenbrook). Inception workshop was held in May 2010.
- SCUSA - Integrated approaches and strategies to address the Sanitation Crisis in Unsewered Slum Areas in African mega-cities (SCUSA), led by Dr. JW Foppen; collaboration with Makerere University and the Kampala City Council in Uganda; supervision of PhD students Philip Nyenje and George Lutterodt (Foppen, Uhlenbrook)
- ACCION project (UPARF II), Adaptation to Climate Change Impacts on the Nile River Basin (2009-2011), led by G. di Baldassarre (HI) and A. van Griensven, collaboration with Marekere Univesrity, University of Dar es Salaam, Addis Ababa University, NBCBN, Nile Forecasting Center, ; supervision of post-doc student Max Kigobe and Semu Moges (van Griensven, Uhlenbrook).
- EnviroGRIDS (EU-FP7), Gridded Earth Observation System for Assessing and Predicting Black Sea Basin Sustainability and Vulnerability , (2009-2013), IHE project leaders: Andreja Jonoski and Ann van Griensven supervision of PhD student Nagendra Kayastha (van Griensven, Solomatine).
- AFROMAISON (EU-FP7), Adaptive and integrated tools and strategies on natural resources management (2011-2014), (IHE project leader: Henrike Helbron), supervision of PhD student Seleshi Yalew (van Griensven, Uhlenbrook, Van der Zaag).
- WETwin (EU-FP7), Enhancing the role of wetlands in integrated water resources management for twinned river basins in EU, Africa and South-America in support of EU Water Initiatives, (2008-2011), IHE project leader: Ann van Griensven, supervision of student Mijail Arias Hidalgo and Gabriela Alvarez (van Griensven and Mynett).
- AQUAREHAB (EU-FP7), 'Development of rehabilitation technologies for multipressured degraded waters and the integration of their impact in river basin management', (2009-2013), IHE is responsible for the integration of remedition technologies in river basin management; IHE project leader: Ann van Griensven, supervision of students Linh Hoang and Girma Yimer (van Griensven and Mynett).
- GDE (UPaRF III)-Remote sensing is used to map vegetation cover and to calculate evapotranspiration which are to be validated by ground measurements. The results will lead to identify groundwater dependent vegetation and ET rate which will be linked to spatial-temporal variations of groundwater table depth and river discharges (China University of geoscience, Hohai University under supervison by Zhou).